

**Human Factors
Opportunities to Improve
Ohio's Transportation
System**



Russ College of Engineering and Technology

Human Factors and Ergonomics Laboratory
Ohio Research Institute for Transportation and the
Environment

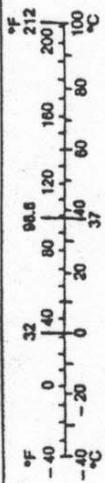
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16. Abstract <p>The aim of this study was to identify opportunities to apply human factors principles and research to improve Ohio's transportation system. The Office of Traffic Engineering assigned thirteen topic areas to provide information and the study was limited to these topics even though there may have been other areas that are important from a human factors perspective. The topic areas included: rumble strips, changeable message signs (CMS), work zone delineation, half-size pavement markings, accident mitigation, older drivers, traffic signal operations, highway lighting, curve delineation, wet/dark delineation, raised pavement markings (RPM), information dissemination, and work zone safety. The aim was to identify opportunities to improve each of these areas by providing the human factors rationale and make recommendations to ODOT that can be adopted to improve Ohio's transportation system. For each topic area an extensive literature survey, using published documents as well as web-based sources, was conducted to identify research that has been done by others in the United States and in other countries. A statewide DOT survey was conducted to determine the best practices of other states with respect to each area. In addition, a product survey was conducted to identify promising new products. Based on this information, human factors opportunities in each area were identified.</p> <p>We found considerable information in the following topic areas: rumble strips and accident mitigation. Some information was found in the topics of work zone safety, changeable message signs (CMS), older drivers, work zone delineation, curve delineation, and information dissemination. Little information was available on raised pavement markings (RPM), highway lighting, traffic signal operations, half-size pavement markings, and wet/dark delineation.</p>			
17. Key Words Transportation system improvements, human factors, rumble strips, changeable message signs (CMS), work zone delineation, half-size pavement markings, accident mitigation, older drivers, traffic signal operations, highway lighting, curve delineation, wet/dark delineation, raised pavement markings (RPM), information dissemination, work zone safety		18. Distribution Statement No Restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161	
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				APPROXIMATE CONVERSIONS FROM SI UNITS			
Symbol	When You Know	Multiply By	To Find	Symbol	When You Know	Multiply By	To Find
LENGTH							
in	inches	25.4	mm	mm	millimetres	0.039	inches
ft	feet	0.305	m	m	metres	3.28	feet
yd	yards	0.914	m	m	metres	1.09	yards
mi	miles	1.61	km	km	kilometres	0.621	miles
AREA							
in ²	square inches	645.2	mm ²	mm ²	millimetres squared	0.0016	square inches
ft ²	square feet	0.093	m ²	m ²	metres squared	10.764	square feet
yd ²	square yards	0.836	m ²	m ²	metres squared	2.47	acres
ac	acres	0.405	ha	ha	hectares	2.47	acres
mi ²	square miles	2.59	km ²	km ²	kilometres squared	0.386	square miles
VOLUME							
fl oz	fluid ounces	29.57	mL	mL	millilitres	0.034	fluid ounces
gal	gallons	3.785	L	L	litres	0.264	gallons
ft ³	cubic feet	0.028	m ³	m ³	metres cubed	35.315	cubic feet
yd ³	cubic yards	0.765	m ³	m ³	metres cubed	1.308	cubic yards
MASS							
oz	ounces	28.35	g	g	grams	0.035	ounces
lb	pounds	0.454	kg	kg	kilograms	2.205	pounds
T	short tons (2000 lb)	0.907	Mg	Mg	megagrams	1.102	short tons (2000 lb)
TEMPERATURE (exact)							
°F	Fahrenheit temperature	$5(F-32)/9$	°C	°C	Celsius temperature	$1.8C + 32$	Fahrenheit temperature

NOTE: Volumes greater than 1000 L shall be shown in m³.



* SI is the symbol for the International System of Measurement

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Prepared in cooperation with the

Ohio Department of Transportation
Office of Traffic Engineering

Prepared by

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The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Ohio Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

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1 INTRODUCTION

Identification of human factors opportunities to apply the principles of human factors for Ohio roadways is crucial in order to maintain safety, reduce congestion and improve efficiency. There are many evident opportunities available to improve Ohio's highway system. The Ohio Department of Transportation (ODOT) has identified various areas where principles of human factors can be applied to make Ohio's highway system more user-friendly and accident free. These areas include:

1. Rumble strip application – This section looks into the different types of rumble strips available for drivers and bicyclists as well as those used by other states along with a before and after study of their effectiveness in reducing accidents. It also includes the human factors consideration involved with use of rumble strips.
2. Changeable Message sign application – Here the various parameters associated with comprehending a CMS are studied alongside suggesting guidelines for placing them.
3. Work zone delineation – In this section, certain retroreflective sheeting materials are studied that could be used on drums used in delineating work zones. Some other systems like the TTI Lane Closure Warning Light System, Direction Indicator Barricades, and Glare Screens etc. are studied.
4. ½ size auxiliary markings – Various pavement markings adopted by different countries along with their recognition distances during day and nighttime are studied
5. Accident mitigation - This section describes the human factors opportunities available for accident mitigation in Ohio's transportation system. Research done by authors and also some of the safety initiatives adopted by Penn DOT are reviewed.
6. Older drivers – This sections looks into older driver countermeasures by increasing sign visibility, public education and conditional licensing, longitudinal pavement markings, etc.
7. Traffic signal operations – A review of the TTI study in Video Imaging Vehicle Detection Systems (VIVDS) and the TTI guidelines are presented in this section. The other topics covered are Dilemma Zone Protection, Red Light Strobes, and studies conducted in Minnesota and San Jose with respect to Countdown Ped heads.
8. Highway lighting – Studies conducted in Switzerland, U.K. and the U.S. are reviewed along with comparison between the U.S. and Swiss illuminating systems in two locations in Wisconsin. The study results are also presented.
9. Curve delineation – A detailed study on the curve delineation concept is provided in this section. Applications of curve delineations in various states are reviewed. The use of chevrons is also reviewed.

10. Wet/dark delineation – A study method and results of a comparative study between pavement marking materials are discussed in this section. Research by authors and a TTI study on wider pavement markings are also discussed.
11. RPM spacing – A review of a section in the Ohio Department of Transportation Manual of Uniform Traffic Control Devices is presented in this segment. RPM location and spacing guidelines, maintenance operations, and evaluation permanent RPMs are discussed.
12. Information dissemination – This section covers the various modes of information dissemination that are possible. Information like traffic incidents, congestion, construction projects, work zones etc. available through websites of various states including Ohio is discussed. The findings of a study conducted by a panel consisting of researchers from U.S. institutes across 8 cities in Europe are also presented
13. Work Zone safety – This section discusses the control of speed in work zones in three levels of increased attention and enforcement. It also discusses the use of intrusion alarms, dancing diamonds, vehicle warning lights etc. to increase conspicuity of signs and reduce accidents.

An extensive research and literature review using published documents and web-based resources was conducted in the above areas in an attempt to identify and document the best practices employed and followed by other states, best proposed ideas in research, need for additional future human factors research, and solutions to identified customer concerns. In addition a state survey with regard to the above mentioned topics along with a product survey were conducted. These topics are accompanied by recommendations to ODOT along with recommended evaluations that would be critical before implementation or application of certain systems. Improvement in the Ohio highway system using the principles of human factors could result in cost – savings besides increasing driver safety and comfort.

2 RUMBLE STRIPS

2.1 Literature and Best Practices Review

Approximately one-third of all traffic fatalities and serious injuries in the United States annually are due to run-off-road crashes. In 2000, almost 16,000 deaths were attributed to these types of accidents [1].

Rumble strips are raised or grooved patterns constructed primarily along paved shoulders. When vehicle tires pass over the strips, they produce a sudden rumbling and vibration in the vehicle. Both the sound and the vibration alert fatigued or distracted drivers that they are beginning to drift off the road [1].

In 2002, 70 % of the all single vehicle fatal crashes were related to the off roadway, shoulder, and median crashes. Out of 22,086 single vehicle fatal crashes, 12,360 were off roadway crashes, 2,021 were shoulder crashes, and 1,077 were median crashes. [2]

2.2 Types of Rumble Strips

Milled-in: This design is made by cutting (or grinding) the pavement surface with carbide teeth affixed to a 600 mm (24 in) diameter rotating drum. The indentations formed are approximately 13 mm (1/2 in) deep, 180 mm (7 in) wide parallel to the travel lane and 400 mm (16 in) long perpendicular to the travel lane. The indentations are approximately 300 mm (12 in) on center and offset from the edge of the travel lane by 100 mm (4 in) to 300 mm (12 in) [3]. A sketch of a milled rumble strip is shown in Figure 1.

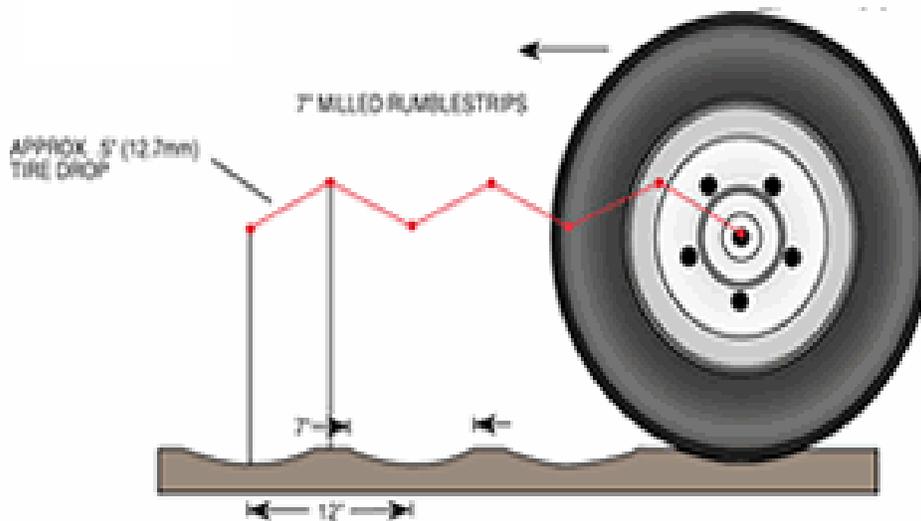


Figure 1. Milled-in rumble strip design. From [3]

Rolled-in: The rolled-in design is generally installed by using a steel wheel roller to which half sections of metal pipe or solid steel bars are welded. The compaction operation presses the shape of the pipe or bar into the hot asphalt shoulder surface. The resultant shape is generally 25 mm (1 in) deep, 50 mm (2 in) to 64 mm (2.5 in) wide parallel to the travel lane and 450 mm (18 in) to 900 mm (35 in) long perpendicular to the travel lane. The indentations are usually set 200 mm (8 in) on center and offset from the travel lane edge by 150 mm (6 in) to 300 mm (12 in) [3]. A sketch of a rolled-in rumble strip design is shown in Figure 2.

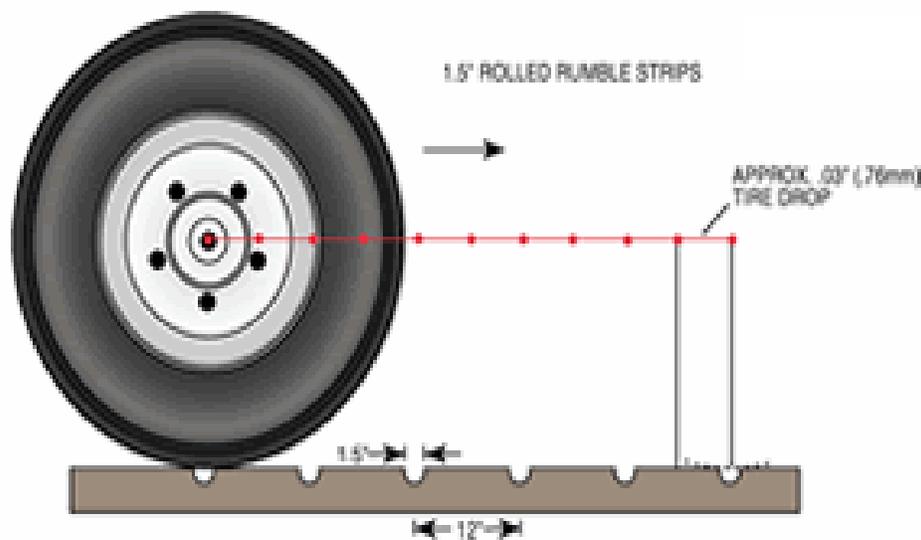


Figure 2. Rolled-in rumble strip design. From [3].

Formed: The formed rumble strip is added to a fresh concrete shoulder with a corrugated form which is pressed onto the surface just after concrete placement and finishing operations. The resultant indentations are approximately 25 mm (1 in) deep, 50 mm (2 in) to 64 mm (2.5 in) wide parallel to the travel lane and 400 mm (16 in) to 900 mm (35 in) long perpendicular to the travel lane. The indentations may be in a continuous pattern, but are generally in groups of five to seven depressions spaced approximately 15 m (50 ft) apart and offset from the travel lane by about 300 mm (12 in) [3].

Raised: Raised rumble strip designs can be made from a wide variety of products and installed using several methods. The elements may consist of raised pavement markers, a marking tape affixed to the pavement surface, an extruded pavement marking material with raised portions throughout its length or an asphalt material placed as raised bars on the shoulder surface. The height of the raised element may vary from 6 mm (1/4 in) to 13 mm (1/2 in). Spacing and width across the shoulder vary widely [3].

2.3 Which Type of Rumble Strip Is Best?

The Virginia Department of Transportation has determined that the 7-inch (177.8 mm) milled rumble strip generated 335% more noise, and produced 1,260% more vibration excesses (denoted on the International Roughness Index) than rolled-in patterns [4].

The best alarm saves the most lives. No highway using rolled-in patterns has reported a reduction in accidents comparable to that achieved by the 7-inch (177.8 mm) rumble strip. Most highway authorities have cited various maintenance and construction problems in their decision to discontinue rolled-in patterns in favor of the 7-inch (177.8 mm) milled cut. These rumble strips are constructed on existing highway shoulders, and does not compromise asphalt density requirements. Nearly all highway authorities using rolled-in patterns have noted the need to sacrifice shoulder [4].

2.4 Existing Standards and Practices

2.4.1 Ohio Standards and Practices

Rumble strip information is given in the Ohio Manual of Uniform Traffic Control Devices (OMUTCD) Section 6F-78 [5]. Here is the definition of “rumble strip” as given in the manual: “Rumble strips consist of intermittent narrow, transverse areas of rough-textured or slightly raised or depressed road surface that alert drivers to unusual motor vehicle traffic conditions. Through noise and vibration they attract the driver’s attention to such features as unexpected changes in alignment and to conditions requiring a stop [5]. Some guidelines are also given:

- Intervals between rumble strips may be reduced as the distance to the approached conditions is diminished in order to convey an impression that a closure speed is too fast and/or that an action is imminent. A sign warning drivers of the onset of rumble strips may be placed in advance of any rumble strip installation.
- Rumble strips should be placed transverse to motor vehicle traffic movement. They should not adversely affect overall pavement skid resistance under wet or dry conditions. In urban areas, even though a closer spacing might be warranted, care should be taken not to promote panic braking or erratic steering maneuvers by drivers. Rumble strips should not be placed on sharp horizontal or vertical curves.

In Section 605-17 of the ODOT Traffic Engineering Manual [6], the uses of rumble strips are given. This includes a recommendation that the first transverse rumble strip pad should be placed before the advance warning devices. The last pad should be placed a minimum of 250 feet (76 m) in advance of the traffic condition prompting the installation. A RUMBLE STRIPS sign (W8-H16) warning drivers of the onset of rumble strips may be placed in advance of any transverse rumble strip installation. The manual also cautions that the noise caused by vehicles traveling on a rumble strip may annoy nearby residents; to avoid this problem, rumble strips should not be used in residential areas.

2.4.2 Federal Standards and Practices

Rumble strip standards are given in the federal Manual of Uniform Traffic Control Devices, Section 6F.84 [7].

- In the installation of rumble strips, it is desirable to use a color other than the color of the pavement for a longitudinal rumble strip; the color of the rumble strip shall be the same color as the longitudinal line the rumble strip supplements. If the color of a transverse rumble strip used within a travel lane is not the color of the pavement, the color of the rumble strip shall be white.
- Intervals between transverse rumble strips may be reduced as the distance to the approached conditions is diminished in order to convey an impression that a closure speed is too fast and/or that an action is imminent. A sign warning drivers of the onset of rumble strips may be placed in advance of any transverse rumble strip installation.
- Transverse rumble strips should be placed transverse to vehicular traffic movement. They should not adversely affect overall pavement skid resistance under wet or dry conditions.
- In urban areas, even though a closer spacing might be warranted, transverse rumble strips should be designed in a manner that does not promote unnecessary braking or erratic steering maneuvers by road users.
- Transverse rumble strips should not be placed on sharp horizontal or vertical curves.
- Rumble strips should not be placed through pedestrian crossings or on bicycle routes.
- Transverse rumble strips should not be placed on roadways used by bicyclists unless a minimum clear path of 1.2 m (4 ft) is provided at each edge of the roadway or on each paved shoulder as described in AASHTO's "Guide to the Development of Bicycle Facilities" (see Section 1A.11).
- Longitudinal rumble strips should not be placed on the shoulder of a roadway that is used by bicyclists unless a minimum clear path of 1.2 m (4 ft) is also provided on the shoulder.

The FHWA is spearheading a movement to increase the nationwide use of rumble strips. A new technical advisory released by FHWA in December 2001, *Roadway Shoulder Rumble Strips*, contained the latest information on the state-of-the-practice design and installation of rumble strips, including recommendations for minimizing the adverse effects rumble strips may have on bicyclists using roadway shoulders. The advisory, which also includes an extensive list of reference materials on rumble strip use and effectiveness, is posted on the World Wide Web at ww.fhwa.dot.gov/legregs/directives/techadvs/t504035.htm [3].

2.5 Other States

2.5.1 California

Rumble strip specifications are given in the California Department of Transportation is their Traffic Manual, Section 6-03.2 [8]. According to the manual, transverse rumble strips are 19 mm (0.75 in) or less in height if raised or 25 mm (1 in) or less in depth if rolled-in indentations, 8.5 mm +/- 1.5 mm (0.33 +/- 0.06 in) if ground-in indentations. The transverse strips generally extend across the travel lanes.

2.5.2 Alabama

In Alabama Standards Specifications, 2001 edition, Section 428, “Scoring Bituminous Pavement Surface” gives information on the use of rumble strips on the shoulders and their installation. Rumble Strips can be installed either by rolling or cutting operations [9].

2.5.3 Arizona

Section 480 of ADOT Traffic Engineering Policies, Guidelines, and Procedures, provides guidelines on when and where longitudinal rumble strips may be applied in the Arizona state highway system. ADOT developed a guideline for the application of rumble strips; selected groove widths are installed on both shoulders according to the type of roadway and right shoulder width, as shown in Table 1 [10].

Table 1. Arizona Department of Transportation guidelines for the application of rumble strips. From [10].

Type of Roadway	Right Shoulder Width	Groove Width (both shoulders)
Undivided	less than 4 ft (1219 mm)	6 in. (152 mm)
Undivided	greater than or equal to 4 ft (1219 mm)	8 in. (203 mm)
Divided	less than 6 ft (1829 mm)	8 in. (203 mm)
Divided	greater than or equal to 6 ft (1829 mm)	12 in. (305 mm)

In Section 928.2 of the ADOT guidelines construction requirements for the rumble strips are given. “Rumble strips shall be formed in the asphaltic concrete by making indentations a minimum of 30 millimeters (1.2 in) deep by 600 millimeters (24 in) in length and spaced with a center to center distance of approximately 200 mm (8 in).”

2.5.4 Colorado

In Section 614 of Colorado Department of Transportation Standard Specifications [11], details for the installation of rumble strips are given. Rumble strips shall not be placed within 100 m (328 ft) of intersecting cross streets, 10 m (32.81 ft) each side of mailboxes, through acceleration and deceleration lanes, and ramps, 50 m (164 ft) of private road approaches for houses or businesses located within 100 m (328 ft) of the roadway or when shoulders are less than 1.2 m (3.94 ft).

A typical transverse rumble strip cluster as used to warn of a coming curve or stop sign is 11 ft 4 in (3.4544 m) with 12 grooves, shown in Figure 4. The grooves are 4 in (0.1016 m) wide and the distance between the centers of the grooves is 12 in (0.3 m). Another option for rumble strips is using raised rumble strips which are 3/8 in (0.009525 m) high, 6 in (0.1524 m) wide and 12 in (0.3048 m) apart from center to center.

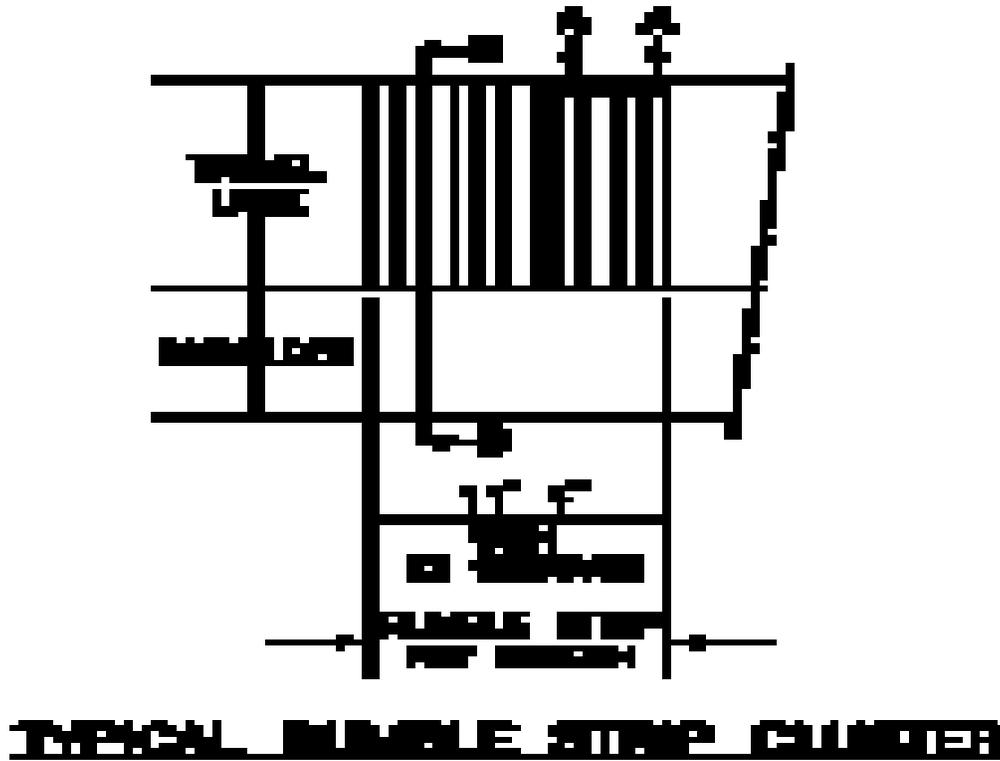


Figure 4. Typical rumble strip cluster used in advance of a stop sign in Colorado. From [12].

Travel lane rumble strip drawings are given in sheet 3 of standard plan M-614-1 [12]. A stop sign approach is shown in Figure 5. In stop sign approach four 11 ft 4 in (3.45 m) long transverse, or travel lane, rumble strips are installed. The four rumble strips are placed 1000 ft (25.4 m), 700 ft (213.4 m), 500 ft (152.4 m), and 300 ft (91.4 m) before the stop sign respectively.

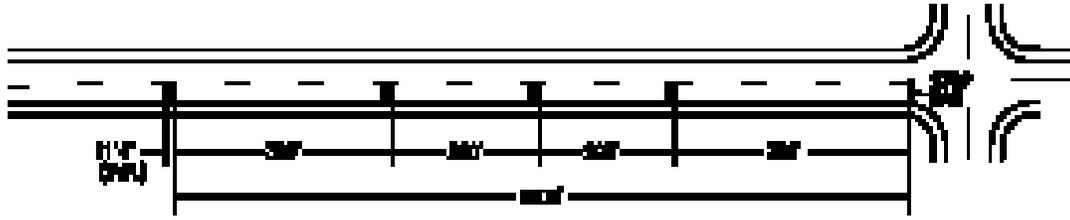


Figure 5. Full stop-sign approach with several rumble strip clusters in advance of a stop sign in Colorado. From the Colorado standard plans [12].

Travel lane rumble strips shall also be installed in lane reduction transitions. Three 11 ft 4 in. (3.45 m) wide rumble strip clusters will be placed in the lane that will be discontinued. The first cluster will be installed 700 ft (213.4 m) before the beginning of the transition marking, the second will be placed 500 ft (152.4 m) before the beginning of transition marking, and the third cluster will be placed 400 ft (121.9 m) before the beginning of transition lane.

In addition, travel lane rumble strips shall also be used in curve approaches. Three rumble strip cluster will be placed in the travel lane before the starting point of the curve. They are placed 700 ft (213.4 m), 500 ft (152.4 m), 400 ft (121.9 m) before the starting point of the curve. A drawing of such a configuration is given in Figure 6.

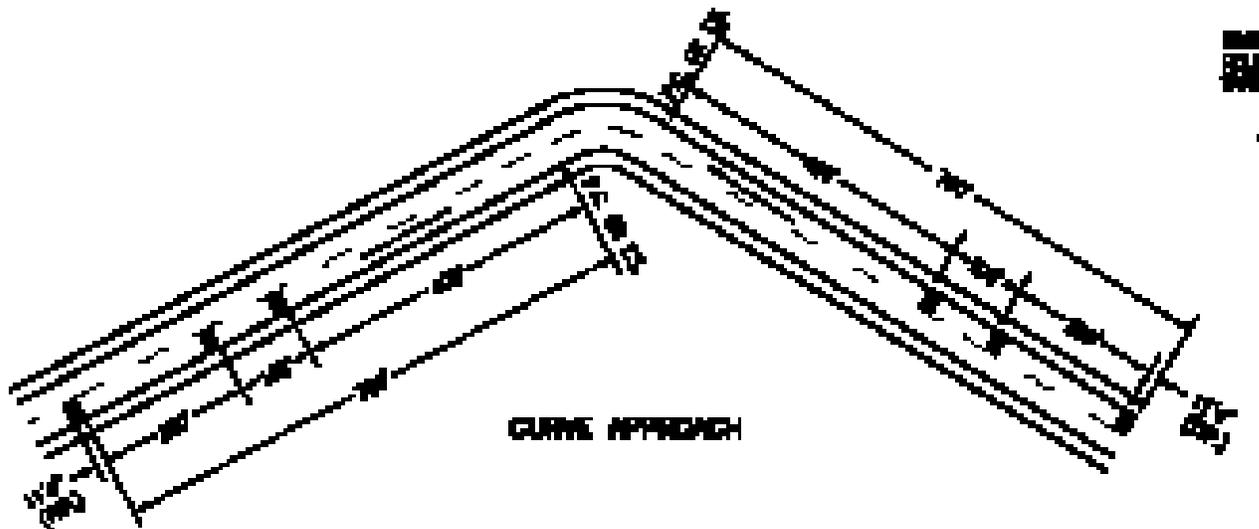


Figure 6. Colorado standard plans for use of transverse rumble strips in advance of a curve. From [12].

2.5.5 *Florida*

In Florida Department of Transportation's 2004 Design Standards, drawing 518 gives the specifications for the rumble strips. Specifications for raised and shoulder ground-in rumble strips are given. Raised rumble strips are installed in asphalt sets.

2.6 Rumble Strip Applications and Studies in Various States

2.6.1 *Utah*

In the study by Cheng et al [13], the effectiveness of rumble strips from a safety perspective is evaluated and the applicability of rumble strips on Utah highways is analyzed. Current standards for the use of rumble strips in Utah call for their use in the following situations:

- Only on plant mix seal coat surface or new concrete pavement.
- Minimum of 32 feet (9.75 m) surface (two 12-foot (3.65 m) lanes with 4-foot (1.22 m) shoulders).
- Highways with 50 mph (80.47 kph) or greater design speed.
- Where accident experience shows need.

Utah uses the one foot offset from the edge of the travel lane on asphalt pavement for rumble strips, but there is no consistent standard among highway agencies for the location of rumble strips. Cheng et al. recommend that rumble strips should be installed as close as possible to the travel lane in order to provide earliest warning. Assuming a passenger car traveling 50 mph (80.47 kph) at the center of a 12-foot (3.65 m) travel lane, it will take 0.082 seconds to reach the edge of the travel lane (using a 30 degree travel path when the driver falls asleep). The location of rumble strip installation is critical to its effectiveness. For every foot the rumble strip is offset from the edge of the travel lane, there is an additional 0.03 second delay in warning. Similarly, an additional foot in the width of a rumble strip generates an additional 0.03 second of warning duration.

The results show that accident rates for both overall and run-off-the-road accidents were lower on those sections with rumble strips. For those sections with rumble strips, the accident rates were found to be 0.713 and 0.394 for overall and run-off-the-road accidents, respectively. Highway sections without rumble strips were found to have accident rates of 0.951 (33.4% higher) and 0.500 (26.9% higher) for overall and run-off-the-road accidents, respectively.

Cheng et al. also made a comparison of serious accidents (incapacitating and fatal). Between the two study groups, with and without rumble strips, it was determined that rumble strips were effective in lowering accident severity. Furthermore, the continuous longitudinal design proved to be even more effective over the discontinuous design.

2.6.2 *Illinois and California*

In a study reported by Griffith [14], installed continuous shoulder rumble strips are evaluated from a safety perspective. The study used a before and after analysis with accident data from Illinois and California. The results of the evaluation showed that continuous shoulder rumble

strips (CSRS) reduce single-vehicle run-off-the-road crashes on average by 18.3% on all freeways and 21.1% on rural freeways.

Griffith also mentioned two possible adverse effects of the continuous shoulder rumble strips. The first potential adverse effect is the possibility that continuous shoulder rumble strips may cause certain drivers to overreact or panic to the warning, resulting in loss of control of their vehicles. The second potential adverse effect of CSRS is crash migration. Crash migration occurs when a driver is temporarily saved from a crash at a treated site but crashes downstream of the treatment area or at a different point in the network. In the study Illinois multi-vehicle accidents were analyzed and no evidence was observed that continuous shoulder rumble strips caused any increase in the multi-vehicle accidents.

2.6.3 California

In 1985, the California Department of Transportation (DOT) performed a before-and-after study where they installed rumble strips along sections of Interstates 15 and 40 in San Bernardino County. The study revealed a 49 percent decrease in the number of run-off-road crashes in the areas with rumble strips. Recent follow-up evaluations of freeway segments where shoulder rumble strips have been in place for 3 or more years have shown a 33 percent average reduction in run-off-road accidents.

2.6.4 Pennsylvania

Hickey [15] evaluated the effectiveness of shoulder rumble strips on the Pennsylvania Turnpike by a before and after study. The shoulder rumble strip it is called the Sonic Nap Alert Pattern (SNAP). After the installation of SNAP, drift-off-road accidents per month decreased by 70 percent. The analysis showed that about 12 percent of all accidents were amenable to the SNAP treatment.

In a study by Porter, Donnell, and Mahoney [16], the authors determined if the presence of centerline rumble strips (CRS) on two-lane rural roads had an effect on lateral vehicle placement and speed. The results of the field data collection and subsequent analysis showed that the presence of rumble strips affected both the mean and variance of lateral vehicle placement for both 12-foot (3.65 m) and 11-foot (3.35 m) lanes. For 12-foot (3.65 m) lanes, the mean lateral placement shifted 5.5 inches (0.1397 m) away from the roadway centerline after the treatment was applied. For the site with 11-foot (3.35 m) lanes, the mean lateral placement shifted 3 inches (0.0762 m) away from the roadway centerline after the treatment was applied. These findings suggest that the presence of CRS affects the mean lateral vehicle placement.

They also observed a statistically significant increase in speed variance for the 12-foot (3.65 m) lane treatment site after installation of CRSs; however the corresponding comparison site showed a statistically significant reduction in speed variance during the after period (no rumble strips). The 12-foot (3.65 m) lane treatment site did not exhibit a statistically significant change in vehicle speed after installation of the rumble strips, yet the comparison site did show a statistically significant increase in mean vehicle speed. For sites with 11-foot (3.35 m) travel lanes, the treatment site exhibited a statistically significant increase in mean

speed, while the comparison site showed a statistically significant decrease in vehicle speed after rumble strip installation. The speed variance was not statistically significant at either the treatment or comparison site in the after period. Overall, the effects of the CRS on mean speed and speed variance were mixed and made it difficult to draw meaningful and accurate conclusions [16].

2.6.5 Massachusetts

In a study by Noyce and Elango [17], the effectiveness of the centerline rumble strips in reducing the cross-over the centerline crashes and improving the safety of undivided roadways was evaluated. The authors analyzed the crashes in Massachusetts, before and after the installation of centerline rumble strips. The authors found that the installation of centerline rumble strips showed no significant change in crash frequencies; however after the installation of centerline rumble strips no fatal crashes were observed at the test sites.

2.6.6 Delaware

The Delaware DOT's US Route 301 Centerline Rumble Strip Project [1] provides some of the most compelling evidence concerning the success of rumble strips. After experiencing a high fatality rate from head-on collisions on Route 301, the Delaware DOT installed centerline rumble strips along the roadway. The result was a 90 percent decrease in the head-on collision rate and a zero fatality rate. These improvements were achieved despite a 30 percent increase in traffic. The project was awarded one of the 2001 National Highway Safety Awards by FHWA.

2.6.7 Michigan

In a recent study conducted at Michigan State University [18], the retroreflectivity of pavement markings applied on rumble strips was found to be 6 and 20 times greater than standard edgeline markings for dry and wet conditions, respectively. A photograph of the nighttime dry comparison of yellow edgelines is shown in Figure 7, and a similar comparison under wet conditions is shown in Figure 8. Thus the application of pavement markings over rumble strips would increase the wet weather and nighttime delineation.



Figure 7. Final dry-night digital photograph of side-by-side comparison of yellow solid and yellow rumble strip edge lines on I75 southbound, April 25, 2003. Adapted from [18].



Figure 8. Final wet-night digital photograph of side-by-side comparison of yellow solid and yellow rumble strip edge lines on I75 southbound, April 25, 2003. Adapted from [18].

In a study conducted by Taylor, Abu-Lebdeh, and Rai [19], it is stated that maintaining the current edge line and adding an additional paint line on the rumble strip results in vehicles moving away from the edge of the pavement, thus reducing noise and potential damage to the pavement.

2.6.8 *Mississippi*

Dean and Willis [20] analyzed the constructability of combining milled rumble strip and pavement marking combinations. The authors call this kind of installation a “rumble stripe”. Latitudinal and longitudinal views of a rumble stripe in daytime are shown in Figure 9 and Figure 10 respectively. For this study, 6”, 9”, 12”, and 16” (0.1524 m, 0.2286 m, 0.3048 m, and 0.4064 m respectively) rumble strips were installed with an edge stripe for evaluation. The study showed that all of the rumble strip designs produced satisfactory audible results. The delineation of the edge line was also increased significantly due to the near vertical facing of the rumble strips.

Concerns about the use of the rumble strips are also mentioned [20] in this study, including noise pollution, an increase in head-on crashes, and an increase in over-correcting incidents. The authors also performed a survey to evaluate the customer satisfaction with rumble stripes. Drivers indicated they saw the edge lines better after the installation of the rumble stripe.

The authors listed several benefits of rumble stripes. They provide an excellent audible alert, increase visual awareness of the travel lane, and increases retroreflectivity of the pavement markings. Application of rumble strips on edge stripe provides similar results as inverted profile striping and the survey showed that the Mississippi residents welcomed the use of rumble stripes.



Figure 9. Daytime side view of Mississippi's rumble stripe [20].



Figure 10. Daytime longitudinal view of Mississippi's rumble stripe [20].

2.6.9 Connecticut

In a study conducted by Smith and Ivan [21], safety benefits and potential crash migration due to the installation of shoulder rumble strips on freeways in Connecticut were evaluated. The study showed that the installation of shoulder rumble strips reduced the single vehicle, fixed object crashes by 33%. The crash reduction factors caused by the rumble strips were greater at the interchange areas, which was about 48%. The study also showed that the run-off-the-road crashes were increased at locations where rumble strips were not installed. The authors recommended the use of continuous rumble strip installation to reduce run-off-the-road crashes and to avoid the increase of crash rates where rumble strips are not installed.

2.6.10 Texas

In the study conducted in Texas [22], the effects of transverse rumble strips at approaches to high speed stop controlled intersections were analyzed. The study showed that the overall installation of transverse rumble strips produced small, but statistically significant reductions in the traffic speed. In general the speed reductions were 1 mph (1.6 kph) or less. Although the rumble strips did not produce meaningful reductions in traffic speeds, authors recommended that they should still be considered based upon previous crash reductions and minimal installation costs.

2.6.11 Ohio

Gupta [23] developed criteria for design, placement, and spacing of transverse rumble strips. In the study rumble strips were defined as pavement corrugations placed perpendicular to the direction of travel across the full width of a roadway approach. Two types of rumble strips were analyzed; raised rumble strips and grooved rumble strips. In the study Gupta used four different types of groove patterns each with a ½ inch (0.0127 m) depth. Pattern A with 4-inch (0.1016 m) wide grooves with a straight edge and an 8-inch (0.2032 m) clear spacing, pattern B with 4-inch (0.1016 m) wide grooves with a tapered edge and a bottom groove width of 3½ inches (0.0889 m). Patterns C and D were similar to

patterns A and B. Figure 11 shows the four grooved rumble strip designs. Gupta also used different designs for the pad spacing; Figure 12 shows the 5 different designs. Gupta recommended a minimum of 18" (0.4572 m) of groove-free pavement for bicyclists in the design and the installation of a warning sign "Rumble Strips Ahead".

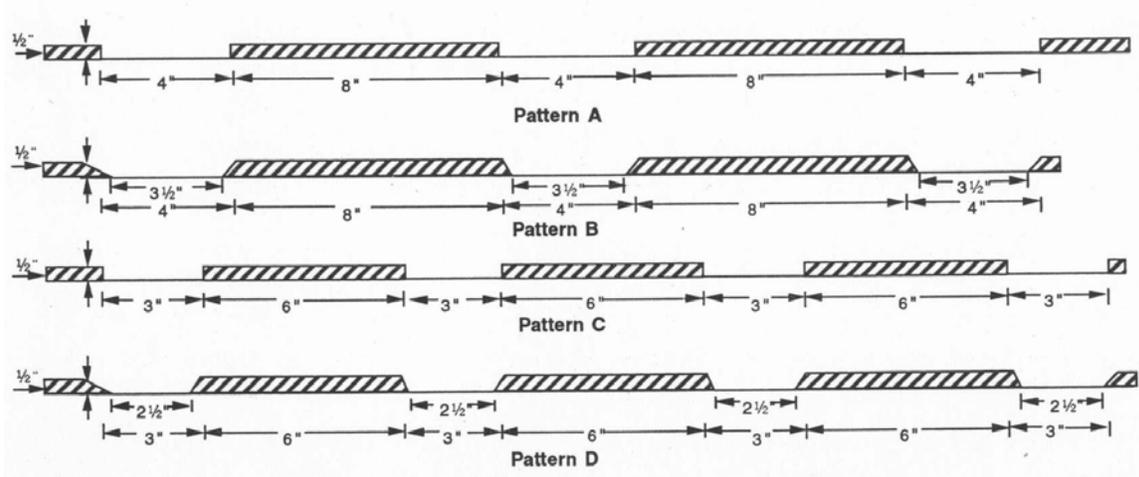


Figure 11. Proposed Grooved Rumble Strips Design Patterns [23]

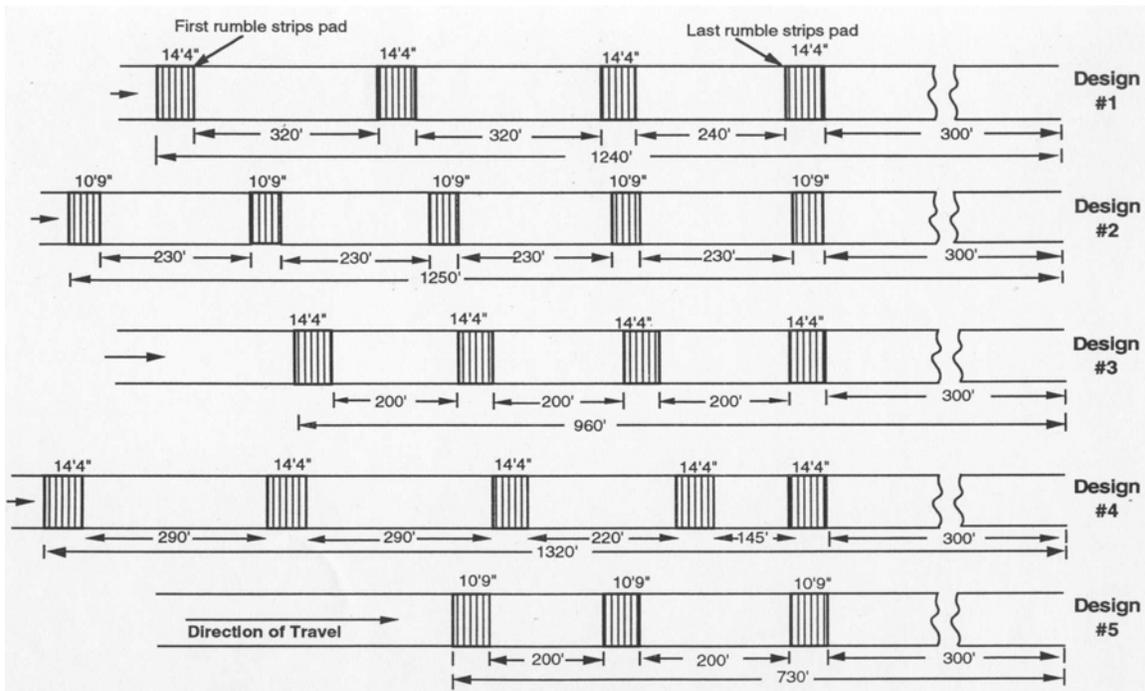


Figure 12. Grooved Rumble Strips Pad Spacing Design Configurations for Research Study [23]

Gupta found that State Departments of Transportation prefer grooved rumble strips over raised rumble strips. Raised rumble strips are preferred for temporary installations, since they are easier to install and remove.

He recommended the installation of 4-inches (0.1016 m) wide, ½ inch (0.0127 m) deep, straight edge grooved rumble strips at locations considered hazardous (work zones, stop signs, sharp curves). Three or four rumble strip pads should be installed. More pads have no significantly different effect on speed than four pads. Rumble strip pads should be a minimum of two seconds and a maximum of four seconds apart. For a speed of 50 mph (80.47 kph), rumble strips pads should be between 150 feet (45.72 m) to 300 feet (91.44 m) apart. The last rumble strip pad from a STOP sign or from the point of curvature should be 300 feet (91.44 m). Each rumble strip pad should contain 15 rumble strips, 12 inches (0.3048 m) center-to-center. In addition he recommended that rumble strips should not be installed close to residential areas as people are sensitive to noise.

2.7 Use of Milled Centerline Rumble Strips by U.S States and Canadian Provinces

The standards used for centerline rumble strips by the U.S. Departments of Transportation are given and evaluated in a study [24]. The noise and vibration effects of the applications are evaluated and the best standard is identified.

Seven different types of vehicles are used in the study. The types of vehicles are chosen to represent the variety of vehicles on the highways: two large trucks, a full-size pickup truck, a full-size passenger car, a compact passenger car, a minivan, and a sport utility vehicle. A comparison of the applications of centerline rumble strips by several states and Canadian provinces is shown in Table 2.

Table 2. Use of Milled Centerline Rumble Strips by U.S States and Canadian Provinces [24] (1 in = 2.54 cm)

State	Width	Length	Depth	Center	All Zones or No Pass Only	Comments
California	6.5"	16"	0.5"	Continuous 24'	No Pass Only	Used with raised thermoplastic striping and reflectors
Washington	6.5"	16"	0.5"	Continuous 12'	No Pass Only	Markings installed over strips
	6.5"	16"	0.5"	Continuous 24'	No Pass Only	Markings installed over strips
Oregon	7"	16"	0.63"	Continuous 12'	No Pass Only	Used with 4' median
Arizona	6.5"	12"	0.5"	Continuous 12'	All Zones	Markings installed over strips
	6.5"	8"	0.5"	Continuous 12'	All Zones	Narrower to reduce residential noise
	6.5"	5"	0.5"	Continuous 12'	All Zones	Narrower to reduce residential noise
Massachusetts	6.5"	18"	0.5"	Continuous 12'	No Pass Only	Markings installed over strips
Pennsylvania	6.5"	30"	0.5"	Alternating 24 & 48"	No Pass Only	Across centerlines - 12' lanes
	6.5"	16" each	0.5"	Alternating 24 & 48"	No Pass Only	Outside centerlines - 12' lanes
	6.5"	16"	0.5"	Alternating 24 & 48"	No Pass Only	Between centerlines - 12' lanes
	6.5"	18"	0.5"	Alternating 24 & 48"	No Pass Only	Across centerlines - 11' lanes
	6.5"	10" each	0.5"	Alternating 24 & 48"	No Pass Only	Outside centerlines - 11' lanes
	6.5"	12"	0.5"	Alternating 24 & 48"	No Pass Only	Between centerlines - 11' lanes
Colorado	6.5"	12"	0.5"	Continuous 12'	All Zones	Markings installed over strips
Connecticut	6.5"	16"	0.5"	Continuous 12'	No Pass Only	Markings installed over strips
Alberta, Canada	6.5"	12"	0.5"	Continuous 12'	All Zones	Markings installed over strips

Note:

Width - represents dimension parallel to travel surface

Length - represents dimension perpendicular to travel surface

Depth - represents dimension downward (cut) from the top of the surface

Center - spacing between center of strips (see Figures 1, 3 and 5)

2.8 Human Factors Considerations

2.8.1 Sound

In highways the posted speed limit is usually 55 mph (88.51 kph) or 65 mph (104.61 kph). Thus research studies for the evaluation of rumble strips are usually performed with these posted speed limits.

If the speed of the vehicle is 55 mph (88.51 kph) a rumble strip causes sound and vibration at 81 Hz (cycles/second). If the speed of the vehicle is 65 mph (104.61 kph) the frequency is 95 Hz (cycles/second).

While 81 or 95 Hz is in a band that the ear is relatively insensitive to, as seen in Figure 13 [25], the sound level of typical milled-in rumble strips is sufficient to be very noticeable. Measured sound levels for milled shoulder rumble strips from several studies are compared in Table 3. The sound inside an operating passenger vehicle is approximately 60 decibels, and the maximum permissible noise inside an operating cab of a large truck is 90dB. The noise produced by the rumble strips should be at least 6dB greater than the background noise value in order to be clearly noticeable [27]; see Table 4. This criterion appears to be met by all the measurements cited in Table 3, with the exception of the heavy vehicle measurement by the California Department of Transportation (Caltrans), where the rumble strip increases ambient sound levels by only 2-5 dB.

Outcalt [27] tested several different sections of rumble strips for sound levels in different vehicles and the results are plotted in Figure 14 for vehicles traveling at 55 mph (88.51 kph) and in Figure 15 for vehicles traveling 65 mph (104.61 kph). All the passenger vehicles were provided adequate increases in sound levels by all the tested strips, except the pickup truck on strips 1 and 3 at 55 mph (88.51 kph) and on strip 3 at 65 mph (104.61 kph). For the large dump truck tested, strips 1-4 and 10 were inadequate at 55 mph (88.51 kph), and all failed the criterion except strip 7 at 65 mph (104.61 kph). This further reinforces the perception that heavy vehicles are less susceptible to rumble strip warnings. Dimensions of the rumble strips used in the study are given in Table 5.

Adversely, high levels of noise can be a significant concern for nearby residential environments. In his study Perrillo [28] reported that complaints have been made by residents living in close proximity to roadways equipped with continuous shoulder rumble strips about the noises produced. Although the rumble strips are rarely driven over (only by those vehicles leaving the roadways), some complaints have been made even based on infrequent events.

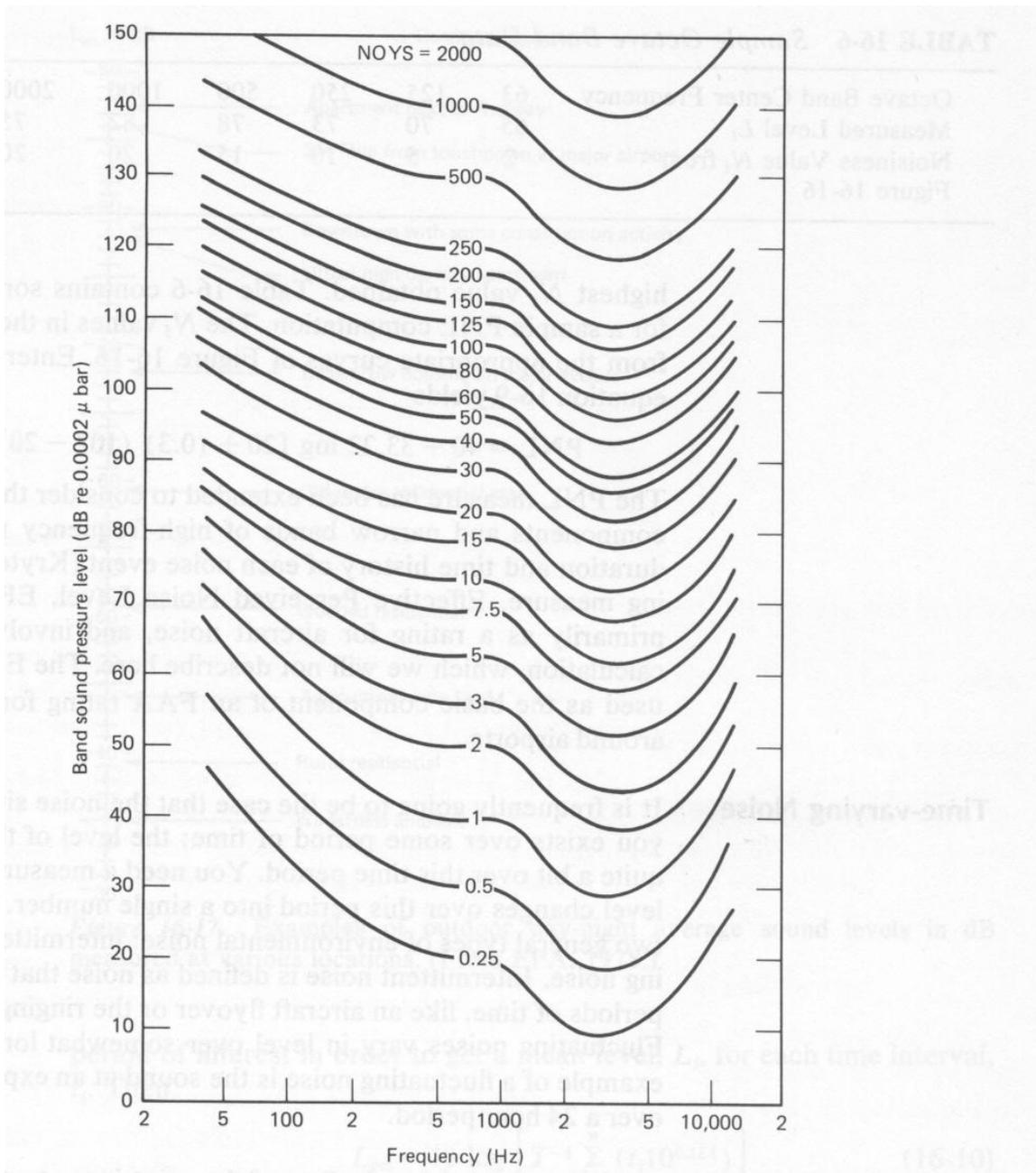


Figure 13. Contours of perceived noisiness. Adapted from [25].

Table 3. Decibel levels produced by milled shoulder rumble strips.

Study authors	Milled SRS sound level (dB)	Location of Measurement
Higgins and Barbel	increase of 7 dB over ambient levels	outside vehicle
Wood	74-80 (auto) 86 (truck)	inside vehicle
Chen	85-86	outside vehicle
Elefteriadiou et al.	75-84 (@ 72 kph) 78-89 (@ 88 kph)	inside vehicle
Caltrans	increase of 12-21 (@ 80 kph) (auto) increase of 10-19 (@ 100 kph) (auto) increase of 2-5 (@ 80 kph) (heavy vehicle)	inside vehicle
Outcalt	increase of approximately 10 dB over ambient levels	inside vehicle

Table 4. Approximate human perception of changes in sound level [27].

Change in Sound Level (dB)	Change in apparent loudness
1 dB	Imperceptible
3 dB	Barely noticeable
6 dB	Clearly noticeable
10 dB	About twice (or half) as loud
20 dB	About four times (or one quarter) as loud

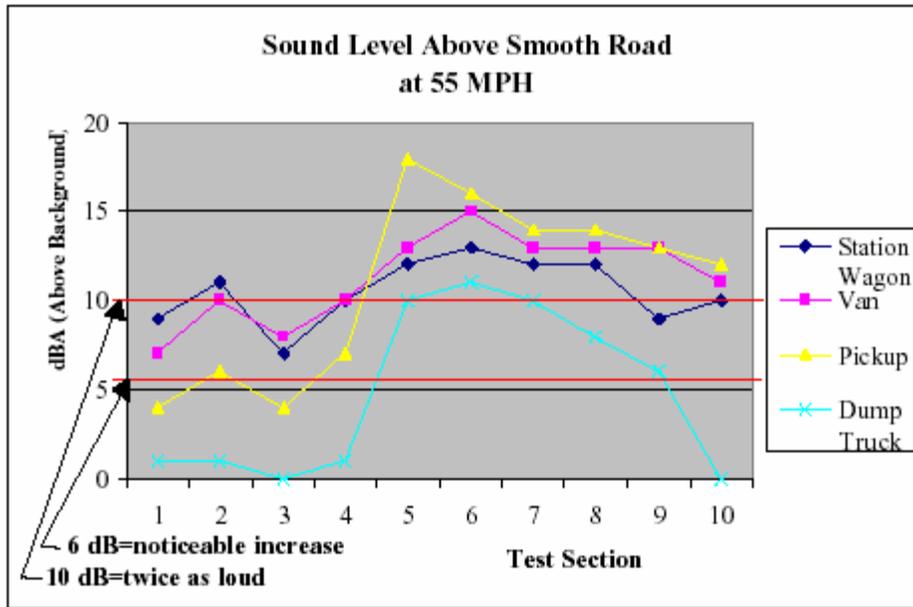


Figure 14. The increase in sound level inside vehicles at 55 mph (88.51 kph) [27].

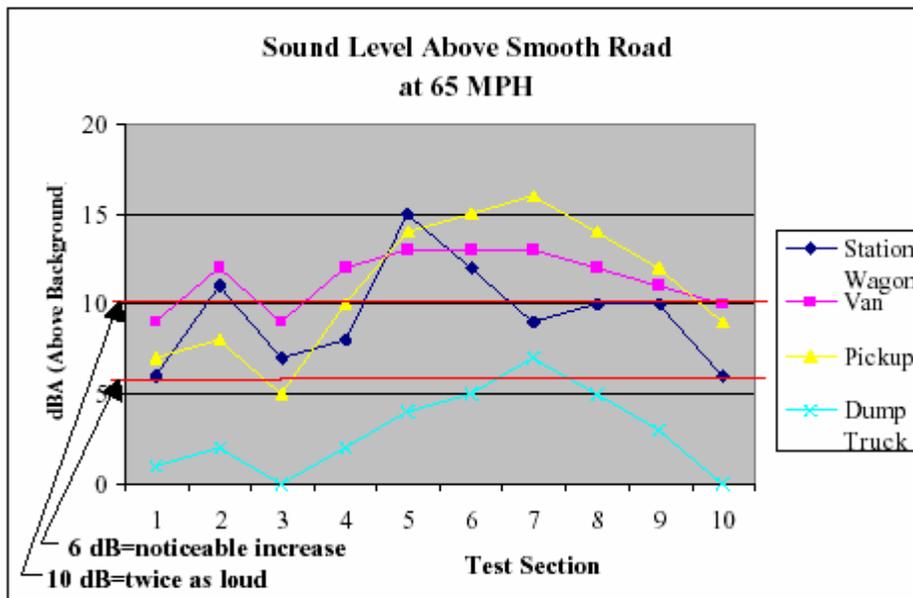


Figure 15. The increase in sound level inside vehicles at 65 mph (104.61) [27].

Table 5. Rumble strip dimensions tested in study of bicycle friendly rumble strips [27].

Section	1	1A	2	2A	3	4	4A	5	6	7	8	9
Groove Width (in.)	2	2	2	2	2	2	2	7-7/2	6-1/2	6	5-1/2	5
Flat Width (in.)	10	10	5	5	5	3	3	4-1/2	5-1/2	6	6-1/2	7
Rumble Strip/Gap (ft)	Cont.	12/6	Cont.	12/6	12/6	Cont.	12-6	48/12	Cont.	Cont.	Cont.	Cont.
Average Depth (in.)	0.44	0.44	0.44	0.44	0.29	0.39	0.39	0.58	0.49	0.46	0.41	0.28
Target Depth	0.5	0.5	0.5	0.5	0.375	0.5	0.5	0.75	0.5	0.375	0.25	0.125
Max. Measured (in.)	0.58	0.58	0.46	0.46	0.38	0.48	0.48	0.71	0.59	0.53	0.47	0.40
Min. Measured (in.)	0.36	0.36	0.43	0.43	0.20	0.33	0.33	0.50	0.35	0.42	0.37	0.22

2.8.2 Vibration

Vibration levels felt in the body from rumble strips fall into the area where the body is sensitive, but not the absolute most sensitive, as shown in Figure 16 [26]. Accelerometer measurements from a GMC minivan for the ten rumble strips (described by measurements in Table 5) tested by Outcault are given in Table 6 [27].

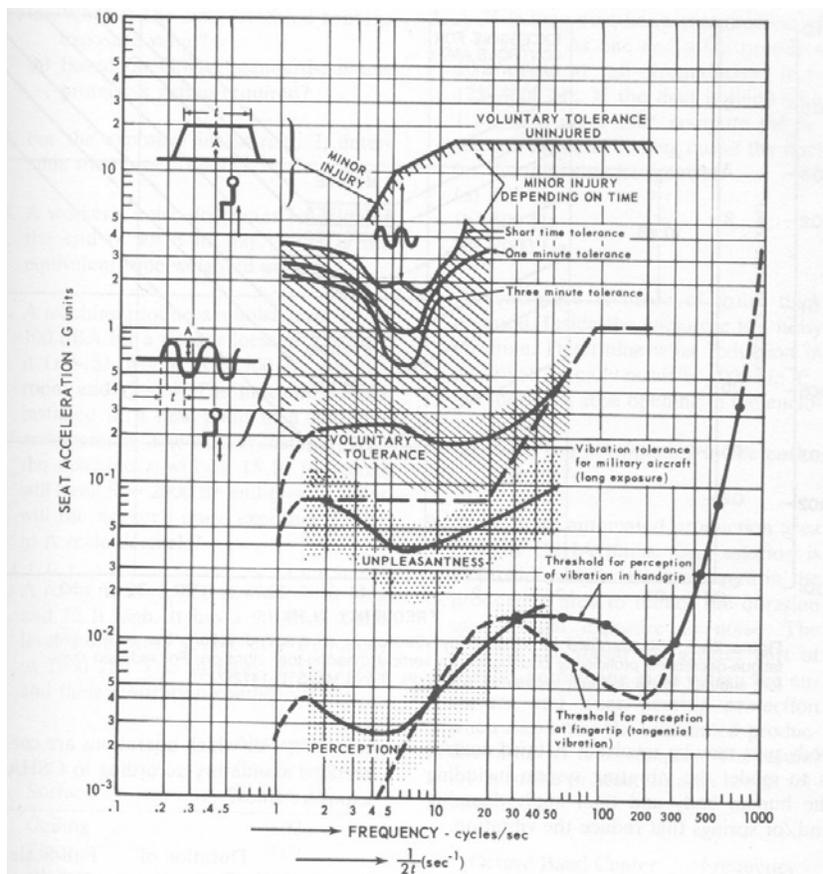


Figure 16. Human response regions for vibration. Adapted from [26].

Table 6. Vibration levels and frequencies of various rumble strip designs tested by Outcalt [27]. Vibration levels were measured in a GMC minivan using a Brüel and Kjaer Type 4370 accelerometer. Maximum levels and frequencies are listed.

	Accelerometer Mounted to Floor				Accelerometer Mounted to Steering Wheel			
	55 MPH		65 MPH		55 MPH		65 MPH	
	Max (dB)*	Freq. (Hz)	Max (dB)	Freq. (Hz)	Max (dB)	Freq. (Hz)	Max (dB)	Freq. (Hz)
Rumble Strip 1	-6	80	-9	100	5	80	-5	40
Rumble Strip 1A	-9	80	-11	200	5	80	-5	100
Rumble Strip 2	-8	125	-6	160	0	80	-6	40 & 160
Rumble Strip 2A	-9	125	-8	160	-3	125	-4	160
Rumble Strip 3	-10	125	-9	160	-5	125	-6	160
Rumble Strip 4	-9	200	-1	250	-6	80	***	***
Rumble Strip 4A	-17	25	-4	250	-4	80	***	***
Rumble Strip 5	6	80	3	100	11	80	7	100
Rumble Strip 6	8	80	3	100	8	80	2	100
Rumble Strip 7	8	80	3	100	9	80	3	100
Rumble Strip 8	5	80	2	100	5	80 & 160	5	100
Rumble Strip 9	-2	160	-1	100	2	80 & 160	7	100
Rumble Strip 10	3	630	8	630	1	63	1	63

* dB, re: 1 m/s²

** Data at or below background acceleration (as measured on smooth pavement alongside rumble strips).

2.9 Design and Deployment

2.9.1 Bicycle Friendly Rumble Strips

In the study by William (Skip) Outcalt [27], ten different types of rumble strips were installed and evaluated by bicyclists. The dimensions of the test rumble strips are given in Table 5. The noise and vibration of the designs on vehicles were measured, as shown previously in Figure 14, Figure 15, and Table 6.

Twenty nine bicyclists evaluated and compared the sections according to comfort and controllability. During the bicyclists' evaluations a consultant measured the vibrations of a bicycle that had an accelerometer mounted to the frame. On later dates, the same consultant measured sound levels in a minivan, a pickup truck, a station wagon, and a dump truck, and vibrations on the floor and steering wheel of the minivan.

In Table 7, comparisons of the bicyclists' preferences, motor vehicle sound level, and motor vehicle vibration are given. Sections 8 and 9 fell in the middle range in all three categories: bicycle comfort, vehicle sound level, and vehicle vibration. Otherwise, strips that were judged to be better by bicyclists tended to give low levels of sound and vibration, and those that gave high levels of sound and vibration to vehicles were judged as more uncomfortable by bicyclists. Therefore, this contradiction in requirements calls for a decision in selecting the correct rumble strips

Table 7. Ranking of rumble strip test sections by bicycle users and automobile drivers. At left bicycle users' comfort, middle automobile drivers' perceived loudness, at right automobile vibration levels [27].

Bicyclist Preference Best at the top Worst at the bottom	Motor Vehicle Sound Level Loudest at the top Quietest at the bottom	Average Motor Vehicle Vibration Strongest at the top Weakest at the bottom
Section 10	Section 6	Section 5
Section 1	Section 5	Section 7
Section 3	Section 7	Section 6
Section 2	Section 8	Section 8
Section 4	Section 9	Section 10
Section 9	Section 2	Section 9
Section 8	Section 4	Section 1
Section 7	Section 10	Section 2
Section 6	Section 1	Section 4
Section 5	Section 3	Section 3

Sections 5, 6, and 7 gave the best sound and vibration levels in the vehicles. However, they were the worst for the cyclists.

Sections 10, 1, and 3 were the best from the bicycle point of view but were at the bottom of the motor vehicle columns. Sections 2, 4, 8 and 9 rated near the middle for all three tests.

During the testing for this study, it was found that the new-style 2-inch (0.0508 m) groove rumble strip and the rolled-in concrete rumble strip did not produce a “noticeable increase” (6dB) in sound over the sound levels in the cab of the dump truck during normal highway operation. Only the “standard design” configurations produced enough sound increase to be noticeable in the cab of a tandem axle dump truck (vibration testing was not done in the dump truck.). Rumble strips 2, 8, and 9 offer the best compromise between comfort for bicyclists and severity of alert for drivers of the 10 strips tested. Rider ratings for these four sections are nearly the same and, for three of the four vehicles tested, they have more than a 6 dB sound increase over the driving lane. However, in the dump truck only section 8 has a sound level close to the 6 dB needed to be “clearly noticeable” (8 dB at 55 mph (88.51 kph) in Figure 14 and 5 dB at 65 mph (104.61 kph) in Figure 15).

If the sound level will be used as the determining factor for an acceptable rumble strip, sections 2, 8, and 9 are all acceptable for small vehicles. However, only sections 8 and 9 raise the sound level 6dBA in the dump truck at 55 mph (88.51 kph), and only section 8 is close (5dB) at 65 mph (104.61 kph). The grooves in section 8 measured an average depth of 0.41 in (0.0104 m), which is slightly over 3/8 inch (0.0095 m). Standards in Colorado, where the studies were conducted, call for the rumble strips to be constructed with gaps at regular intervals. With the gaps and the less aggressive grooves in the section 8 rumble strips, bicyclists should be able to use the shoulders without problems. Cyclists need to be aware that the rumble strips are there and to respect them. But they should be able to avoid the strips most of the time and, by using caution when they do have to ride across a rumble strip, be able to enjoy riding without worry of injury or damage to their bicycles [27].

The study finally recommends using the standard design rumble strip with gaps, grinding the grooves to a depth of 3/8 inch ($\pm 1/8$ inch) (0.0095 m \pm 0.0031 m) on 12-inch (0.30 m) centers in a gap pattern of 48 feet (1.21 m) of rumble strip followed by 12 feet (3.6576 m) of gap. This depth provides a relatively high level of sound and vibration in motor vehicles and can be crossed by a bicycle without causing loss of control [27].

According to Per Garder [29], wide paved shoulders on busy two-lane roads are sometimes designated as bicycle routes. However such a shared shoulder may not be a safe place for bicyclists if inattentive and dozing drivers infringe on it. Preliminary estimates for a road carrying 1,000 vehicles per hour show a fatality rate substantially higher than the average rate for bicycling. To make the shoulder safe, dozing vehicle drivers have to be awakened before they infringe on the bicyclists' part of the shoulder. Thus narrow but adequately wide continuous shoulder rumble strips are recommended to alert wandering drivers and thus reduce the number of run-off-road automobile crashes as well as enhance the safety of bicyclists and others using the shoulder. It is important that this non-rumble strip portion of the shoulder is kept free from debris so that bicyclists are not forced to ride on the rumble strip area or out in traffic.

2.9.2 Lane Line Rumble Strips

Stanford and Carlson studied lane line rumble strips in Texas [30]. A lane line rumble strip is applied to the stripe area separating two lanes of traffic traveling in the same direction, as shown in Figure 17. Lane line rumble strips are smaller than the usual rumble strip applications. The aim of the lane line rumble strips, with pavement markings applied over them, is to increase the wet/night visibility without adding too much noise. The application has also advantages in winter weather conditions. They will not be affected by the snow plowing operations.



Figure 17. Lane line rumble strips as applied in Texas [30]. Note also the presence of a centerline rumble strip in the background.

2.9.3 Raised Temporary Transverse Rumble strips

Different types of raised temporary rumble strips are manufactured by Swarco Industries Inc [31]. The company manufactures rumble strips in different colors (white, yellow (shown in Figure 18), orange, and black) and in reflective or non-reflective versions. There have been questions raised about whether these raised rumble strips can hold under heavy traffic conditions when they are glued or even when they are nailed down. Even properly glued

down pavement marking tape, which has a much lower profile, has difficulty holding, especially when heavy trucks pass over it.

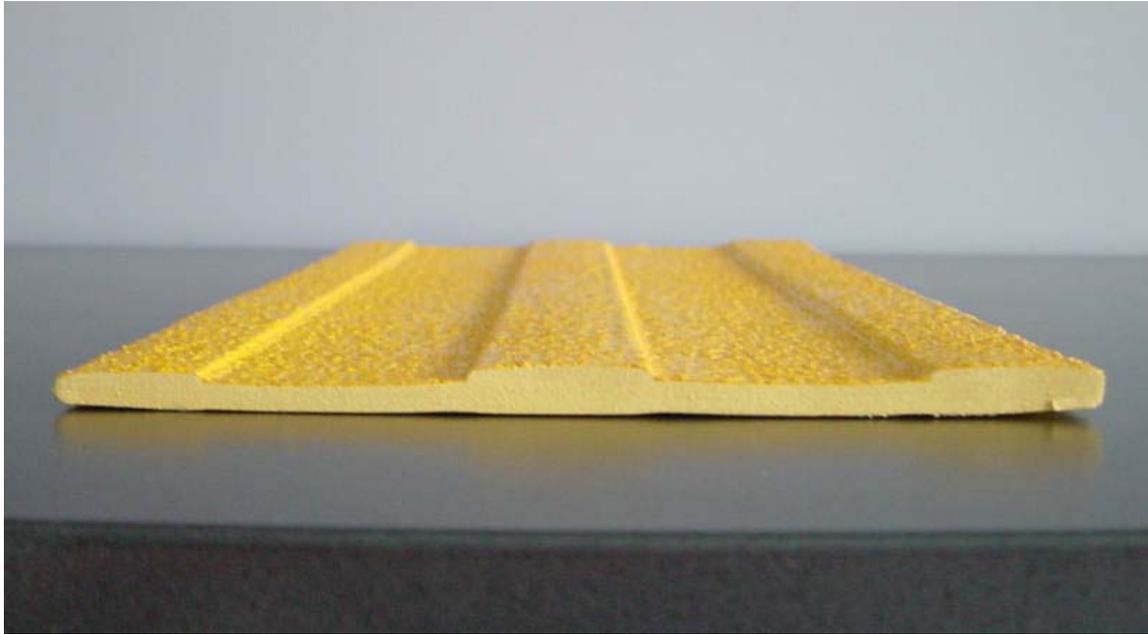
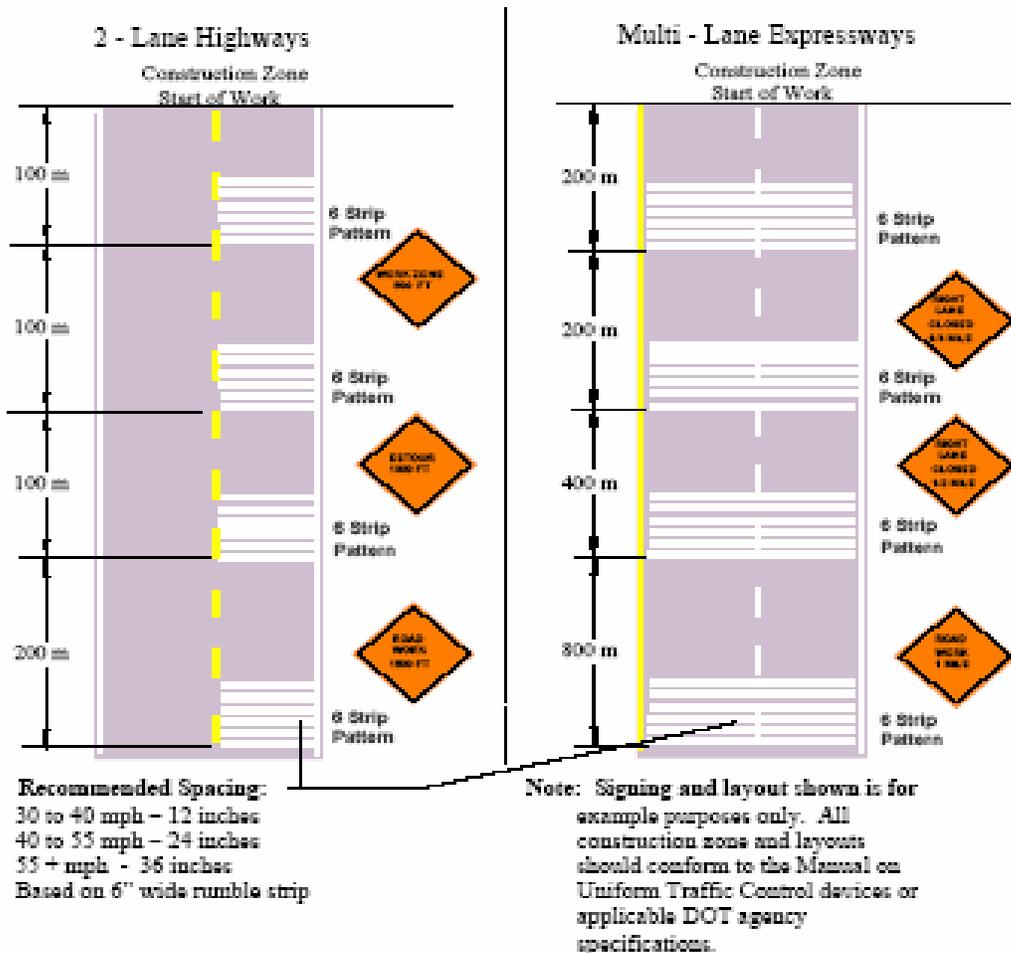


Figure 18. Swarco raised temporary rumble strip sample [31].

A suggested layout configuration for the temporary rumble strips manufactured by Swarco is given in Figure 19. However, there has been no research studies conducted for this or other given configurations. Swarco's suggested configurations should be evaluated before implementation.

SUGGESTED LAYOUT DETAILS

TEMPORARY RUMBLE STRIPS



RUMBLER - Preformed Rumble Strips Reflective and Non-Reflective Permanent and Temporary Applications

Figure 19. Suggested layout configuration for the temporary rumble strips manufactured by Swarco [32].

2.9.4 Rumble Strip Fabrication

There are several devices and systems for applying rumble strips. The system used in Colorado is depicted in Figure 20, taken from Outcalt's report [27]. It consists of a grinder trailer towed by an attached truck. The key component is the toothed drum shown in the bottom view of the trailer in Figure 21. The teeth are removable, so that the width of the rumble strip can be adjusted by removing or replacing teeth. The fully toothed drum removed from the grinder trailer is shown in Figure 22.



Figure 20. The machine that grinds the standard rumble strips. Inside the large wheel at the front of the machine is the cam that determines the spacing of the rumble strip grooves [27].



Figure 21. The underside of the grinder trailer. This shows the grinding drum with its teeth. By adding more teeth or taking some out the length of the grooves - the width of the rumble strip can be adjusted. The lateral offset in the teeth causes the rough texture of the grooves [27].



Figure 22. The grinding drum determines the length of the grooves. By leaving some of the end sockets empty, the length of the grooves (the width of the rumble strip) can be varied [27].

Thomas Grinding sells a device similar to the one discussed above, shown in Figure 23 [33]. The device can grind 1.8 miles (2.9 km) of rumble strip in an hour. A stand-alone system called the Noiseprint by Surface Preparation Technologies, Inc. is shown in Figure 24 [34]. It boasts a computer controlled exclusive milling process that can cut 180 cuts per minute.



Figure 23. One of the rumble strip machine providers is Thomas Grinding. The machine is capable of production rates in excess of 1.8 miles per hour in asphalt [33].



Figure 24. Surface Preparation Technologies', Inc. (SPT), Noiseprint delivers the industry's leading shoulder rumble strip installation technology. Noise print's exclusive milling process is controlled by computer for maximum speed. Noiseprint can achieve speeds of up to 180 cuts per minute [34].

2.10 Recommendations to ODOT

In addition to increased safety, rumble strips have been shown to cut costs. Several states have analyzed the benefit/cost ratio of shoulder strips, and the results are as dramatic as the accident reduction rates. New York State Thruway data indicates a benefit/cost ratio ranging from 66:1 to a high of 182:1. The Nevada DOT found that with a benefit/cost ratio ranging from 30:1 to more than 60:1, rumble strips are more cost-effective than many other safety features, including guardrails, culvert-end treatments, and slope flattening. And a Maine DOT survey of 50 state DOTs identified a benefit/cost ratio of 50:1 for milled rumble strips on rural Interstates nationwide.

It should also be noted that the longitudinal rumble strips are effective in winter weather conditions when the roads are covered with snow. They help drivers to know whether they are within the road by providing vibration, auditory, and visual warning. Rumble strips also warn sleepy drivers. Sleepy drivers have more lateral deviation during travel and rumble strips would keep them in their driving lane.

2.10.1 Milled-in Shoulder and Centerline Rumble Stripe Installations

Below are diagrams of two rumble stripe patterns that could benefit Ohio's drivers. The first is a shoulder rumble stripe placed on the right edge line. The 4 in (0.1016 m) wide edge line marking is along the inside surface of the rumble strip. Rumble strip grooves are 16 in by 7 in (0.4064 m x 0.1778 m) with a ½ in (0.0127 m) depth. They are spaced 12 inches (0.3048 m) apart, center to center. This is shown in Figure 25. Figure 26 shows a full two-lane road

treatment, with rumble stripes on the outside edges of both lanes and a centerline rumble stripe. Along the centerline, the rumble strip grooves are the same dimensions as those on the shoulder, but the yellow lines are placed differently. In the figure there are two yellow stripes, positioned 1 in inside the edge of the rumble strip. The stripes are 4 in (0.1016 m) wide, leaving 6 in (0.1524 m) separating the stripes (inside edge to inside edge).

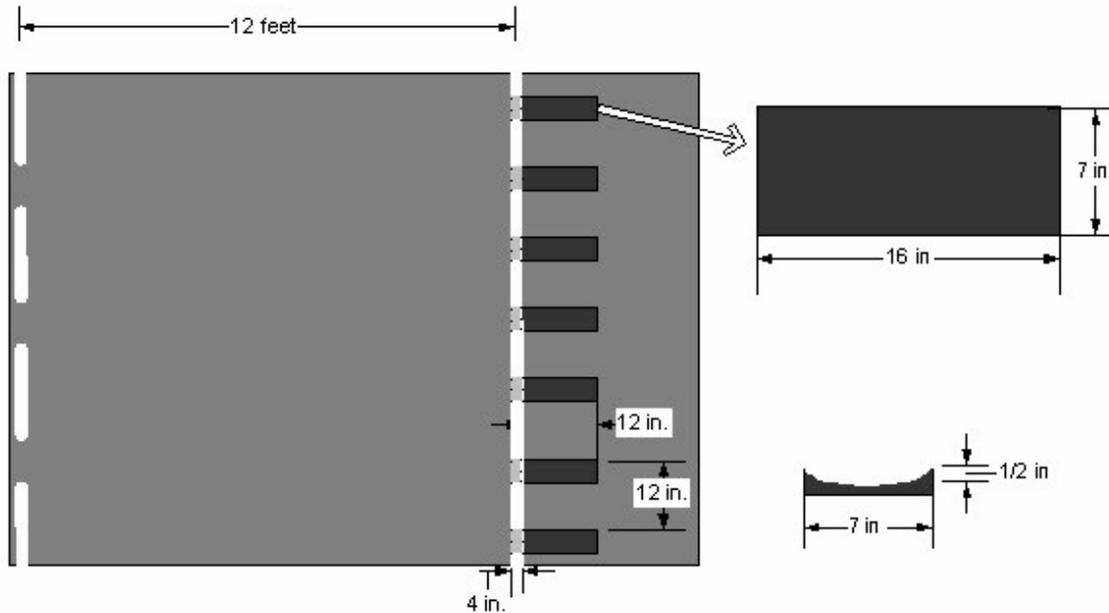


Figure 25. Diagram showing suggested application of edge line (shoulder) rumble stripe with edge line applied on inside portion of rumble strip.

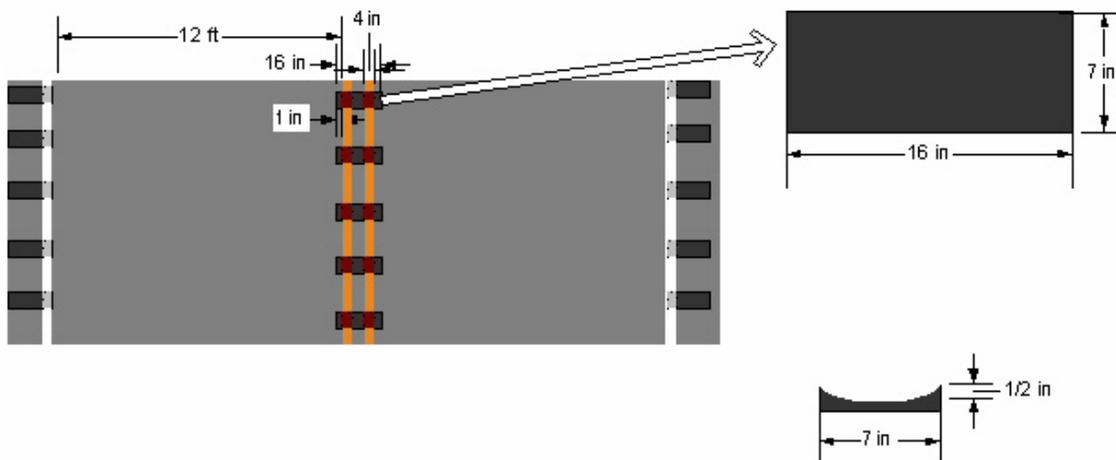


Figure 26. Diagram showing suggested application of centerline rumble stripe in addition to suggested edge line rumble stripe application shown in Figure 25.

- According to the literature reviewed on rumble strips, we recommend the installation of milled shoulder rumble strips on Ohio highways. The effectiveness

of shoulder rumble strips have been evaluated by several states and they have been shown to reduce the single vehicle run-off-the-road crash rate, as shown in Table 8.

- A 7-inch (0.1778 m) milled rumble strip generates 335% more noise, and produces 1,260% more vibration excesses than rolled-in patterns. Therefore Ohio should use a milled rumble strip and not a rolled-in type.

Table 8. Crash reduction due to rumble strips in several states. From [35].

State/Date	Highway Type	% Crash Reduction
Pennsylvania/1994	Thruway - Rural	70
New Jersey/1995*	Turnpike - Rural	34
New York/1994	Thruway - Rural	72
Massachusetts/ 1997*	Turnpike - Rural	42
Washington/1991*	Six Locations	18
California/1985	Interstate - Rural	49
Kansas/1991*	Turnpike - Rural	34
FHWA/1985	Interstate - Rural (Five States)	20

- The recommendations in the Technical Advisory T 5040.35 on rumble strips by FHWA should be implemented in the installation of rumble strips [3].
- Milled rumble strips should be installed close to the edge line on roadways with a 10-foot shoulder, leaving at least an 8-foot (2.43 m) clear shoulder width.
- Milled depth of approximately 10 mm (3/8 inch) provides reasonable warning to most motorists while not being unduly dangerous to bicyclists.
- The application of additional pavement markings on rumble strips, called a “rumble stripe”, is recommended to improve nighttime visibility of pavement markings in addition to providing the auditory and vibrational warning benefits of rumble strips. Delineation will also be improved.
- A passenger car traveling 50 mph (80.46 kph) at the center of a 12-foot (3.65 m) travel lane will take 0.082 second to reach the edge of the travel lane assuming a 30 degree travel path when the driver falls asleep.
- The location of rumble strip installation is critical to its effectiveness.
- For every foot the rumble strip is offset from the edge of the travel lane, there is an

additional 0.03 second delay in warning.

- Each additional foot in the width of a rumble strip generates an additional 0.03 second of warning duration.
- Centerline rumble strips may be installed at no pass zones of two-lane rural highways. A study conducted by Delaware DOT showed that the head-on collision rate decreased by 90 percent and no fatalities were observed after the installation of centerline rumble strips, despite a 30 percent increase in traffic [1].
- The recommended design for the application of shoulder rumble strips is given in Figure 25 and Figure 26.
- Application of rumble strips as close as possible to the driving lane will provide an early warning for the driver, which will increase the time the driver has to react to avoid a collision.
- Studies showed that installing centerline rumble strips reduces run-off-road crashes and head-on collisions.
- Centerline rumble strips may be installed at no passing zones of 2-lane rural roads with paved shoulders. No passing Zone sign should be placed before the start of the no passing zone. In addition, warning about the rumble strips on the centerline may be given to the drivers.
- The recommended design for the application of centerline rumble strips is given in Figure 26.
- Centerline rumble strips will provide early warning for drivers drifting to the center of the road, better delineation, and better nighttime and wet weather visibility.
- Centerline rumble strips can also be installed at locations where high head-on collision rates and high traffic is observed. Locations should be selected based on the Pareto principle, i.e. starting with those locations in the top 10-25% of head-on collisions or fatalities, and in locations with substantial traffic.
- Shoulder rumble strips should also be installed following a Pareto principle, this time based on the top 10-25% of run-off-the-road accidents.
- Noise complaints from both drivers and nearby residents must be considered when specifying the rumble strip installation.

Looking at the future, to build on current rumble strip successes, additional installations and evaluations of centerline rumble strips and shoulder rumble strips on two-lane rural roads are needed.

2.11 Recommended Evaluations

2.11.1 Longitudinal Rumble Strips

The cost of installing rumble strips as a stand-alone project is estimated at \$2/ft in Pennsylvania, \$0.38-0.40/ft (\$0.38-0.40/0.3048 m) in Virginia, with lower costs expected on longer projects, and \$0.68/ft (\$0.68/0.3048 m) for centerline and shoulder rumble strips described in an NCHRP report [36]. This makes the cost of 80 ft (24.38 m) of rumble strip \$30-\$160; the cost of a single raised pavement marker is estimated at about \$30. Thus a centerline rumble stripe may function as a cost-competitive replacement for raised pavement markers and standard pavement marking. An evaluation would need to be performed to make sure that the wet-weather visibility of the rumble stripe (rumble strip with pavement marking overlaid) is as good as that of raised pavement markers combined with standard pavement markings and that these installations would indeed be cost effective; the brightness of the yellow line in Figure 8 appears to compare well to that of the raised pavement markers on the right. There may be some weathering or deterioration issues with rumble stripes versus RPMs to be considered (the pavement marking material may weather differently than RPMs), as well as snowplowability issues (RPMs can be damaged or stripped by snowplows). There would be no doubt that the vibrational warning provided by rumble strips would be considerably superior to the sparse bumping of hitting an RPM every 80 ft (24.38 m).

A short-term study of rumble stripes could include a photometric visibility study to compare daytime and nighttime visibility of rumble stripes and standard markings. Also, a driver evaluation similar to that performed for unlighted overhead guide signs could be conducted using panels of older drivers or general motorists.

While longitudinal rumble strips have been installed on some Ohio highways, for instance on US Route 33 near Lancaster, a more widespread and consistent use of them should save lives and property across the state. An evaluation study would help quantify that benefit and better determine the conditions under which rumble strips should be used to obtain a substantial economic benefit. Such a study could be a before and after study of three years of accidents along several miles of road over several locations, or a comparison between similar stretches of road, one treated and the other untreated (new pavement markings only). One could pick the top five or ten hot spots with run-off-the-road or crossing-the-centerline crashes for the before and after study. An evaluation could also determine the best criterion for the deployment of rumble strips, whether it is accident rate (of relevant types), average daily traffic, cost of accidents, type of road (urban or rural), etc. It may be possible to get an estimate of the benefit of longitudinal rumble strips by comparing before and after accident rates along sections of highway where rumble strips have already been installed, controlling for traffic volume.

It should also be noted that the full rumble stripe treatment shown in Figure 26 has not been evaluated. Previous studies have focused either on edge line rumble stripes, as shown in Figure 7 through Figure 10, or on centerline rumble strips milled on existing lines, as shown in Figure 17. A full treatment should show reductions in both head-on collisions and run-off-the-road accidents.

2.11.2 Transverse Rumble Strips

Transverse rumble strips can be installed in advance of work zones, particularly at crossovers, and in advance of dangerous curves, intersections, and road sections. Again, a before and after study of accidents at selected qualifying hot spots would better quantify the benefits of these rumble strips in the state. In the case of work zones and other temporary situations, a comparison between pairs of similar sites, one with and one without rumble strips would be in order. Perhaps a construction site impacting traffic in both directions could be studied with rumble strips applied to one direction of traffic and not to the other, perhaps even switching directions midway through the test period. Possible criteria for installation, which could also be evaluated, include recommended speed of curve, difference between recommended speed of curve and posted speed limit, curve or intersection geometry, accident frequency, accident severity or an index of severity and frequency, difference between posted speed of road and posted speed in work zone, etc.

A more comprehensive evaluation proposal could be prepared for any of these studies if ODOT thinks they are warranted.

More information regarding rumble strips can be found in section 15 and 16 of this report.

3 CHANGEABLE MESSAGE SIGNS

3.1 ODOT standards

The ODOT Traffic Engineering Manual discusses standards for Changeable Message Signs (CMSs) in Section 605-9. It gives the following recommendations concerning display messages:

- Up to 3 lines, 8 characters per line
- Up to two phases – if more use additional CMS
- Top line: problem; center line: location or distance ahead; bottom line: driver action
- Visible for a half mile in day and night
- Legible at 650 feet (192.18 m)
- Message can be read twice when approaching sign at 85th percentile off-peak speed

The display must adjust brightness to match lighting conditions and be a minimum height of 7 feet (2.13 m) above roadway when operating. CMSs are to be used as a supplement to other signs, not as replacement for them. CMSs should appear before standard signs.

Trailers are to be marked with retroreflective strips to enhance their visibility at night.

Multiple CMSs placed on the same side of road are spaced at distances specified in Table 697-11. [37]

3.2 Federal MUTCD

The 2003 Edition of the Federal *Manual on Uniform Traffic Control Devices* (MUTCD) specifies that each letter on a CMS be shown in a 5x7 pixel matrix. It further states “When a changeable message sign is used to display a safety or transportation related message, the display format shall not be of a type that could be considered similar to advertising displays. The display format shall not include animation, rapid flashing, or other dynamic elements that are characteristic of sports scoreboards or advertising displays” (Section 2A.07).

The MUTCD specifies a minimum letter height of 18” (0.4572 m) or 10” (0.254 m) for truck mounted signs. Minimum message duration should be 3 seconds and the message should be readable twice when approaching at the 85th percentile speed. Sign trailers should have a power source and battery backup for use when there are power outages [38].

3.3 Combination Flip-Disk/LED Changeable Message Signs

Addco manufactures the DH-1000 LED-DOT CMS. It uses fluorescent flip-disks during daytime and LEDs at night to transmit messages. This reduces power consumption to a level where solar power can be used [39]. The trailer is depicted in Figure 27.



Figure 27. Addco DH-1000 LED-DOT Solar Powered CMS [39].

3.4 Factors affecting VMS comprehension and response

Cao, Wang, and Hunter applied a design of experiment approach with simulated VMSs, and measured response times to various messages (real and fake) to determine significant factors in driver response time [40]. They found that font color, driver age, and gender significantly affected response time. Older drivers responded faster than younger ones but with lower accuracy. Female drivers responded faster than males but with lower accuracy. No significant correlation between response time and accuracy was found. Green was found to be the best font color. Significant variation was observed in response times and accuracies between members of the same age/gender group.

The authors also listed factors that affected comprehension of CMS messages. These include: CMS board size, letter height, sign height, viewing angle, background and legend colors, display words, display format, display sequence or duration, number of signs if more than one, preview time of each sign, driver age, driver gender, and environmental characteristics such as weather.

In a study by Ullman et al [41], legibility distances of 9-inch (0.2286 m) and 10.6-inch (0.2692 m) LED CMSs were investigated. The study showed that the 85th percentile legibility distance for the 9-inch (0.2286 m) letter height was 228 ft (69.5 m) during daytime conditions and 114 ft (34.7 m) for nighttime conditions and for the 10.6-inch letter height, these were 324 ft (98.7 m) and 203 (61.8 m) ft respectively. The legibility distances were used to identify the available viewing times for drivers. These available viewing times dictate the units of information that can be presented on a CMS of a particular letter size.

3.4.1 Improved Sign Messages and Operations

Dudek et al of the Texas Transportation Institute (TTI), in a report entitled *Improved Dynamic Message Sign Messages and Operations*, investigated 15 issues by showing subjects simulated CMS messages on laptop screens. The authors make the following recommendations based on their findings [42]:

- Use day of week rather than calendar dates when conditions will change within next week
 - Drivers had an 85% comprehension rate with day of week vs. 21% comprehension rate with date
- Use day of week instead of “FOR 1 WEEK”
- WEEKEND means Saturday morning through Sunday night
- Show time of day with travel time – e.g. 20 MINS at 7:20 AM.
- Avoid “RAMP” for exit ramp – subjects interpreted RAMP as entrance ramp
- Use route designation with number – I76, US30, etc.
- Use one-frame messages where possible
- Do not flash message frames or lines to grab attention
 - It takes 8.6 s to read static message vs. 10.1 s to read flashing message
- Avoid redundancy on two-frame messages
- Limit message to two frames maximum
- Two frame messages: flash 4 seconds per frame (read once at 55 mph – 88.5 kph) or 2 seconds per frame (read twice at 55 mph)
- Add lane closed messages to CMS rather than “USE CAUTION” if there is a lane closure ahead and no additional information to give to motorists on CMS

McCoy and Pesti studied the deployment of changeable message signs for incident management in the Omaha, Nebraska area [43]. Their report includes guidelines for positioning message signs for optimum legibility and also guidelines for making messages more intelligible to drivers.

3.4.2 Guidelines for Positioning CMSs

The first step in deriving a method for optimum positioning of a CMS is to compute available reading time using speed and legibility distance [43]:

$$ART = \frac{d_l}{1.47v}$$

where ART is the available reading time, d_l is the legibility distance in feet, and v is the vehicle speed in mph. In addition, the driver needs to see the sign and have at least 4 seconds

to prepare for reading it, which requires an additional distance to make up the target value. Since 4 seconds at 60 mph (96.6 kph) is 350 ft (106.68 m), the target value should be at least 350 ft (106.68 m) longer than the legibility distance. McCoy and Pesti recommend target values of 1350 (411.5 m) and 1000 ft (304.8 m) for fiber optic and LED CMSs, respectively.

The average reading time determined above will be reduced because when the driver gets too close to the sign, yet not past it, it will disappear from view [43]. The distance lost in by these effects is called the lost legibility distance. For overhead CMSs, lost legibility distance occurs when the roof of the vehicle blocks the sign, as shown in Figure 28. This distance can be computed by:

$$d = \frac{h_m - h_i}{\sin \phi}$$

where d is the lost legibility distance, h_m is the height of the center of the sign above the road, h_i is the driver's eye height above the ground, and ϕ is the vertical cutoff angle between the driver's eye and the windshield. Using a sign height h_m of 23 ft (7 m), which is enough to position a sign with three lines of 18-inch (0.4572 m) characters with a standard clearance of 17.5 ft (5.3 m), 7.5° for the cutoff angle, and 3.5 ft (1.1 m) as an AASHTO-specified design eye height, lost legibility distance is 150 ft (45.72 m).

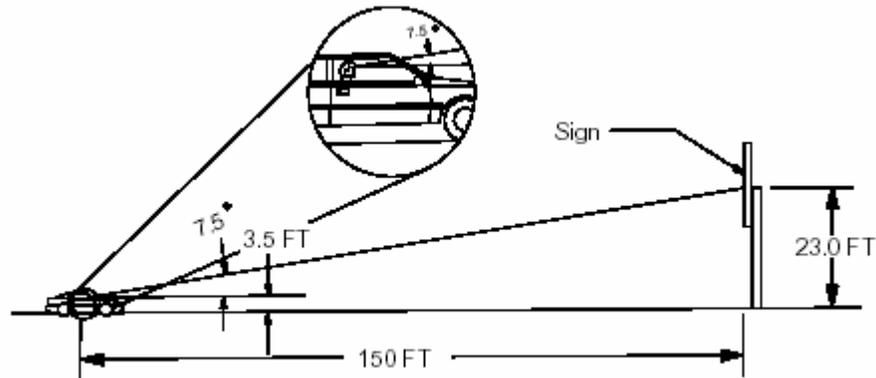


Figure 28. As a driver approaches an overhead CMS, his or her view becomes obstructed by the roof of the car. For the dimensions given, the lost legibility distance is 150 ft (45.72 m) [43].

This 150 ft (45.72 m) is taken as a minimum acceptable lost legibility distance [43]. Lost legibility distance is computed for CMSs at the side of the road and then the authors recommend repositioning the signs to reduce lost legibility distance to this value if possible. For a sign positioned on the side of the road, the lost legibility distance may be computed by:

$$BC = \left(\left[(N - 1) + 2/3 \right] L + x \right) \cot \theta$$

where BC is the lost legibility distance, N is the number of lanes, L is the lane width, x is the distance from the edge of the road to the center of the CMS, and θ is the maximum viewing angle, which is one-half of the cone of legibility. The diagram in Figure 29 shows these

parameters. Fiber optic CMSs have a cone of legibility of 30° while LED CMSs have a cone of legibility of 20° ; this means that a fiber optic CMS has less lost legibility distance and can be read longer than a comparable LED CMS.

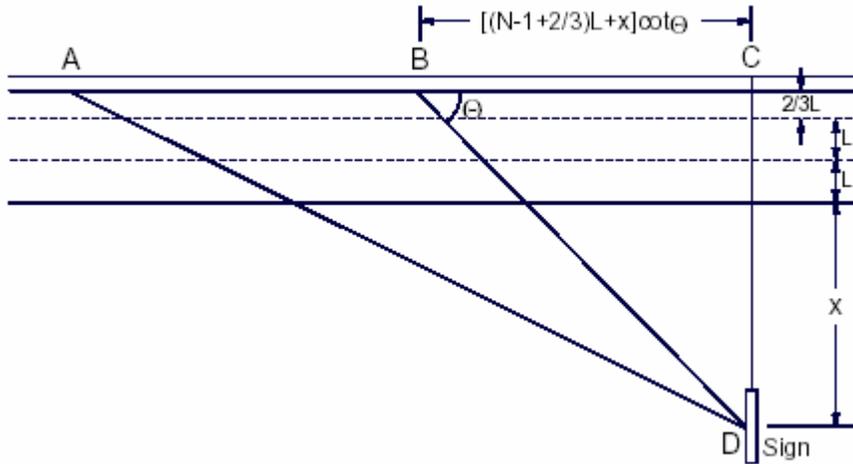


Figure 29. Lost legibility distance for a CMS positioned on the side of a road. The lost legibility distance is represented by the line segment BC [43].

Assuming 12-ft (3.66 m) lanes and a sign offset x of 15 ft (4.57 m), lost legibility distances for fiber optic and LED CMSs can be computed for different numbers of lanes [43]. Results are tabulated in Table 9. This lost legibility distance can be reduced by rotating the sign slightly towards the road. This rotation cannot exceed half the legibility cone without causing a loss of legibility for drivers in the outside lane. The rotation angles needed to reduce the lost legibility distance to 150 ft (45.72 m) are shown in Table 10. The values for the LED CMS for 4 and 5 lanes exceed 10° or half the legibility cone, which means that on a 4- or 5-lane road an LED CMS cannot be turned as far as indicated to decrease lost legibility distance for drivers on the inside lane without reducing legibility for drivers in the outside lane. Thus the authors recommend that LED CMSs not be used on 4- and 5-lane highways.

Table 9. Lost legibility distances for fiber optic and LED CMSs as a function of number of lanes on a roadway [43].

Number of lanes	Lost Legibility Distance – ft (m)	
	Fiber optic CMS	LED CMS
2	131 (39.93)	198 (60.35)
3	175 (53.34)	267 (91.37)
4	220 (67.06)	335 (102.1)
5	265 (80.77)	403 (122.8)

Table 10. Rotation angles for CMSs on tangent sections to reduce lost legibility distance to less than 150 ft (45.72 m) [43]. Note that for 4 and 5 lanes, the rotation angle for LED CMS exceeds 10° or half the cone of legibility.

Number of lanes	Viewing angle	Rotation angle (°)	
		Fiber optic CMS	LED CMS
2	13	0	3
3	17	2	7
4	21	6	11
5	25	10	15

For curved sections of road, lost legibility distances can also be computed. McCoy and Pesti give compensating rotation angles for curves up to 5° as shown in Table 11. Again the LED CMS is unsuitable for 4- and 5-lane roads, and for 4° or 5° curves an LED CMS is unsuitable for 3-lane roads as well.

Table 11. Rotation angles for CMSs on curved sections of road [43]. For LED CMSs, rotation angles for 4-, 5- and sometimes 3-lane roads are greater than half the cone of legibility.

Degree of curvature	Number of lanes	Rotation Angle (°)			
		Left curve		Right curve	
		Fiber optic CMS	LED CMS	Fiber optic CMS	LED CMS
1	2	0	3.8	0	3.9
	3	3.1	8.1	3.2	8.2
	4	7.1	12.1*	7.3	12.3*
	5	10.9	15.9*	11.2	16.2*
2	2	0	4.6	0	4.7
	3	3.8	8.8	4.0	9.0
	4	7.8	12.8*	8.2	13.2*
	5	11.6	16.6*	12.1	17.1*
3	2	0.3	5.3	0.5	5.5
	3	4.4	9.4	4.8	9.8
	4	8.4	13.4*	9.0	14.0*
	5	12.8	17.8*	13.9	18.9*
4	2	1.0	6.0	1.3	6.3
	3	5.1	10.1*	5.7	10.7*
	4	9.1	14.1*	9.9	14.9*
	5	12.8	17.8*	13.9	18.9*
5	2	1.7	6.7	2.1	7.1
	3	5.8	10.8*	6.5	11.5*
	4	9.7	14.7*	10.7	15.7*
	5	13.4	18.4*	14.8	19.8*

*Rotation exceeds maximum allowable rotation for sign (10° for LED CMS, 15° for fiber optic CMS)

McCoy and Pesti provide some other guidelines for the placement of CMSs:

- The CMS must be placed upstream of the exit ramp sign of the nearest ramp to be used for diversion.
- CMS should be placed between the two advance guide signs for the ramp, provided the second is at least ½ mile (804.7 m) from the ramp, otherwise place before both advance signs.
- CMS should be placed before both advance guide signs if queuing is expected upstream of diversion ramp.
- When interchange sequence signs are used, CMS should come before at least two advance interchange signs for that ramp.
- Minimum spacing between a CMS and a downstream advance guide sign should be 1000 ft (304.8 m).

- Minimum spacing between CMS and upstream advance guide sign should be 350 ft (106.7 m) plus the minimum required legibility distance of the CMS.
- CMSs should be placed so that they are backlit by roadside lighting to improve their legibility.

3.5 Guidelines for messages

3.5.1 Message statements

McCoy and Pesti also discuss guidelines for messages for CMSs, some of which are based on the TTI recommendations [43]. The authors begin by dividing a message into four statements: problem, effect, attention, and action. The problem statement describes the traffic condition, e.g. “ACCIDENT ON I95”; the effect statement describes the impact of the problem on traffic, e.g. “THRUWAY EXIT CLOSED”; the attention statement indicates who the message is specifically directed at, e.g. “THRUWAY TRAFFIC”; and the action statement tells the driver what to do, e.g. “USE PARK ST. EXIT”.

Each of these components, or units of information, has guidelines [43]. For instance, in a problem statement it is better to use a broader category from an existing library than to give a more detailed and possibly inaccurate message, e.g. “ACCIDENT” rather than “TRUCK OVERTURNED”. For location, if the drivers are predominantly local commuters, it is better to refer to cross streets (“AT THIRD ST”), but if most traffic consists of unfamiliar drivers, distance ahead to the nearest half mile is better (“3 MILES AHEAD”).

For the effect statement, “DELAY” or “MAJOR DELAY” is preferred to “CONGESTION” or “HEAVY CONGESTION” because “delay” is a shorter word [43]. Delay times should not be given if the expected delay is less than 5 minutes or more than one hour. Drivers understand “LANE BLOCKED” to denote a temporary condition and “LANE CLOSED” to denote a longer-term condition, however later in the report the authors advocate using “LANE CLOSED” in all cases as the practical effect is the same on drivers. If the freeway has 2 or 3 lanes, the closed lane may be designated as “LEFT”, “RIGHT”, or “CENTER”. If there are 4 or more lanes, a graphic display such as that shown in Figure 30 is recommended. “FREEWAY CLOSED” or “ROUTE 33 CLOSED” is understood to mean all lanes are closed.

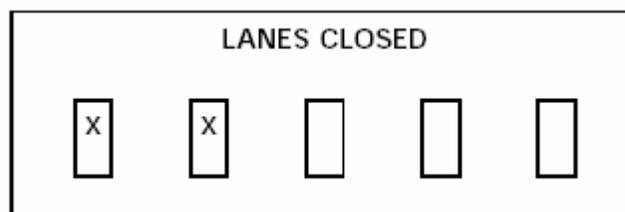


Figure 30. Graphic display indicating closed lanes on a 5-lane highway [43].

An attention statement designates who is to respond to the message, whether “ALL TRAFFIC”, certain vehicles (“TRUCKS”), some traffic (“LOCAL TRAFFIC”), traffic on

certain routes (“ROUTE 33 TRAFFIC”), or traffic going to a specific destination (“NELSONVILLE”) or event (“OHIO U GRADUATION”) [43].

Action statements fall into diversion and non-diversion categories [43]. Diversion messages are signified by certain verbs, such as “USE” (temporary bypass), “TAKE” (next exit), “FOLLOW” (detour), or “CONSIDER” (optional alternate route). Non-diversion messages may include “MERGE LEFT”, “KEEP RIGHT”, “STAY IN LANE”, “USE RIGHT LANE”, “SLOW”, “REDUCE SPEED”, and various exhortations to use caution (“WATCH FOR . . .”, “PROCEED WITH CAUTION”, “USE CAUTION”, “PREPARE . . .”).

3.2.8 Message Length

Drivers can read about one word per second, where a word in a message does not include prepositions [43]. Thus the maximum message length N in words is given by the following formula:

$$N = (d_l - d) / 1.47v$$

Where d_l is the legibility distance in feet, d is the lost legibility distance in feet, and v is the traffic speed in mph. The maximum message length for a sign with legibility distance d_l of 650 ft (198 m) or 900 ft (274.3 m) is given as a function of traffic speed in Figure 31; a lost legibility distance d of 150 ft (45.72 m) is assumed. At highway speed 60 mph (96.6 kph), the maximum message length is 8 words for a sign with 900 ft (274.3 m) of legibility distance and 5 words for a sign with 650 ft (198 m) of legibility distance. Thus 8 words are regarded by the authors as a practical upper limit on message size; CMS messages should always be as short as possible. Conversely, the legibility distance required to read a message of 8 words as a function of speed is given in Figure 32.

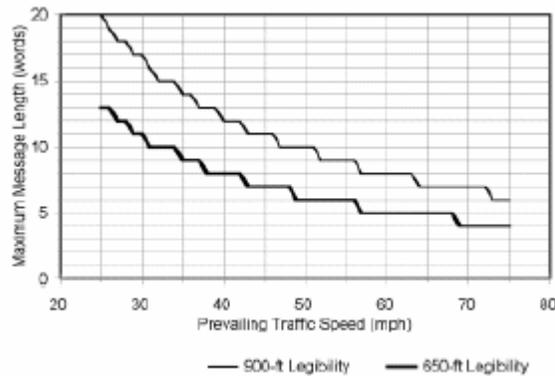


Figure 31. Maximum CMS message length as a function of prevailing traffic speed assuming legibility distances of 650 (198 m) and 900 ft (274.3 m). The number of words excludes prepositions [43].

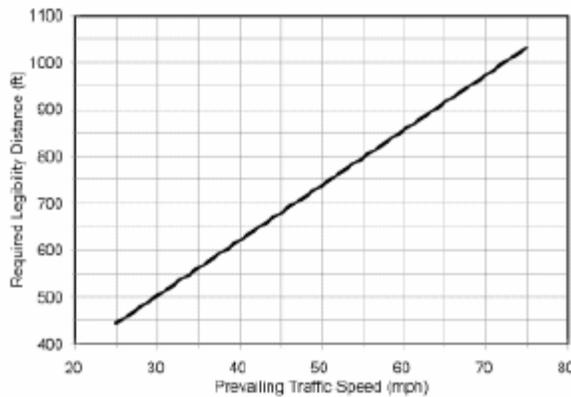


Figure 32. Legibility distance required for driver to read a message containing 8 words, excluding prepositions, as a function of prevailing speed [43].

Table 12 compares the legibility distances of LED and fiber optic CMSs [43]. The fiber optic CMS always has a greater legibility distance, except at night, where its legibility distance is nearly equal to that of the LED CMS.

Table 12. Legibility distance of LED and fiber optic CMSs under varying conditions [43].

Condition	Legibility Distance (ft)	
	LED CMS	Fiber optic CMS
Mid-day	740	980
Night	690	680
Wash-Out (sun shining on face of CMS)	490	850
Backlit (sun shining behind CMS)	500	660

McCoy and Pesti give further recommendations for CMS messages [43]. A unit of information consists of 1 to 4 words, typically 2 words that answer a specific question the driver may have, such as the location or nature of the traffic problem. A message should display no more than three units of information on a single phase, and should display no more than four units of information total. The latter rule is based on 2 words per unit of information and 8 words maximum for message length discussed above; more units of information can be displayed if the message stays within the 8-word limit. It is permissible to have a fourth unit of information on a phase if that fourth unit is not one the driver needs to remember. If all four units must be recalled, a sequence of two phases should be used. No more than two phases should be used and each phase should last for 1 second per word (excluding prepositions) or longer if possible. It is desirable for the driver to read the entire message twice while approaching the sign. If the message can be fit into a single phase with three or fewer units of information, that is best. A run-on or scrolling message format should never be used as it takes longer to read.

A TTI study covers similar territory [44]. The authors characterize messages in terms of units of information. A maximum of 4 units of information is recommended for traffic at highway speeds; 5 are possible where speeds are less than 35 mph (56.4 kph). They recommend that if rainfall exceeds 2 inches (0.0508 m) per hour the maximum number of units of information displayed be reduced by 1. The base maximum units of information for CMSs recommended by TTI are given in Table 13. In this table newer LED CMSs (e.g. aluminum indium: gallium phosphide) appear to have the best performance. Reflective flip-disk units have clearly worse performance at night and when backlit. The TTI authors provide very lengthy and complicated flowcharts for determining the maximum number of units of information that can be displayed depending on sight restrictions due to vertical curves, horizontal curves, and/or fog. The flowchart is so complicated enough that it has been translated into a software tool [45].

Table 13. Maximum units of information to be displayed on CMS (here called DMS for Dynamic Message Sign) [44].

Type of DMS	Speed Range	Condition			
		Mid-Day	Washout	Backlight	Nighttime
Light-Emitting Diode (LED) ^A	0-35 mph	5 units	5 units	4 units	4 units
	36-55 mph	4 units	4 units	4 units	4 units
	56-70 mph	4 units	4 units	3 units	3 units
Fiber-optic	0-35 mph	5 units	5 units	4 units	4 units
	36-55 mph	4 units	4 units	3 units	3 units
	56-70 mph	3 units	3 units	2 units	3 units
Incandescent Bulb	0-35 mph	5 units	5 units	4 units	4 units
	36-55 mph	4 units	4 units	3 units	3 units
	56-70 mph	3 units	3 units	2 units	3 units
Reflective Disk	0-35 mph	5 units	4 units	2 units	3 units
	36-55 mph	4 units	3 units	1 unit	2 units
	56-70 mph	3 units	2 units	1 unit	1 unit

^A Valid only for the newer aluminum indium gallium phosphide (or equivalent) LEDs.

Maximum units of information that should be displayed on LED CMS according to the letter heights and approach speed as specified by Ullman et al [41] is shown in Table 14.

Table 14. Maximum Units of Information that should be displayed on the LED CMS [41]

Character Height (in)	Average Roadway Approach Speed									
	Daylight Viewing Conditions					Nighttime Viewing Conditions				
	30	35	40	45	50	30	35	40	45	50
9	3	2	2	2	2	1	1	1	1	1
10.6	4	3	3	2	2	2	2	2	2	2
12 ^a	5	4	4	3	3	3	3	2	2	2
18	5	5	5	5	5	5	5	5	4	4

^a Extrapolated from other letter height data

Ullman et al [41] also stated that motorists require two seconds of reading time for each unit of information on a CMS, and can only process a maximum of 5 units of information while traveling.

Each unit of information on a CMS should be thought as an answer to a question to help motorists to make a better decision. Example of a CMS message is given below.

- What is the problem? ACCIDENT 1 Unit
- Where is the problem? AT ABRAMS 1 Unit
- How many lanes are closed? 2 LANES CLOSED 1 Unit

3.6 Luminance Requirements of CMSs

Woolridge of the TTI studied luminance requirements of CMSs [46]. He recommended a minimum daytime luminance of 4000cd/m² (2.58 cd/in²) and a minimum nighttime luminance of 30 cd/m² (0.01935 cd/in²). No recommended maximum nighttime luminance was found in literature. He further recommends that protective screens should be well maintained to maximize contrast, and he notes that backlit and washout conditions still present enormous problems for CMSs.

3.7 Recommendations to ODOT

Changeable message signs allow us to display real time traffic information to motorists. Traffic events (accidents, lane closures) and winter driving conditions can be displayed using CMSs

Proper design and installation of CMSs is important to ensure that the intended information is communicated to the motorists. CMSs must be designed to avoid information overload and to make sure driver can read the message within the available time. Installing CMSs to provide appropriate legibility distances at the driving speed is essential. These are the some of the important factors that need to be addressed from a human factors perspective when using CMSs.

The findings and the recommended applications from the literature can be summarized as below.

For sign messages and operations

- Use day of week rather than calendar dates when conditions will change within next week
 - Drivers had an 85% comprehension rate with day of week vs. 21% comprehension rate with date
- Use day of week instead of “FOR 1 WEEK”
- WEEKEND means Saturday morning through Sunday night
- Show time of day with travel time – e.g. 20 MINS at 7:20 AM.
- Avoid “RAMP” for exit ramp – subjects interpreted RAMP as entrance ramp
- Use route designation with number – I76, US30, etc.
- Use one-frame messages where possible
- Do not flash message frames or lines to grab attention
 - It takes 8.6 s to read static message vs. 10.1 s to read flashing message
- Avoid redundancy on two-frame messages
- Limit message to two frames maximum
- Two frame messages: flash 4 seconds per frame (read once at 55 mph (88.6 kph)) or 2 seconds per frame (read twice at 55 mph)
- Add lane closed messages to CMS rather than “USE CAUTION” if there is a lane closure ahead and no additional information to give to motorists on CMS

In a study by McCoy and Pesti, guidelines for the placement of CMSs are provided [43]:

- The CMS must be placed upstream of the exit ramp sign of the nearest ramp to be used for diversion.
- CMS should be placed between the two advance guide signs for the ramp, provided the second is at least ½ mi (0.81 km) from the ramp, otherwise place before both advance signs.
- CMS should be placed before both advance guide signs if queuing is expected upstream of diversion ramp.
- When interchange sequence signs are used, CMS should come before at least two advance interchange signs for that ramp.

- Minimum spacing between a CMS and a downstream advance guide sign should be 1000 ft.
- Minimum spacing between CMS and upstream advance guide sign should be 350 ft (106.68 m) plus the minimum required legibility distance of the CMS.
- CMSs should be placed so that they are backlit by roadside lighting to improve their legibility.

Minimum daytime luminance of 4000cd/m^2 (2.58 cd/in^2) and a minimum nighttime luminance of 30 cd/m^2 (0.01935 cd/in^2) are recommended for the CMSs.

CMSs should be more widely used to provide real time traffic information to motorists.

3.8 Recommended Evaluations

The technological improvements in the displays will eventually affect the CMSs. High definition screens might be available to be used as changeable message signs.

More information regarding CMSs can be found in section 15 and 16 of this report.

4 WORK ZONE DELINEATION

4.1 Drums

The specifications pertaining to the use of drums in work zone operations are outlined in sections 7F-7 & 7F-8 in the OMUTD, section 605-11.4 of the Traffic Engineering Manual (TEM), and several Standard Construction Drawings (SCD). Drums can be used to delineate a new vehicle path that has been created to accommodate construction activity. The effectiveness of drums as delineation devices depends on their ability to clearly mark a path and on their conspicuity during both day and nighttime. Drums are marked with orange and white reflectorized stripes (section 7F-7 OMUTCD). Type G or H material is recommended for drums. Using retroreflective sheeting material for the orange and white stripes helps increase the conspicuity of drums. Some reflective sheeting materials are found to be more visible from longer distances while others are found to be better when viewed from a shorter distance. Zwahlen et al. [47] found Type VII reflective sheeting materials to have a higher legibility when viewed from afar whereas Type IX material was best when viewed from a shorter distance. This property of the different types of materials can be used to make the drums more visible to the driver from far out as well as close in. Thus instead of using a single strip of material of a particular color (orange or white) two strips (each half the original width) of Type VII and Type IX of the same color can be used as shown in Figure 33. This will make the drums more visible at both near and far distances.

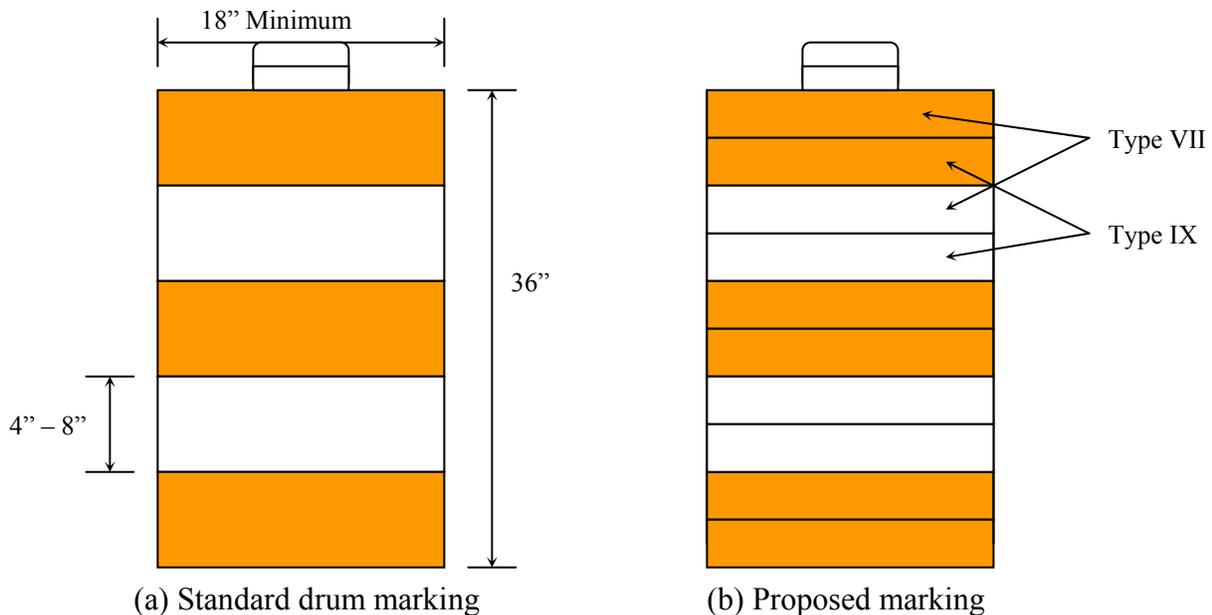


Figure 33: Using Type VII and Type IX reflective sheeting material on drums. (a) Standard drum marking with orange and white stripes and (b) Proposed drum marking with alternate strips of Type VII and Type IX material to replace single strips.

Delineation of the travel path can also be improved by placing directional arrows on the barrels (as an alternative to chevron signs and arrow signs) to indicate in which direction the motorists should drive. This will help give the driver clear directions on how to maneuver through the work zone. Placing directional arrows on barrels would be especially useful in situations where there are several lanes and the driver has to know which path should be followed.

4.1.1 Direction Indicator Barricades

To meet this need, a direction indicator barricade has been developed under the SHRP and used in several states, and evaluated in Georgia [48]. Such a direction indicator barricade is depicted in Figure 34. It has a 60 cm by 30 cm (24 in by 12 in) horizontal arrow panel and a 60 cm by 20 cm (24 in by 8 in) bias-striped panel mounted on a plastic barricade. Georgia DOT employees indicate the new barricade is far superior to barrels, and crews continued to use them after the initial testing. They are also more compact than regular barrels, making them easier and faster to set up and remove. Being more compact than barrels, more of the devices can be loaded onto a single truck. Georgia DOT crews also reported that drivers were more aware of the barricades than they were of barrels, but that could be a novelty effect. The devices have also been evaluated in Alabama, Arkansas, Illinois, and South Dakota.



Figure 34. Direction Indicator Barricade [48].

Initial highway testing of the direction indicator barricade in the early 1990s [49] suggested that these devices were slightly less effective than barrels in preventing closed-lane violations, an effect ascribed to the larger size and conspicuity of the barrels. It was recommended that a combination of the two devices, that is a barrel with a directional arrow, would combine the best of both devices.

These additional recommendations would serve to increase the usefulness of drums as effective delineation devices. Therefore ODOT should consider revising the work zone guidelines to provide for these requirements.

The center-to-center drum spacing for non-linear road sections is specified as 20 ft (6.1m) in ODOT Standard Construction MT Series Drawings. This is satisfactory given that better delineation is required in such areas. The drawings also specify different center-to-center spacing of drums for linear road sections based on specified driving speed. For example,

when the speed is 30-40 mph (48.3-64.4 kph), the center-to-center distance is specified as 30 ft (9.14 m) and increases for higher speeds. However, it is questionable if varying drum spacing distances need to be used depending on speed specified. Instead, it may be more appropriate to use 30 ft (9.14 m) in all situations with linear road sections. The tables for maximum spacing of drums on MT 95-30, MT 95-31, MT 95-32, MT 95-40, MT 95-41, MT 95-60, MT 96-61, MT 102-10, and MT 102-20 might have to be changed according to this suggestion.

A narrower version of the direction indicator barricade, called a “vertical SafetyCade” was evaluated in Kansas [50]. There was no statistically significant change in speeds or lane distributions, which the author takes as an indication that these barricades are as visible as drums. Observations at the test site by Kansas DOT personnel before and after erection of the barricades suggested that the barricades provided improved guidance. The author also noted that the barricades fold flat when struck by traffic and may be easily reerected, which may represent advantages in durability and in space savings.

4.1.2 TTI Work Zone Lane Closure Warning Light System

The Texas Transportation Institute has tested a synchronized flashing warning light system mounted on barrels in lane closure tapers [51]. The drums in the taper have flashing LEDs mounted on them that are synchronized to flash in a sequence that suggests motion from the closed lane into the open lane, as depicted in Figure 35. This differs from standard Texas DOT specs, which call for steady-burn lights on drums in a work zone taper and flashing lights (not synchronized) on barricades, drums, or warning signs in advance of hazardous situations.

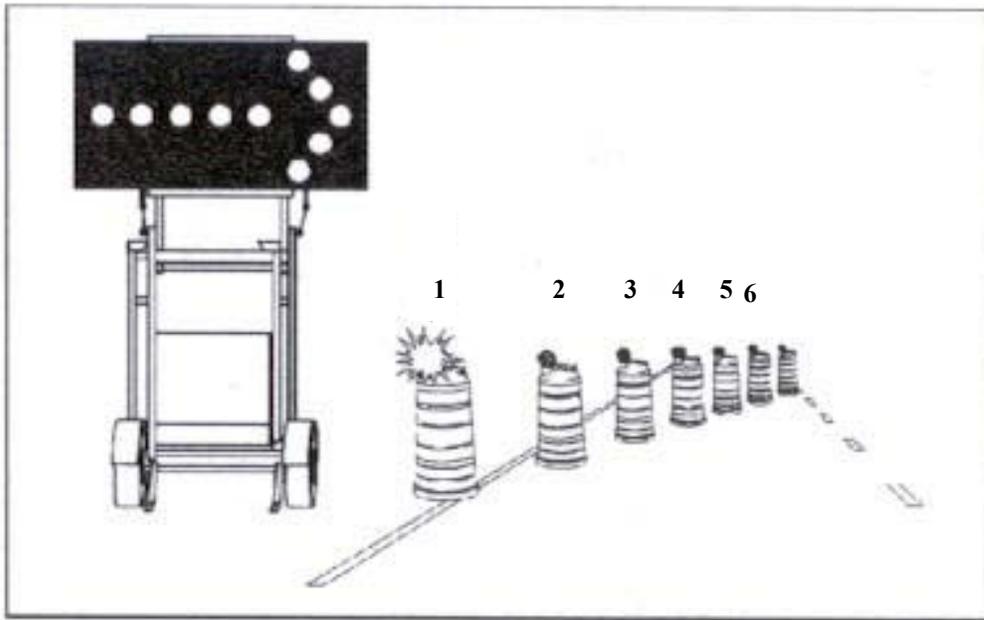


Figure 35. The Texas Transportation Institute's Work Zone Lane Closure Warning Light System. The five drums with numbers over them have flashing LEDs set up to flash in the numerical order indicated to suggest movement into the target lane. The actual number of drums with flashing lights depends on the length of the taper. Adapted from [51].

The human factors justification for the system lies in research conducted in the 1870s by Sigmund Exner, who showed that two brief but stationary flashes are perceived as a single object in motion. He concluded that motion was a primary sensation, not just a deduction based on time order or space position of the flashes. Max Wertheimer's 1910 model extended Exner's results and formed the foundation for subsequent research on the effects of duration and space and time separation of the flashes. In 1915 Korte gave his Third Law of Apparent Movement, which states that apparent motion will occur if an increase in the distance between two successive objects (flashes) is accompanied by an increase in time between the successive presentations. Increasing the distance between the two objects leads to an increase in perceived speed [51, p. 2].

Korte's study involved two components: a proving ground component and a field component. The proving ground component consisted of subjects driving a test course with a lane taper set with barrels at speeds of 30 mph (48.3 kph) and 65 mph (104.65 kph) under 5 conditions: no drum lights, steady burn drum lights, and flashing lights at rates 17 flashes per minute (fpm) and 60 fpm, and 60 fpm plus steady burn lights. Each treatment also included a flashing arrow panel. (A pilot study indicated that 17 fpm plus flashing lights with steady burn background would not be significantly different from the 60 fpm with steady burn background.) As subjects approached the lane closure, the speed and distance of braking and lane-changing were measured. Subjects also driven through the setup five times in each of its various configurations in random order at 30 mph (48.3 kph) and 65 mph (104.65 kph) and

were then asked their preferences. The 59 subjects in the proving ground study included about half in the 18-35 age group and the rest split evenly between the 60-74 age group and the 75+ age group. Each age group was evenly split between male and female members.

In the field test a configuration with 35 fpm with steady burn background was compared to the configuration without the flashing lights. The 35 fpm rate was chosen to keep the combined rate of flashing under the 360 fpm threshold for photosensitive epilepsy, though it is not known for sure whether the combined flashes, coming from different sources, would actually cause seizures [51, p. 23]. The field study occurred at two work zone sites. The first was on FM60 west of College Station and used 12 drums in the 770 ft (234.7 m) past the arrow panel. The posted nighttime speed limit was 65 mph (104.65 kph). Data were collected with the warning light system on and with it off at night. Video cameras in unmarked vehicles were used to document driver lane choices and erratic maneuvers. The measures of effectiveness were speed and percent of traffic in closed lane at various distances (2000 ft (609.6 m), 1000 ft (304.8 m), 500 ft (152.4 m), and 0 ft) before the closure. The second site was on I-10 in Houston, which had a double lane closure. The first (leftmost) lane closure had a standard treatment while the second had the experimental treatment which used 11 drums in the 605 ft (184.4 m) taper after the arrow panel. The posted nighttime speed limit was 65 mph (104.65 kph) for passenger vehicles and 55 mph (88.55 kph) for large trucks. Speed and lane choice data at various distances (1000 ft (304.8 m), 500 ft (152.4 m), 0 ft) were recorded from unmarked vehicles and using a TRANSTAR closed-circuit television camera. Data for trucks and cars were analyzed separately.

The results of the proving ground study indicated that the two treatments that had the longest average distance upstream at which lane changing was initiated were the bare 17 fpm setup (495 ft (150.9 m)) and the steady-burn configuration (485 ft (147.8 m)). The other treatments were considerably lower: steady-burn with 60 fpm (215 ft (65.53 m)), no lights (215 ft (65.53 m)), and bare 60 fpm (154 ft (46.94 m)). It's also worth noting that the 18-35 age group changed lanes at about twice the distance the 60+ age group did (400 ft (121.9 m) versus 213 ft (64.92 m)). Subjects were also asked for subjective impressions. For the 17 fpm lights, 2 of 27 subjects (7%) indicated that they did not understand what to do; of the 27, 5 (19%) indicated they did not like the "moving light". For the 60 fpm lights with steady-burn background, 11% (1 of 9) did not know to exit until the last moment, and 22% (2) liked the moving lights. Subjects also ranked the treatments in order of preference. The top ranked treatment was the steady-burn lights augmented by the 60 fps flashing lights, second was the existing steady-burn light treatment; the bare flashing light systems and no lights took the next 3 places.

At the FM60 field test site, no significant change in approach speed was observed with the two treatments. The percentage of traffic in the closed lane as a function of distance was comparable for the two conditions at each distance. This was expected because the lane closure had been well established before the warning light system was installed. At the I10 site in Houston, the speed was also observed to remain unchanged between the two conditions. For lane choice, a significantly lower percentage of vehicles was seen in the closed lane 1000 ft (304.8 m) before the taper when the warning light system was on (23% versus 30% for cars and 7% versus 19% for trucks). At the nearer distances of 500 ft (152.4

m) and 0 ft, the warning light condition saw fewer vehicles left in the travel lane, with the exception that more trucks switched lanes at the last minute with the warning system on (5% versus 3%); none of these differences was statistically significant, however.

There are some design issues that were noted with the system. The total cable length can be no more than 900 ft (274.32 m), which affects the ability of the project engineer to modify drum spacing. The system was cumbersome and time-consuming to construct; it took 4 people 30 minutes to wire the 11 barrels at the Houston site. The cable connection was also easily broken, which meant the system required a lot of maintenance; this was particularly likely when a cable was driven over (as in the case of the FM60 installation). The flashing LEDs used in the system are highly directional, making the system very sensitive to alignment; even if one drum is misaligned, the moving light effect can be disrupted. Thus the study finally recommends that the system be modified to work as a wireless system with a wider cone of vision and that this modified system be evaluated on some more lane closure sites [51].

4.2 Glare Screens

4.2.1 Present ODOT standards and guidelines

Glare screens are designed and used to shield motorists' eyes from the glare of headlights of oncoming vehicles. They can also serve other purposes, namely to obscure the view of construction work to reduce rubbernecking and perhaps also to reduce work zone dust settling onto the roadway. Reducing rubbernecking is the key to minimizing the formation of queues inside work zones due to slowing traffic.

In Section 604 of Ohio Department of Transportation Location and Design (L&D) Manual Volume I, glare screens are defined. Glare screens are used primarily for the shielding of motorists from headlight glare of opposing traffic. They are normally used in the median of divided highways but may be used in other areas where a specific problem exists or is anticipated. Glare screen use is justified based on traffic volumes and median widths in unlighted sections, and on traffic volumes and the number of lanes in lighted sections. Figure 604-1 in L&D Manual I shows this relationship. In Section 604-2 expected performance characteristics of glare screens are given. Glare screening may be accomplished in a number of ways. Section 604-3 gives the glare screen options.

Section 605-18 of the TEM also contains information on glare screens. Screens are also used to block the road users' view of activities that can be distracting. Screens might improve safety and motor vehicle traffic flow where volumes approach the roadway capacity because they discourage gawking and reduce headlight glare from oncoming motor vehicle traffic. They can also help contain the work area and reduce the accumulation of dust and debris on the pavement. On ODOT-maintained highways a glare screen shall be used at all crossover locations. The upper portion of the 50-inch (1.27 m) portable concrete barrier (PCB) serves as a glare screen. (Figure SCD-RM 4-1).

In Section 642-21 of the TEM, the 50-inch (1.27 m) and 32-inch (0.813 m) portable concrete barriers are described. The specifications of 50-inch (1.27 m) portable concrete barriers are given (Standard Construction Drawing RM-4.1). Portable concrete barriers that are 32 inches

(0.813 m) high with an 18 inch (0.457 m) minimum height glare screen may be substituted at the option of the contractor. Paddle or intermittent type glare screens shall be designed using a 20-degree cut-off angle based on tangent alignment. That spacing shall be used throughout the barrier length without regard to barrier curvature.

The glare screen system shall be securely fastened to the 32-inch (0.813 m) portable concrete barrier using the hardware and procedures specified by the manufacturer.

The objectives of glare screen use are given in Table 697-1c of the TEM. They are used to maximize motorist/worker safety and maximize corridor capacity. Glare screens are an effective way to separate work and keep traffic moving, make work safer, and reduce rubbernecking. The cons of glare screens are that they take longer to set up than drums, cost more than 32 inch (0.813 m) barriers without screens, may reduce driving speed, and can interfere with wide loads. There are restrictions on glare screen widths in certain areas, and there are also sight restrictions at intersections and ramps.

Existing standards for glare screens are designed to reduce glare from headlights of oncoming traffic. To ensure a reduction in rubbernecking behavior by drivers distracted by work zone activities, glare screen height needs to be raised considerably.

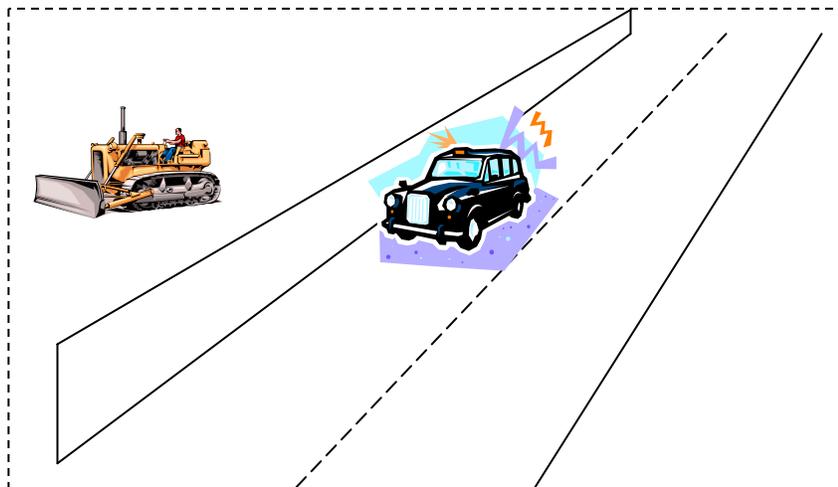


Figure 36. Depiction of glare screen used to obscure view of work zone from traffic

4.2.2 Height of screens

Glare screens impact driver behavior in two ways. The first is to eliminate glare from opposing traffic, removing a source of distraction. The second is to shield the driver's view of work zone activities, thus eliminating another source of distraction. With the driver better able to focus on the road, traffic flows better. The question is how high should a glare screen be to accomplish these objectives.

In the study "Driver-Headlamp Dimensions, Driver Characteristics, and Vehicle and Environmental Factors in Retroreflective Target Visibility Calculations" conducted by Zwahlen and Schnell [52] the average driver eye heights for various vehicle types are

calculated. 1988 U.S. Army Personnel Data are used in the calculation of the driver eye height positions. The maximum eye height position resulted from the use of the data for average large vans or buses, which have dimensions similar to those of trucks. The 95th-percentile adult driver eye height of a large van or bus is found to be 1920 mm (76.1 in), as indicated in Table 15 [52].

4.2.3 Computing height of screens to shield drivers from glare of oncoming cars

The second purpose for which glare screens are used for is to reduce headlight glare from oncoming motor vehicle traffic. The height of glare screens should accommodate most motorists, including truck and bus drivers. This height depends basically on 4 variables:

- The height of the driver's eye
- The height of the headlamps of the oncoming vehicle
- The eye distance from the driver in the vehicle to the glare screen in the direction perpendicular to travel
- The headlamp distance from the oncoming vehicle to the glare screen in the direction perpendicular to travel
- The last two variables will be different depending on which lane the vehicle is in. Figure 37 illustrates these variables.

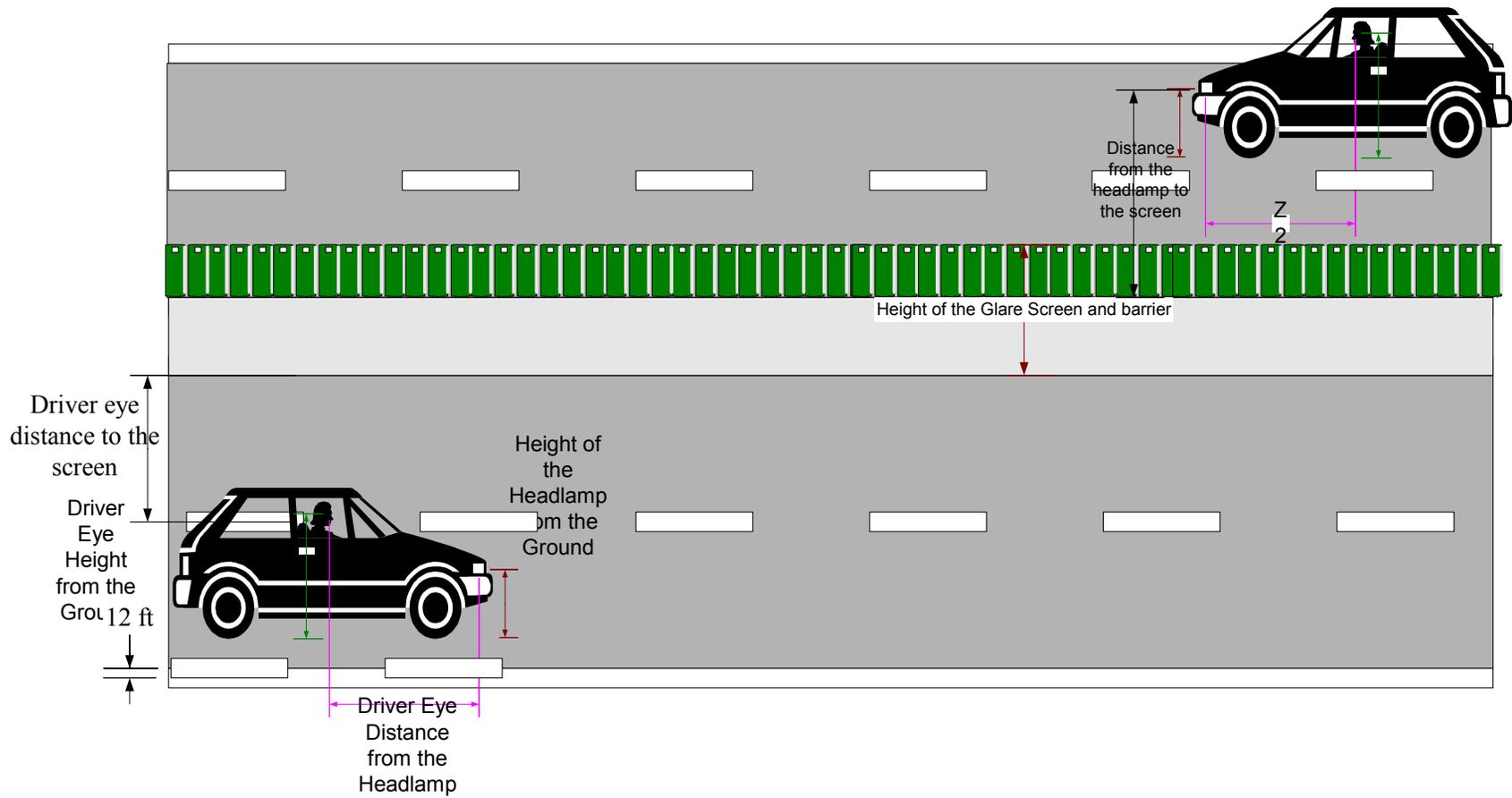


Figure 37. Variables used in the calculation of the recommended glare screen heights

The values of the aforementioned variables can be obtained from the paper of Zwahlen and Schnell [52]. We used 95th percentile values to accommodate the vast majority of American adults. For the eye distance to the glare screen it is assumed that the vehicle is driving in the center of a 12 ft (3.66 m) wide lane. In our case we want to make sure the glare screen is high enough to shield a driver almost in the upper 5% in eye height from a vehicle with headlights at an elevation almost in the upper 5% of all vehicles.

Table 15. 95th percentile longitudinal and vertical eye positions resulting from applying 1988 US Army personnel anthropometric data to average dimensions of surveyed vehicles. Adapted from Zwahlen and Schnell [52].

Vehicle type	95th percentile Vertical distance from ground to eyes (mm)			95th percentile Vertical distance from ground to headlamps (mm)	Driver eye distance from the center of the vehicle	Headlamp distance from the center of the vehicle
	Female (N=2208)	Male (N=1774)	Adults (N=3982)			
Compact car (N=12 cars)	1202 (47.3 in)	1256 (49.4 in)	1242 (48.9 in)	620 (24.41 in)	332 (13.37 in)	527 (20.75 in)
Minivans (N=5 vans)	1530 (60.2 in)	1584 (62.4 in)	1570 (61.8 in)	756 (29.76 in)	425 (16.73 in)	677 (26.65 in)
Large vans or buses (N=7 vehicles)	1880 (74 in)	1934 (76.1 in)	1920 (75.6 in)	832 (32.76 in)	493 (19.41 in)	729 (28.7 in)

Calculations for all possible combinations of car type and lane were done. Table 16 [mm] and Table 17 [in] show the results for the different combinations of vehicles and lane positions.

Table 16. Calculated total height of glare screen for 95th percentile drivers [mm].

Driver on the right lane, oncoming vehicle on the opposite right lane

		<i>Driver's eye position</i>		
		compact car	minivan	large van or bus
<i>Headlamp position</i>	compact car	955	1136	1330
	Minivan	1021	1203	1399
	large van or bus	1056	1239	1435

Driver on the right lane, oncoming vehicle on the opposite left lane

		<i>Driver's eye position</i>		
		compact car	minivan	large van or bus
<i>Headlamp position</i>	compact car	815	922	1037
	Minivan	915	1026	1145
	large van or bus	968	1080	1201

Driver on the left lane, oncoming vehicle on the opposite right lane

		<i>Driver's eye position</i>		
		compact car	minivan	large van or bus
<i>Headlamp position</i>	compact car	1118	1390	1684
	Minivan	1147	1419	1713
	large van or bus	1162	1434	1728

Driver on the left lane, oncoming vehicle on the opposite left lane

		<i>Driver's eye position</i>		
		compact car	minivan	large van or bus
<i>Headlamp position</i>	compact car	1000	1215	1450
	Minivan	1060	1278	1515
	large van or bus	1091	1308	1547

Table 17. Calculated total height of glare screen for 95th percentile drivers [in].

Driver on the right lane, oncoming vehicle on the opposite right lane

		<i>Driver's eye position</i>		
		compact car	minivan	large van or bus
<i>Headlamp position</i>	Compact car	38	45	52
	Minivan	40	47	55
	large van or bus	42	49	56

Driver on the right lane, oncoming vehicle on the opposite left lane

		<i>Driver's eye position</i>		
		compact car	minivan	large van or bus
<i>Headlamp position</i>	Compact car	32	36	41
	Minivan	36	40	45
	large van or bus	38	43	47

Driver on the left lane, oncoming vehicle on the opposite right lane

		<i>Driver's eye position</i>		
		compact car	minivan	large van or bus
<i>Headlamp position</i>	Compact car	44	55	66
	Minivan	45	56	67
	large van or bus	46	56	68

Driver on the left lane, oncoming vehicle on the opposite left lane

		<i>Driver's eye position</i>		
		compact car	minivan	large van or bus
<i>Headlamp position</i>	Compact car	39	48	57
	Minivan	42	50	60
	large van or bus	43	51	61

It follows that to prevent 95% of large van and bus drivers from the glare of oncoming large vans and busses, the total height of the separator should be 70 inches (1.78 m). This height will also protect drivers of other types of vehicles from all normal headlight configurations, e.g. compact car from large van or bus. This height may be obtained by adding a 20-inch (0.51 m) glare screen onto a 50-inch (1.27 m) portable concrete barrier or a 38-inch (0.96 m) glare screen onto a 32-inch (0.81 m) portable concrete barrier.

In addition to reducing headlight glare from oncoming motor vehicle traffic, glare screens can improve the delineation. To achieve this purpose glare screens should be equipped with reflective stripes as shown below. The distance between single boards should be 10 in (0.25 m) to 20 in (0.51 m). Furthermore, the screens used in the work zone can also help contain the work area and reduce the accumulation of dust and debris on the pavement. Taking into consideration all discussed requirements it is recommended to design glare screens as shown in Figure 38 below.

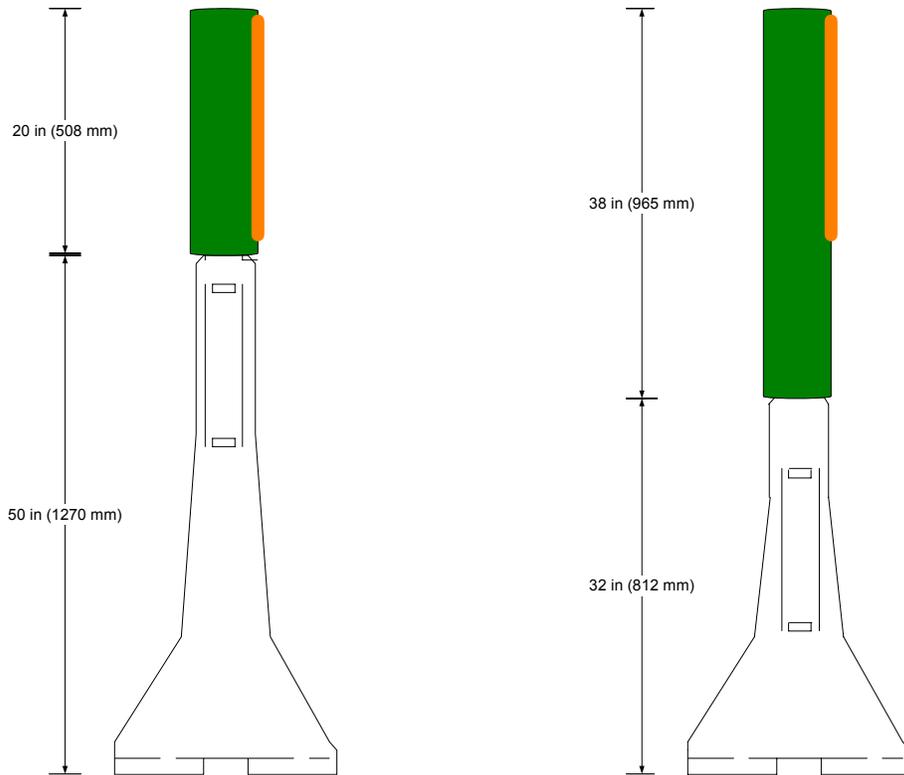


Figure 38: Drawing of proposed glare screens of 70 inch (1.78 m) height to shield 95% of all drivers, including those of trucks and busses. On the left is a 20 inch (0.51 m) glare screen mounted on a 50 inch (1.27 m) jersey barrier and on the right is a 38 inch (0.96 m) glare screen mounted on a 32 inch (0.81 m) jersey barrier. Each glare screen is equipped with a reflective fluorescent orange strip made of Type IX retroreflective sheeting.

4.3 Pavement Markings and Raised Pavement Markers

The use of directional pavement arrows in the center of the lane is addressed neither in the Ohio standards nor in the literature. It is expected that adding such arrows can only help drivers navigate through a work zone. Therefore their use, particularly at lane shifts and crossovers, is recommended. As an alternative to full-size arrows one may want to consider the low-wear, material saving half-size arrows previously tested and recommended for general use by Zwahlen, Schnell, and O'Connell [53].

The recommended implementation of 3M 750 wet retroreflective removable pavement marking tape and half-size arrows is shown in Figure 39. An alternate implementation using raised pavement markers and half-size arrows of 750 tape is shown in Figure 40.

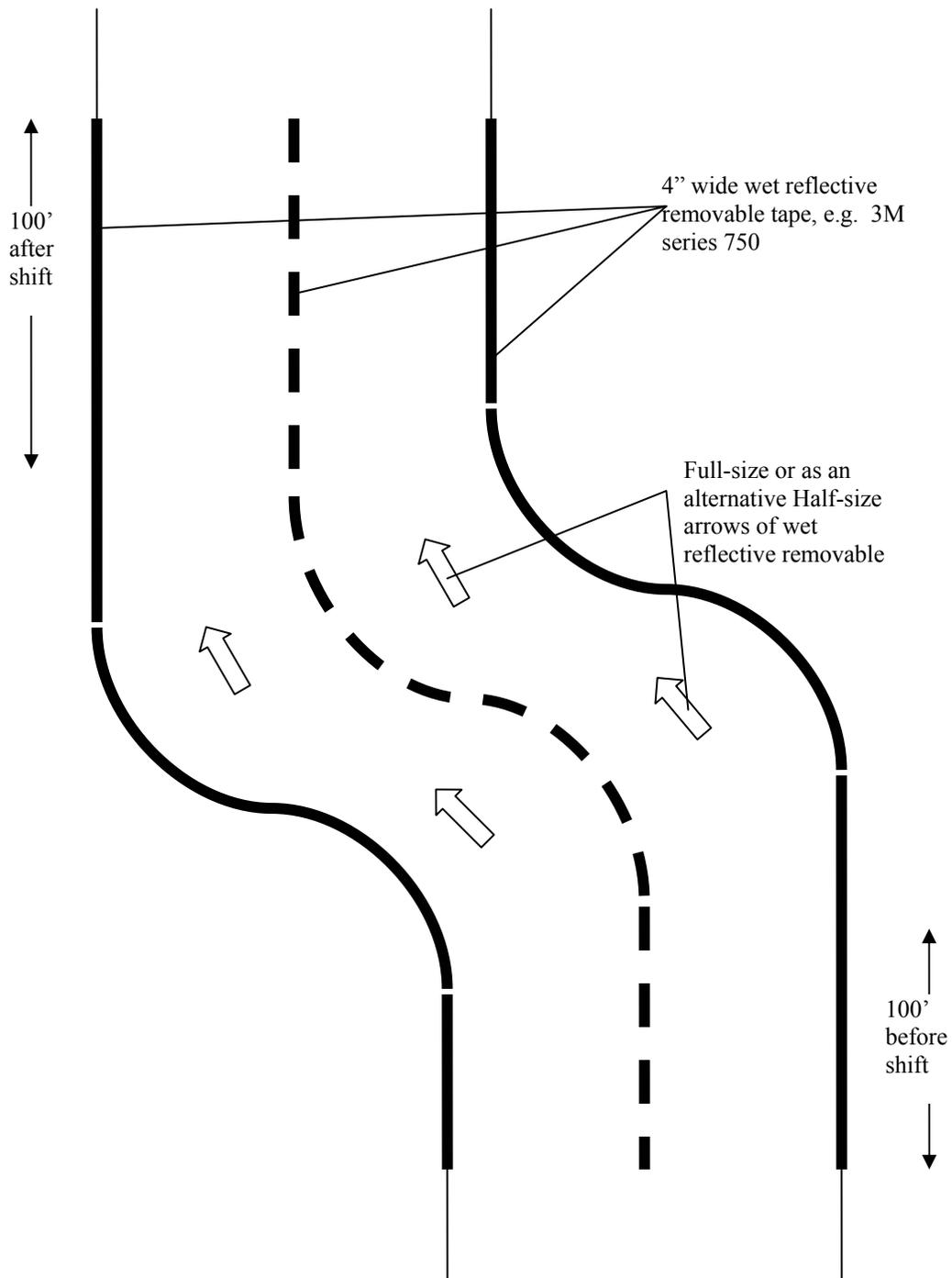


Figure 39. Recommended implementation of pavement marking materials in a lane shift. A high visibility retroreflective marking such as 3M 750 tape is suggested. Half-size arrows provide additional guidance to drivers.

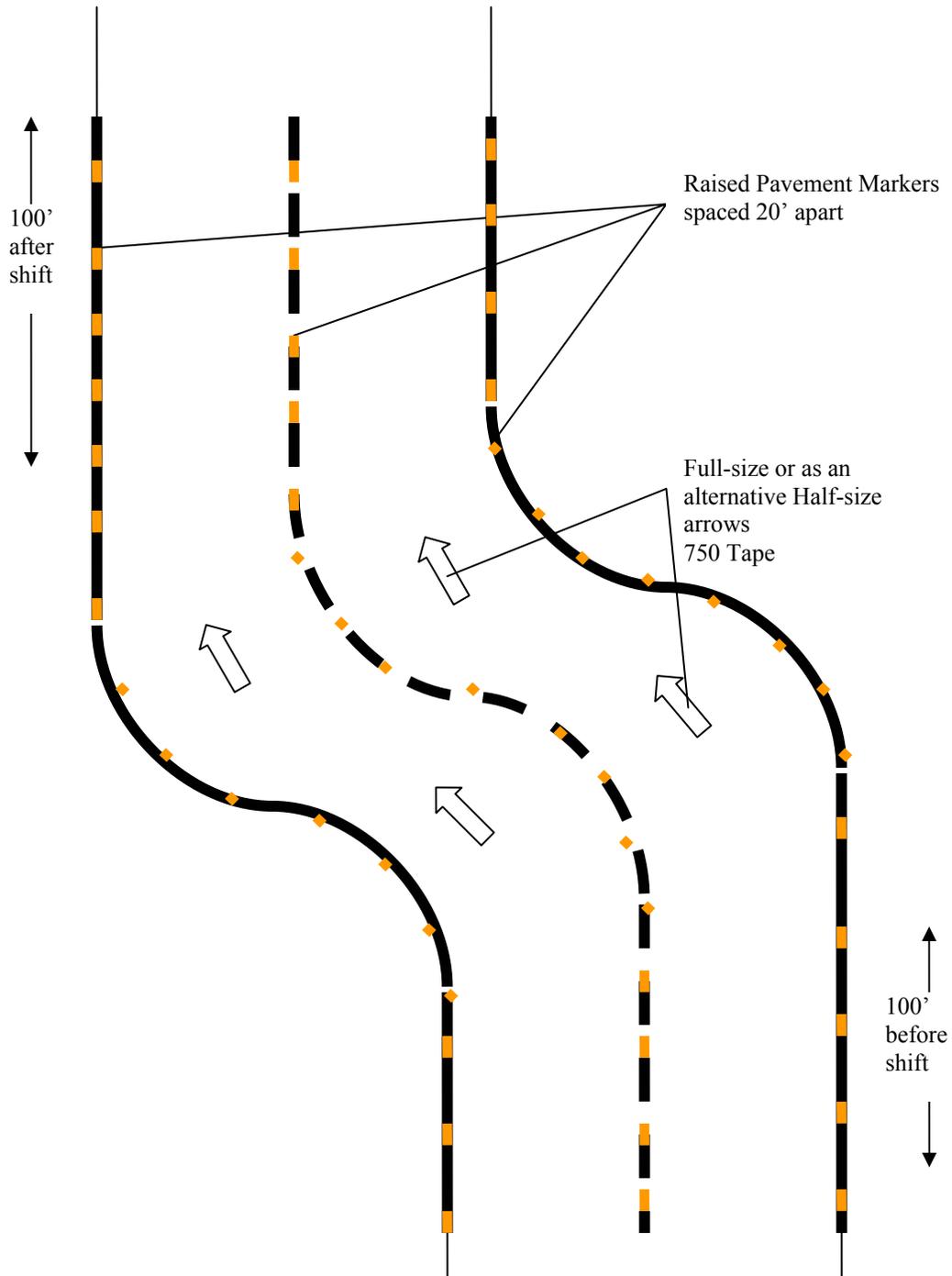


Figure 40. Recommended implementation of raised pavement markers in a lane shift. Half-size arrows made with a high visibility retroreflective marking such as 3M 750 tape provide additional guidance to drivers.

4.3.1 Lightguard Lighted Raised Pavement Markers

The Kansas Department of Transportation deployed Lightguard lighted raised pavement markers (LRPMs) in a crossover [50]. The LRPMs were evaluated with the Safety Warning System (SWS), which is designed to inform drivers of an upcoming work zone through a message encoded in a radar signal broadcast from a trailer mounted transmitter.

When the Lightguard system was turned on (the SWS remaining active), an additional decrease in the mean and 85th percentile speeds occurred. The change was statistically significant at a 95% confidence level for both trucks and passenger cars during both daylight and darkness conditions, though the more dramatic change occurred at night. The percentage of passenger cars passing within 30 cm (1 ft) of the edge line decreased from 8.9 to 5.2 percent with the deployment of the LRPMs, indicating that drivers were keeping closer to the center with the LRPMs active. Before and after pictures of the lighted RPM installation are given in Figure 41.



a) before installation of Lightguard lighted raised pavement markers



b) after installation of Lightguard lighted raised pavement markers

Figure 41. Crossover implementation of Lightguard lighted raised pavement markers a) before installation, b) after installation [50].

4.3.2 Interplex Solar Powered Raised Pavement Markers

The state of Kansas also evaluated Interplex solar powered LRPMs [50]. They have the advantages of being easy to install and maintain; unlike the Lightguard LRPMs discussed above, there is no wiring. However no significant changes in lane distributions were observed with this system. The Interplex LRPMs were much less visible than the Lightguard ones. The system may work better in a flashing mode or with closer spacing, but the tested configuration was not recommended.

4.4 Lighted Guidance Tube

A new device for guiding drivers through work zones is the lighted guidance tube devised by 3M [54]. It consists of 20 ft (6.1 m) long sections of optically coated polycarbonate tubing and connectors suitable for mounting on jersey barriers illuminated internally with 50W halogen lamps stationed every 3-5 sections. An installation is shown in Figure 42. The tube can be configured to appear yellow and/or to be seen in only one direction if desired. The Oregon Department of Transportation installed a section of the tubing on a detour curve in a highway construction project where two accidents had occurred.

There were no accidents reported at that curve in the five months after installation, however the time was not long enough to judge if the reduction was significant. There was no significant reduction in speed; in fact speed increased in one direction. However, 87% of surveyed motorists reported that the tube did help guide them through the curve. The lighted guidance tube system can be set up by two people. The tubing does need to be kept clean and dry on the inside to prevent damage to the optical coating.

The lighted guidance tube was manufactured by the 3M Company, who are no longer marketing the product.



a) daytime view



b) lighted nighttime view

Figure 42. Lighted Guidance Tube installed on a detour curve in Oregon. a) daytime view b) nighttime view [54].

4.5 Implementing Positive Guidance Principles with Inspections

Ullman and Schrock of the TTI recommend the use and the implementation of well-known positive guidance principles in complex work zones [55]. They list the positive guidance principles as:

1. site definition,
2. problem description,
3. hazard identification,
4. hazard visibility assessment,
5. expectancy violation determination,
6. information load analysis,
7. information needs specification, and
8. current information system evaluation.

Of these, steps 4-7 are singled out for particular attention because steps 1-3 are straightforward and 8 simply involves comparing information needs to what information is actually provided. These principles are already well embedded in the traffic control procedures and standards adopted by the state of Texas. However, there is a failure to always implement and maintain these principles. The authors had several test drivers drive through several complex work zones and identify areas which were confusing. Drivers found a confusing location at every 1.2 miles (1.93 km) of work zone on average, with the number decreasing to as low as every 0.5 miles (0.8046 m) for one north of Dallas. These confusing locations could each be identified as violating some of the positive guidance principles. Thus regularly inspecting and maintaining work zone traffic control devices to adhere to positive guidance principles should eliminate most of these confusing locations and presumably reduce the incidence of crashes and other problems. Particularly singled out in these studies were poorly constructed messages on portable changeable message signs.

The authors describe the four non-straightforward principles:

- A **hazard visibility assessment** determines if a hazard can be detected, and recognized with enough time for the driver to respond safely and effectively. This time depends on the driver reaction required.
- **Expectancy violation determination** entails figuring out how a situation may be confusing, for instance if the feature(s) involved are surprising, such as a mismatch between pavement markings and barrier alignment. Someone looking for expectancy violations should note unusual features, first-of-a-kind features, surprising features, and visibility restrictions.
- An **information load analysis** involves identifying all information sources, including signs (both traffic and commercial or otherwise), roadside alignment, lighting, other traffic, and more. Visual clutter and information that is misleading, ambiguous, or confusing will increase information load. Unfortunately there is no absolute scale for information load, but some general guidelines do exist.
- An **information needs analysis** involves identifying the information the driver needs to negotiate a section of road or a hazard.

When the above has been done one is ready to evaluate whether the current system described in the information load analysis meets the needs identified in the information needs analysis. The authors note that necessary information that is presented too soon or too late is as useless to a driver as missing or wrong information.

The report recommends that regular inspections should be made of work zone sites looking for violations of positive guidance principles. Informal inspections should be made daily and formal inspections every two weeks. Once a month the formal inspection should occur at night. Ullman and Schrock provide a form that can be used in formal inspections; both pages are shown in Figure 43 and Figure 44. They recommend that inspections be conducted by a team of two – a driver and a recorder. It may also be necessary to travel through the work zone several times to complete an inspection, perhaps once emphasizing each of the four major steps.

Project _____		WORK ZONE FIELD REVIEW
Contractor _____		
Review Date _____	Time _____	
Reviewers _____		
I. HAZARD VISIBILITY ASSESSMENT Note any possible hazard that cannot be seen and recognized from 15 seconds away. <ul style="list-style-type: none"> Does any object, device, or geometric feature require a reaction from approaching traffic? 	EXAMPLES <ul style="list-style-type: none"> Arrow panels Portable CMS Moving work vehicles Traffic queues Unprotected workers Construction equipment Construction material Lane drops, lane shifts, ramps Uneven lanes/bumps/kits Potholes, damaged pavement Vertical/horizontal curves 	
II. DRIVER EXPECTANCY VIOLATION Note any features that may "surprise" drivers. Also note those features that can "lull" drivers into incorrect decisions or behaviors. <ul style="list-style-type: none"> Does any geometric feature such as a vertical or horizontal curve hide hazards from a driver's view? Does any feature lead the driver in an unintended direction or into an incorrect decision? 	EXAMPLES <ul style="list-style-type: none"> Curves or lane shifts designed for a lower speed than the remainder of the facility. Curves or lane shifts where drivers also must make a path decision (i.e., at the gore of an exit ramp). Exit ramps that are temporarily closed. Visible lane joints, pavement markings obliterations, or pavement edges that lead off the desired path. Barriers/barrels adjacent to travel lanes that follow the exit ramp alignment. Interruptions in channelizing devices, pavement markings, or barriers that mark the travel lanes. 	
III. INFORMATION LOAD ANALYSIS Note locations where too much information is visible to be read at one time, and locations where visual clutter distracts drivers from seeing the information being presented. <ul style="list-style-type: none"> Do signs or messages have to compete for the drivers' attention with other information? Are there ways that the amount of information presented can be spread out or reduced? 	EXAMPLES <ul style="list-style-type: none"> Glare from sun, headlights, or construction lighting preventing drivers from seeing signs and devices. More than seven permanent and work zone signs in the driver's field of view at one time. Portable CMS messages that do not follow basic guidelines, long messages, and locations where drivers have to make a path decision at the same time they are to read the CMS. Visual clutter in the area of high information load, or where path decisions must be made. 	
IV. INFORMATION NEEDS SPECIFICATION Advance warning should both warn drivers of the presence of a hazard and direct the driver as to the best course of action. <ul style="list-style-type: none"> Does each hazard or expectancy violation have correct advance information to direct drivers? Is the advance warning information too close or too far away from the hazard? Is the proper driving path emphasized enough to overcome the visual clutter that is present? 	EXAMPLES <ul style="list-style-type: none"> A final warning located greater than one-half mile from the hazard. A warning located less than the stopping sight distance from the hazard (8 seconds at 70 mph). A warning that does not grab the attention of drivers, such as a small warning sign lost in the visual clutter of other signs. Temporary pavement markings that do not stand out against the pavement patches, joints, etc. or against the light sources from nearby roadside businesses. 	

Figure 43. Page 1 of form for formal inspection of work zone traffic control based on positive guidance principles [55].

Studies showed that Type VII reflective sheeting materials have a higher legibility when viewed from far whereas Type IX material is best when viewed from a shorter distance. This property of the different types of materials can be used to make the drums more visible to the driver from far out as well as close in. Thus instead of using a single strip of material of a particular color (orange or white) two strips (each half the original width) of Type VII and Type IX of the same color can be used. This will make the drums more visible at both near and far distances.

Delineation of the travel path can also be improved by placing directional arrows on the barrels to indicate in which direction the motorists should drive. This will help give the driver clear directions on how to maneuver through the work zone. Placing directional arrows on barrels would be especially useful in situations where there are several lanes and the driver has to know which path should be followed.

Glare is another important distraction factor from motorists traveling during nighttime. In order to prevent 95% of large van and bus drivers from the glare of oncoming large vans and busses, a 70 inches (1.78 m) high separator is needed. This height will protect drivers of all types of vehicles from all normal headlight configurations, e.g. compact car from large van or bus. This height may be obtained by adding a 20-inch (0.51 m) glare screen onto a 50-inch (1.27 m) portable concrete barrier or a 38-inch (0.96 m) glare screen onto a 32-inch (0.81 m) portable concrete barrier. In addition to reducing headlight glare from oncoming motor vehicle traffic, glare screens can also improve the delineation. To achieve this purpose glare screens could be equipped with reflective stripes. Reducing glare from the oncoming vehicles will improve the comfort level of drivers during nighttime conditions, and especially for older drivers.

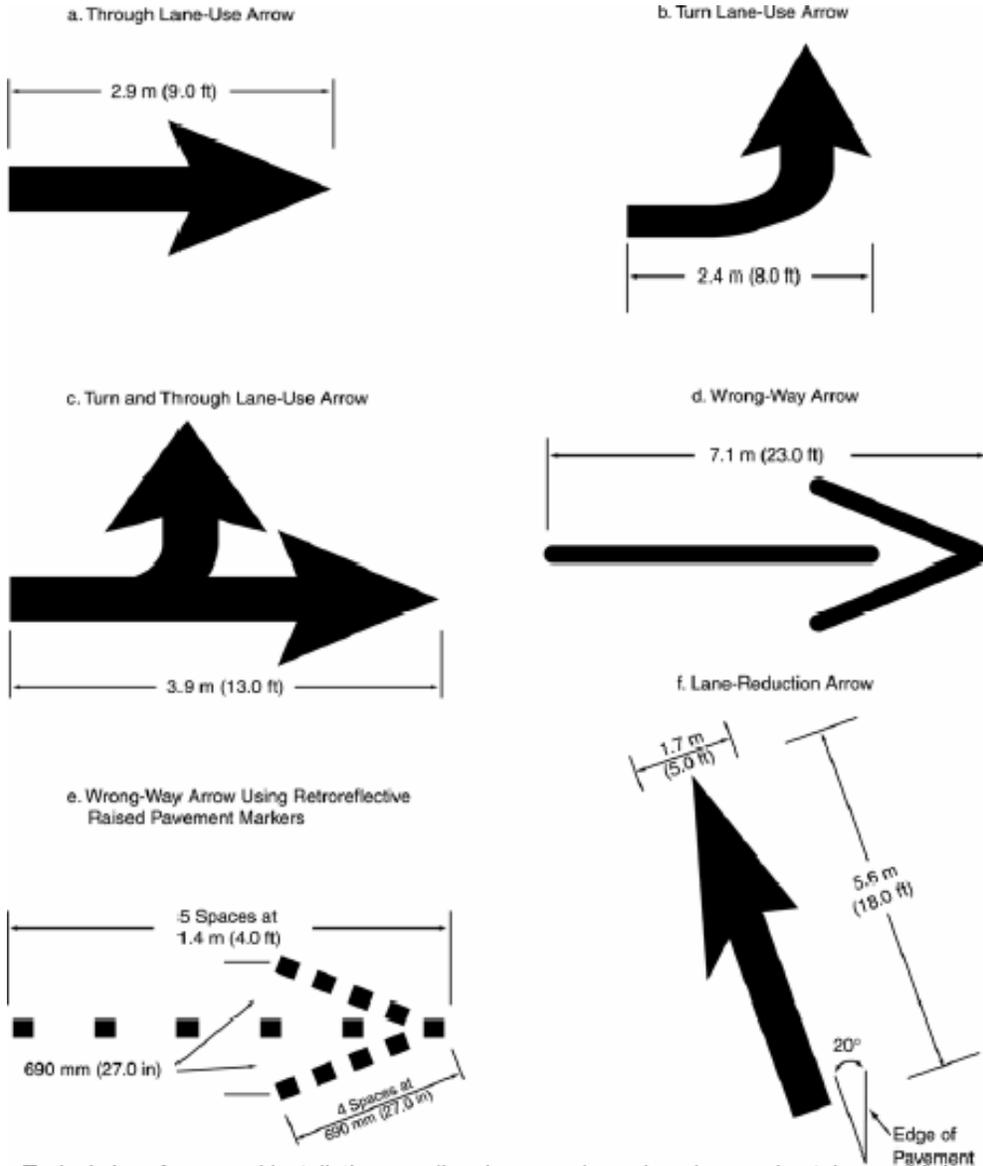
Another recommendation would be the use of directional pavement arrows in the center of the lane at lane shifts and crossovers. One may want to consider the low-wear, material saving half-size arrows previously tested and recommended for general use by Zwahlen, Schnell, and O'Connell.

More information regarding work zone delineation can be found in section 15 and 16 of this report.

5 HALF SIZE AUXILIARY PAVEMENT MARKINGS

5.1 Existing Practice Using Pavement Marking Arrows

Pavement symbol markings are used to guide and regulate traffic. In the OMUTCD and Federal Highway Administration MUTCD typical lane-use, lane-reduction, and wrong-way arrows for pavement markings are given, and these are reproduced in Figure 45 [5].



Typical sizes for normal installation; smaller sizes may be reduced approximately one-third for low-speed urban conditions; larger sizes may be needed for freeways, above average speeds, and other critical locations. A narrow elongated arrow design is optional.
For proper proportion, see "Typical Alphabets for Highway Signs and Pavement Markings"
(Available from FHWA, 400 Seventh St., SW., HOTO-1, Washington, DC. 20590)

Figure 45. Typical lane-use, lane-reduction, and wrong-way pavement marking arrows.

Drivers can have difficulty in selecting which lane to drive in when they are not able to see or recognize pavement arrows. If a driver has to change lanes when approaching an intersection and does not recognize the pavement arrows in the lanes, the driver may hold up traffic until getting into the correct lane, miss a turn, or turn in the wrong direction and then possibly get lost attempting to return. All of these scenarios waste the time and energy of the driver and others in the road. Furthermore, any of these circumstances can possibly cause an accident [56].

In Figure 46, a drawing of the typical lane use control word and symbol markings use is given.

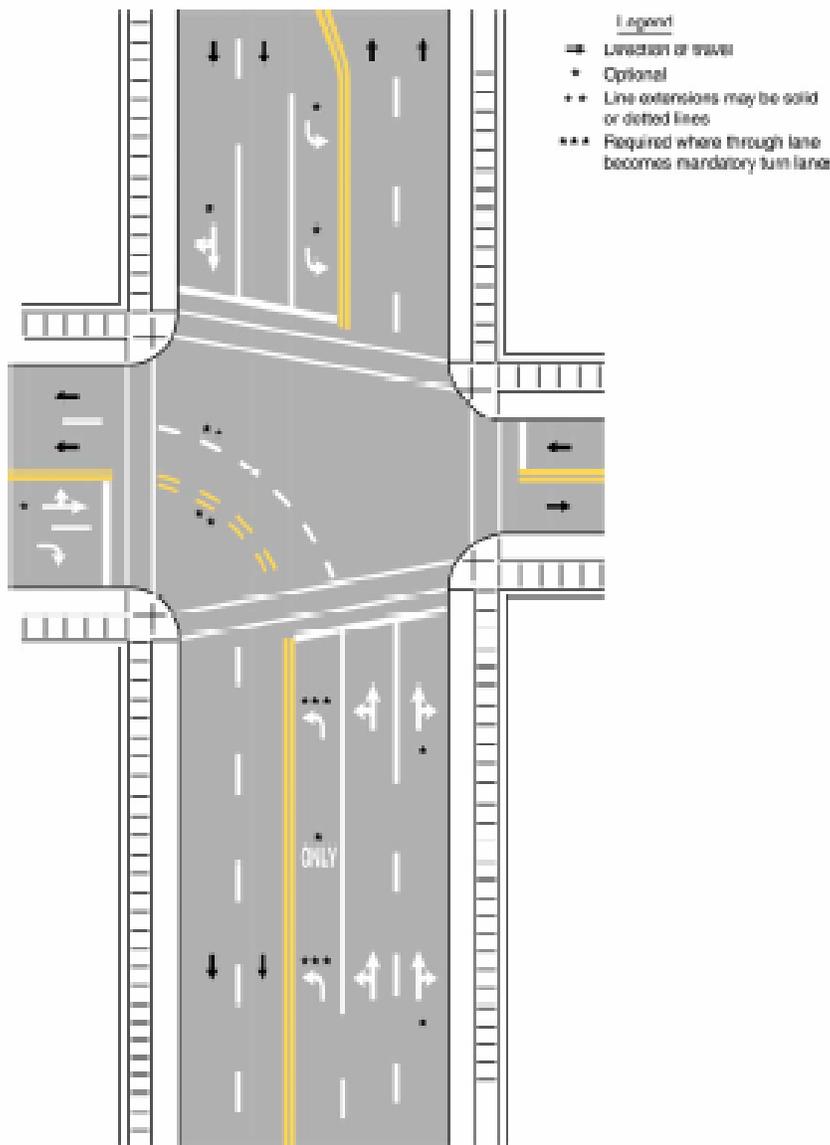


Figure 46. Typical lane-use control word and symbol markings (*Ohio Manual of Uniform Traffic Control Devices*, 2003 Edition, Figure 3B-21)

5.2 Half-Size Pavement Markings

In a study conducted by Sarah O’Connell [56], the recognition distances of 5 different arrow types were tested to find which arrow design rated best in terms of longest recognition distance. The arrows were also tested at full and half scale sizes to find how much the recognition distance changes for the different scales. The drawings for the arrow designs tested in the study are given in Figure 47. Their full-size dimensions are given in

Table 18, and half-size dimensions are given in Table 19 [56].

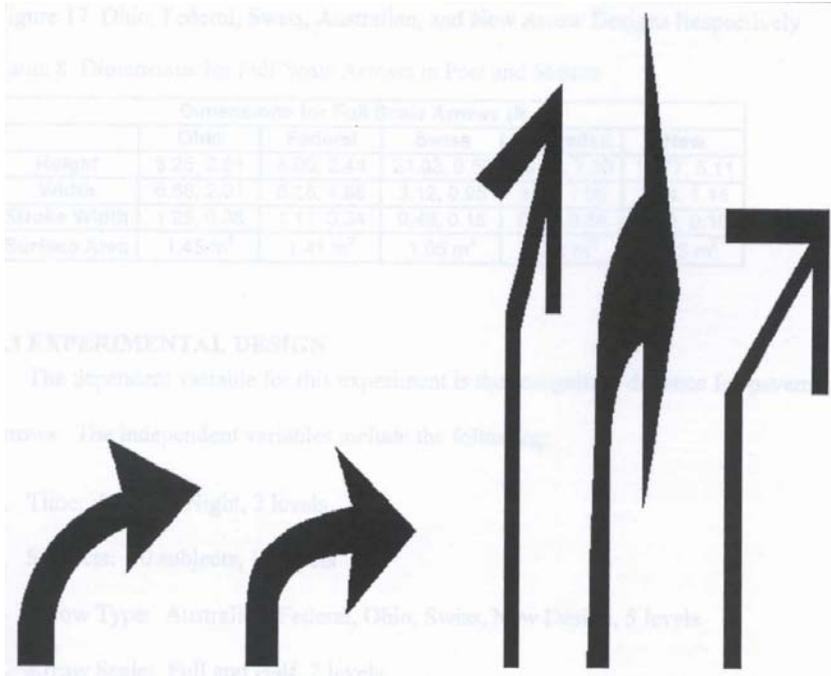


Figure 47. From left to right: Ohio, Federal, Swiss, Australian, and new arrow designs.

Table 18. Dimensions for full scale pavement arrows (ft, m).

	Ohio	Federal	Swiss	Australian	New
Height	8.25, 2.51	8.00, 2.44	21.33, 6.50	23.95, 7.30	16.77, 5.11
Width	6.58, 2.01	6.18, 1.88	3.12, 0.95	3.28, 1.00	3.74, 1.14
Stroke Width	1.25, 0.38	1.11, 0.34	0.49, 0.15	0.79, 0.24	0.59, 0.18
Surface Area	1.45 m ²	1.41 m ²	1.65 m ²	2.32 m ²	1.23 m ²

Table 19. Dimensions for half scale pavement arrows (ft, m).

	Ohio	Federal	Swiss	Australian	New
Height	4.125, 1.25	4.00, 1.22	10.66, 3.25	11.97, 3.65	8.38, 2.55
Width	3.29, 1.01	3.09, 0.98	1.56, 0.47	1.64, 0.50	1.87, 0.57
Stroke Width	0.625, 0.19	0.55, 0.17	0.25, 0.075	0.40, 0.12	0.30, 0.09
Surface Area	0.36 m ²	0.35 m ²	0.41 m ²	0.58 m ²	0.31 m ²

The results of the study showed that the Australian arrow provided the longest average recognition distance of 163.55 m (536.59 ft) and the Ohio arrow provided the smallest average recognition distance of 111.25 m (364.99 ft) during daytime, as seen in Figure 48. The recognition distances for the half scale arrows did not differ greatly among themselves. The percent differences between the scales for the five different arrow types are: 8.9% for the Ohio arrow, 24.7% for the Federal arrow, 37.8% for the Swiss arrow, 48.6% for the Australian arrow, and 27.1% for the new arrow design.

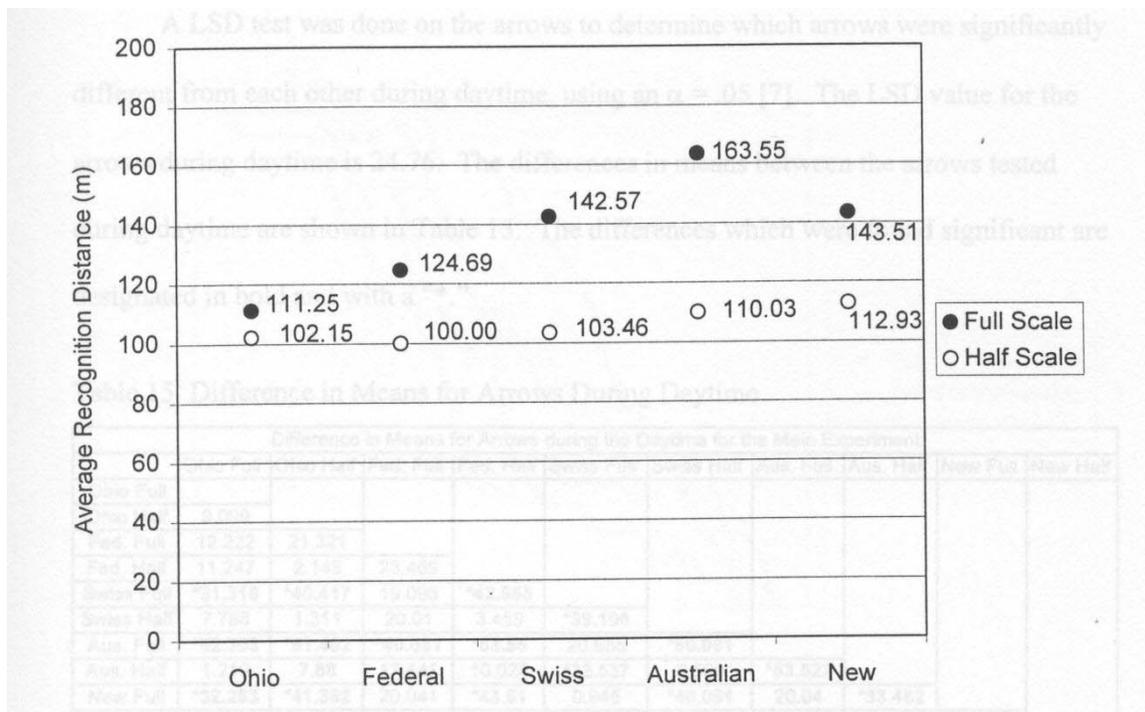


Figure 48. Recognition Distance Graph for Different Arrow Designs and Scales during Daytime

Figure 49 shows recognition distances for all arrows and scales during nighttime. The half scale arrows did not differ greatly and the difference between the full scale arrows was less pronounced. The full scale Australian arrow provided the longest average recognition distance of 124.84 m (409.59 ft) and the full scale Federal arrow provided the smallest average recognition distance of 98.83 m (324.24 ft). The percent differences between the scales for five arrow types are: 8.9% for the Ohio arrow, 15.8% for the Federal arrow, 29.0% for the Swiss arrow, 31.3% for the Australian arrow, and 17.8% for the new design arrow.

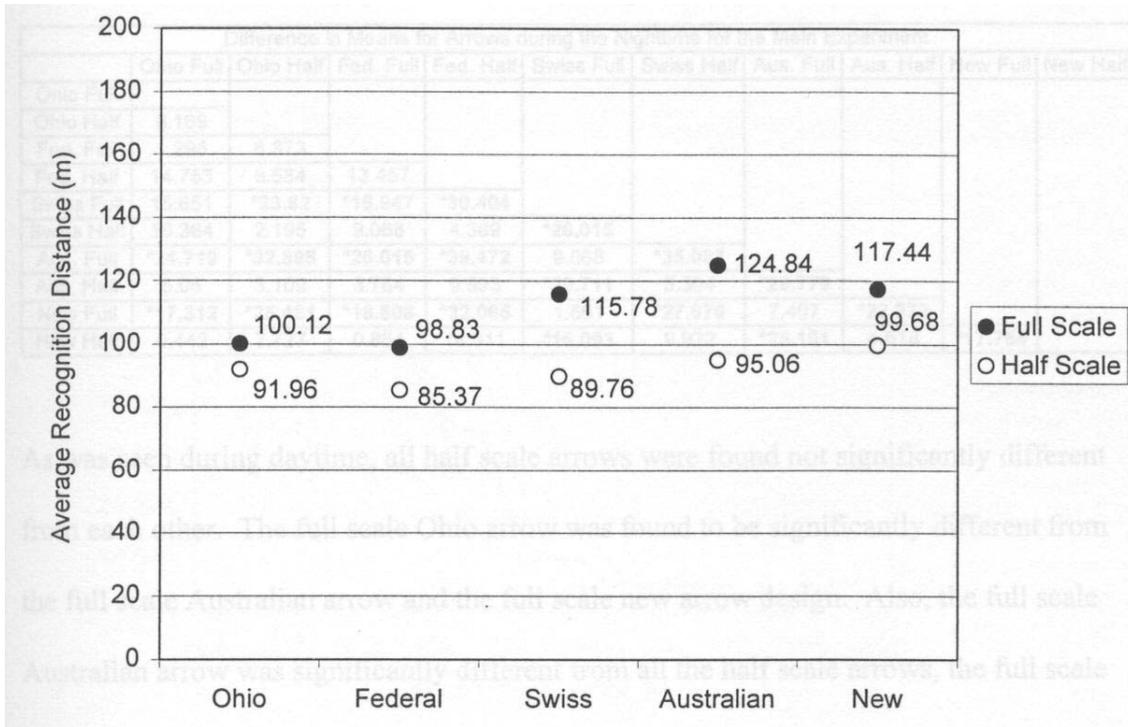


Figure 49. Recognition Distance Graph for Different Arrow Designs and Scales during Nighttime

The cumulative recognition distance graph for the Ohio arrow during daytime given in Figure 50 shows the percentage of subjects who recognized the arrows at certain recognition distances. The difference in recognition distance between full-size and half-size Ohio arrows was not found to be significant and the graph shows that the difference between scales for the Ohio arrow was very small in the study.

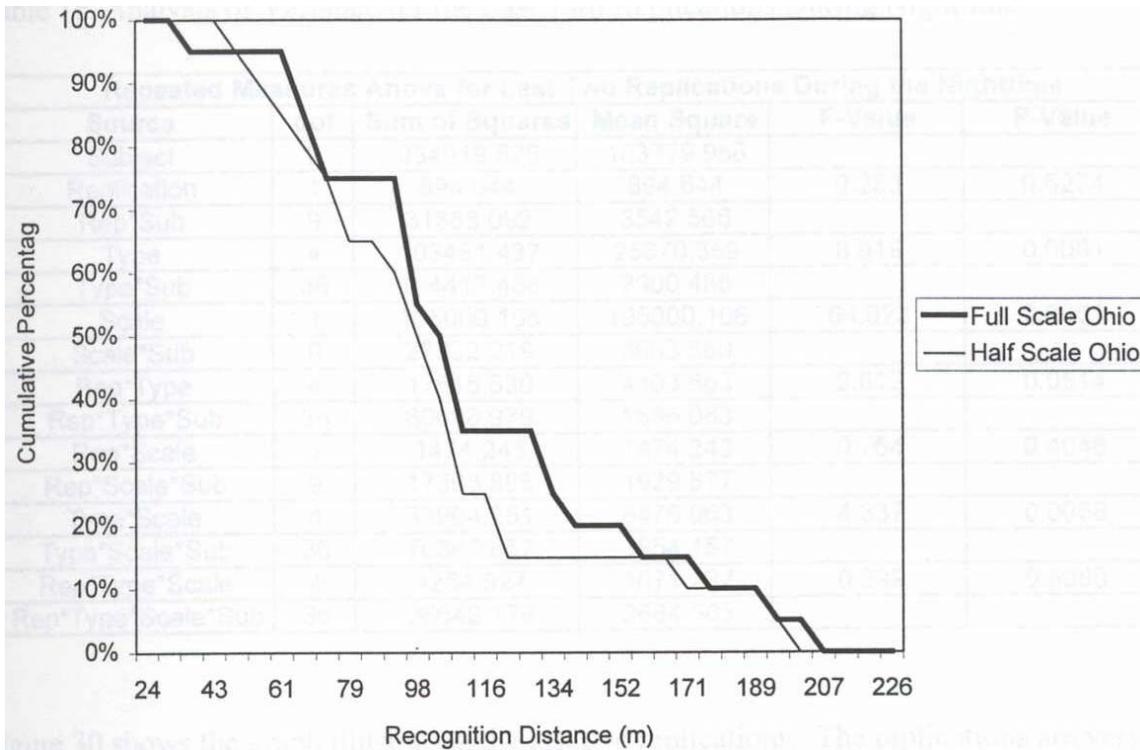


Figure 50. Cumulative Graph for the Recognition Distance of Ohio Arrows during Daytime for Full-scale and Half-scale arrows

The cumulative recognition distance graph for the Ohio arrow during nighttime is given in Figure 51 which shows the percentage of subjects who recognized the arrows at certain recognition distances. The difference between the two sizes of the Ohio arrow was not found to be significant as the graph shows.

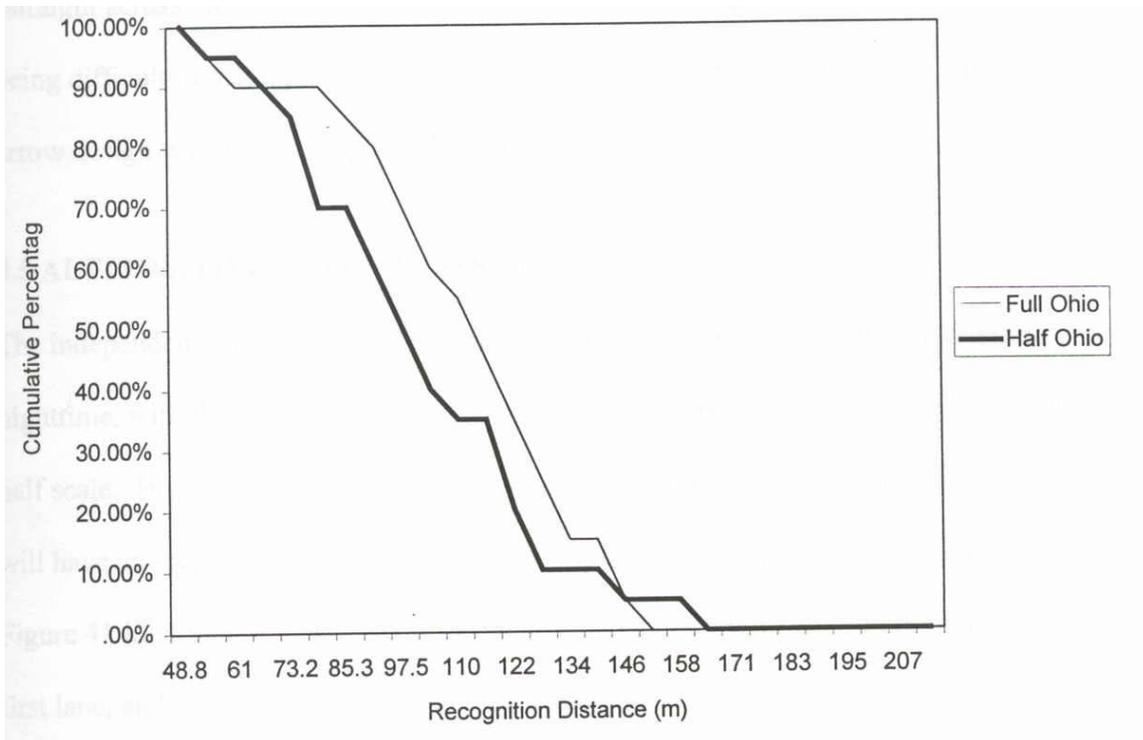


Figure 51. Cumulative Graph for the Recognition Distance of Ohio Arrows during Nighttime for Full-scale and Half-scale arrows

5.3 Recommendations to ODOT

The O’Connell study showed that there was not much difference between the recognition distances of full-size and half-size arrows. By providing two half size arrows in succession rather than one full scale arrow the overall recognition distance can be substantially increased. The percentage gain in recognition distance by using two-half scale Ohio arrows in succession is about 84% in both daytime and nighttime. In Table 20 and Table 21 the average recognition distances for arrows and gain for using two half-scale arrows in succession for each arrow type during daytime and nighttime are given respectively. The new arrow design provided the longest recognition distances when used in half-size pairs compared to the other four designs. The new arrow design half-size measurements are given in Figure 52. In addition to the improvement in the recognition distance, the use of two half-scale arrows in succession wherever longitudinally possible provides:

- Reduced material costs, due to requiring only half of the material.
- Less wear and tear from automobile tires, due to the smaller width of the half-size arrows.
- Capability of maintaining current arrow designs to which drivers are accustomed.
- Earlier recognition in congested traffic conditions due to earlier arrow placement.
- Redundancy by providing twice the number of arrows.

The first arrow should be placed as far away as possible from the second arrow. This would provide early information about the direction of the lanes.

We further recommend that pavement word legends, such as “ONLY” be reduced to half size and used in pairs also. However stop bars and other similar transverse markings should be kept at their existing standard size.

Table 20. Average Recognition Distances for Arrows and Gain for Two Half Scale Arrows in Succession for each Arrow Type during Daytime

Daytime Data				
Arrow Type	Average Recognition Distance (ft, m)		Recognition Distance Gain (ft, m)	Recognition Distance Percent Gain
	One Full Scale	Two Half Scale		
Ohio	365, 111	670, 204	305, 93	83.6%
Federal	405, 123	656, 200	250, 76	62.0%
Swiss	468, 142	679, 206	210, 64	45.1%
Australian	536, 163	722, 220	183, 56	34.6%
New	471, 143	741, 225	269, 82	57.4%

Table 21. Average Recognition Distances for Arrows and Gain for Two Half Scale Arrows in Succession for each Arrow Type during Nighttime

Nighttime Data				
Arrow Type	Average Recognition Distance (ft, m)		Recognition Distance Gain (m)	Recognition Distance Percent Gain
	One Full Scale	Two Half Scale		
Ohio	328, 100	604, 184	275, 84	83.7%
Federal	321, 98	561, 171	236, 72	72.8%
Swiss	377, 115	590, 180	210, 64	55.1%
Australian	407, 124	623, 190	213, 65	52.3%
New	384, 117	653, 199	269, 82	69.8%

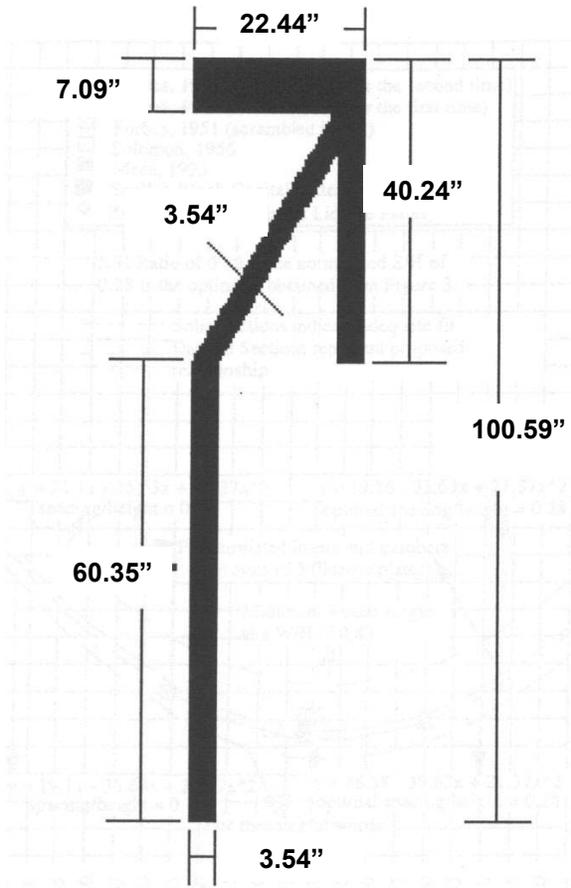


Figure 52. Recommended new half-size arrow design

In a study by Schrock, Hawkins, and Chrysler [57] the use of pavement marking arrows on two way frontage roads was evaluated. They performed a before and after study to evaluate the effects of lane direction pavement marking arrows. At the selected research site 1 out of every 13 drivers were driving on the wrong lane before the study. After the installation of pavement arrows only 1 out of 150 drivers selected the wrong way for driving. Researchers concluded that lane direction pavement marking arrows had a beneficial effect on safety at the study location and recommended expanded efforts to determine other locations that could benefit from this low-cost treatment.

The use of pairs of half-size wrong-way arrows on freeway entrance and exit ramps could help prevent future accidents like that described in the newspaper article shown in Figure 53 [58]. The driver is most likely to look at the road ahead, and these arrows would be nearly unmistakable.

Wrong-way driver charged in riders' deaths

CLEVELAND (AP) — A woman driving the wrong way on the highway when her car crashed into a motorcycle, killing a newlywed couple, has been charged with two counts of aggravated vehicular homicide, authorities said.

Robbie Moore had a blood-alcohol level of 0.2, police Lt. Wayne Drummond said Satur-

day. Ohio's legal limit is 0.08.

Moore, 29, of Warrensville Heights, was driving with a suspended license about 1 a.m. Thursday when her car crashed head-on into a motorcycle near downtown, police said. Jeffrey Bliss, 25, and his wife, Ann Marie Roalofs Bliss, 20, died at the scene.

Police said Moore entered I-

71 near Cleveland Hopkins International Airport and drove north in the southbound lanes for more than 8 miles. Once downtown, she merged onto the innerbelt, traveling east in the westbound lanes.

Officers were looking for Moore when the accident happened because several drivers had called 911.

Figure 53. Newspaper story of newlywed couple killed by driver traveling the wrong way on an interstate [58].

5.4 Recommended Evaluations

Before undertaking a statewide implementation of half size paired pavement markings (wherever longitudinally possible), which would be expected to reduce material and application costs while at the same time improving driver information presentation, an evaluation would need to be performed to analyze the effectiveness of using two half-size pavement markings and half-size “ONLY” markings in succession. Half-size pavement markings could be installed at a number of test sites with different average daily traffic volumes, vehicle mixes, and different geometrics in such a way that they would be a representative sample of Ohio conditions.

An evaluation study could include a photometric visibility study to compare and analyze daytime and nighttime visibility of half-size pavement markings and “ONLY” markings and to compare and analyze the optimal spacing between two successive pavement arrows. Also, a driver evaluation study could be conducted to analyze the acceptance of half-size pavement markings by the drivers. In addition wear data could be collected and compared to matched regular pavement marking implementations.

More information regarding half size pavement markings can be found in section 15 of this report.

6 ACCIDENT MITIGATION

This section describes the human factors opportunities available for accident mitigation in Ohio's transportation system. The accident mitigation measures available are two fold: those that help reduce the frequency of accidents and measures that can be used to reduce the severity of accidents.

The safety programs currently available in the state of Ohio, accident mitigation measures that are practiced in other states and countries, the human factors implications of such strategies, their advantages and disadvantages, and cost involved (where available) are discussed in the following sections. In some cases, the existing practices need to be further evaluated before they can be implemented successfully. In other situations, where recommendations are based on expert observations, further evaluations are necessary. These instances are also emphasized where relevant.

Roads can be improved to mitigate accidents by better horizontal and vertical alignment. This will provide a driver with an adequate preview of the road and more time to process information and make decisions. Therefore, the underlying requirement for accident mitigation is better roads that provide higher preview distances. Some strategies that can be implemented to achieve this are also discussed in this section.

6.1 Ohio Programs

Ohio has two primary highway safety initiatives, the newer Safety Hot Spot Program that targets urban roads and freeways with hot spots defined by crash frequency and the older Highway Safety Program that targets rural roads and freeways with selected segments determined by crash rates among other factors. The goal of both programs is to develop a safety and congestion countermeasures toolkit; a countermeasures checklist has already been developed [59].

6.2 Ohio Hot Spot Program

Ohio's Hot Spot Program divides roads into 2-mile (3.22 km) segments then counts all accidents on each stretch in both directions and in all lanes over the previous three years. If a 2-mile stretch of road exceeds 200 crashes per 3 years for freeways or 100 crashes per 3 years for other roads, then that stretch is a "hot spot" and is marked for special attention. The program may be expanded in the future to focus on snow and ice incidents, truck crashes, work zone crashes, and rear end crashes [59].

6.3 Ohio Highway Safety Program

The Ohio Highway Safety Program, in place for over 30 years, identifies high crash locations using a system. Roads are divided into half-mile (0.8 km) segments and all crashes in both directions on all lanes combined are counted. Intersections of interest are also identified by the number of crashes. Excluded from the counts are animal accidents, falling from vehicle accidents, non-collisions, and work zone accidents. If an intersection has 14 crashes per period or a road segment has 20 crashes over the time of interest, then it is designated for further attention. A half-mile road segment is then extended by 0.1 miles (161 m), if there is a

crash in that tenth of a mile, the segment is extended in 0.1 mile (161 m) increments until a gap is found [59].

Crash counts are then indexed by weighting as follows: severity – 15%, crash rate – 20%, frequency/density – 30%, equivalent property damage rate – 15%, fatal: multiply by 152.47, injury: multiply by 5.52, property damage only: multiply by 1.0, “delta change” (spike in crashes) – 10%. Then a Relative Severity Index is determined by dividing the weighted index by cost for each of 17 crash types on rural, urban, and freeway roads. ODOT has software that does this. Sections that meet criteria are ranked by each of the criteria above under weights, and then ranks are combined with weights to get a priority index [59].

The top problem sections are listed in the Safety Congestion Annual Work Plan. For freeways, the top 5 sections and interchange studies must start within one year and preliminary studies are conducted on the additional 40 locations on the list to determine if fast and inexpensive countermeasures can be implemented. For other roads, the top 200 sections and intersections must be studied within one year. Districts with few items on the list assist those districts that have more items on the list [59].

6.4 Ohio Safety Studies Components

A safety study includes the following components [60]:

- Condition diagram: a to-scale drawing of existing physical conditions, including identification of streets and locations, traffic control devices, driveways, curbs, medians, sight distances, bridges and culverts, parking, and other features if applicable
- Collision diagram: a compilation of a minimum of three years’ worth of crash reports. The diagram notes the direction of vehicles, presence of pedestrians if they are involved, date, time, pavement conditions, relevant factors (e.g. intoxication), and any injuries.
- Crash data summarized by severity, type, contributing factors, environmental conditions, time of day.
- An analysis of crash data.
- Recommendations, including all alternatives.
- Rate of return for various recommendations.
- Photographs of the area studied.

6.5 Swiss Blackspot Analysis

Switzerland uses a slightly similar method to identify and fix high-crash locations, which are termed “blackspots”. In targeting blackspots accidents can be reduced by as much as 66%.

The Blackspot analysis method has the following steps [61]:

- Identify high accident locations
- Study accident causes and factors to see which are most common then extract these “determinant accidents”.
- Determine probable deficiencies that contributed to these accidents – make a list of probable deficiencies.
- Independently study the intersection configuration, signing, marking, etc. and make a list of all detected deficiencies and deviations from standards.

- Compare the two lists and assign resources to fix problems that appear on both lists, the “determinant deficiencies”.

This method saved 5.8 million Swiss Francs over 54 months by investing 0.3 million Swiss Francs in corrections, a rate of return of 19.3. One weakness of the method is the lack of feedback to road designers, which would be needed to prevent recurring problems. Figure 54 shows photographs and scale drawings of a blackspot intersection in Switzerland before and after this method was used on it. This method is an interesting alternative to Ohio’s methods, but in the final analysis may not be any better.

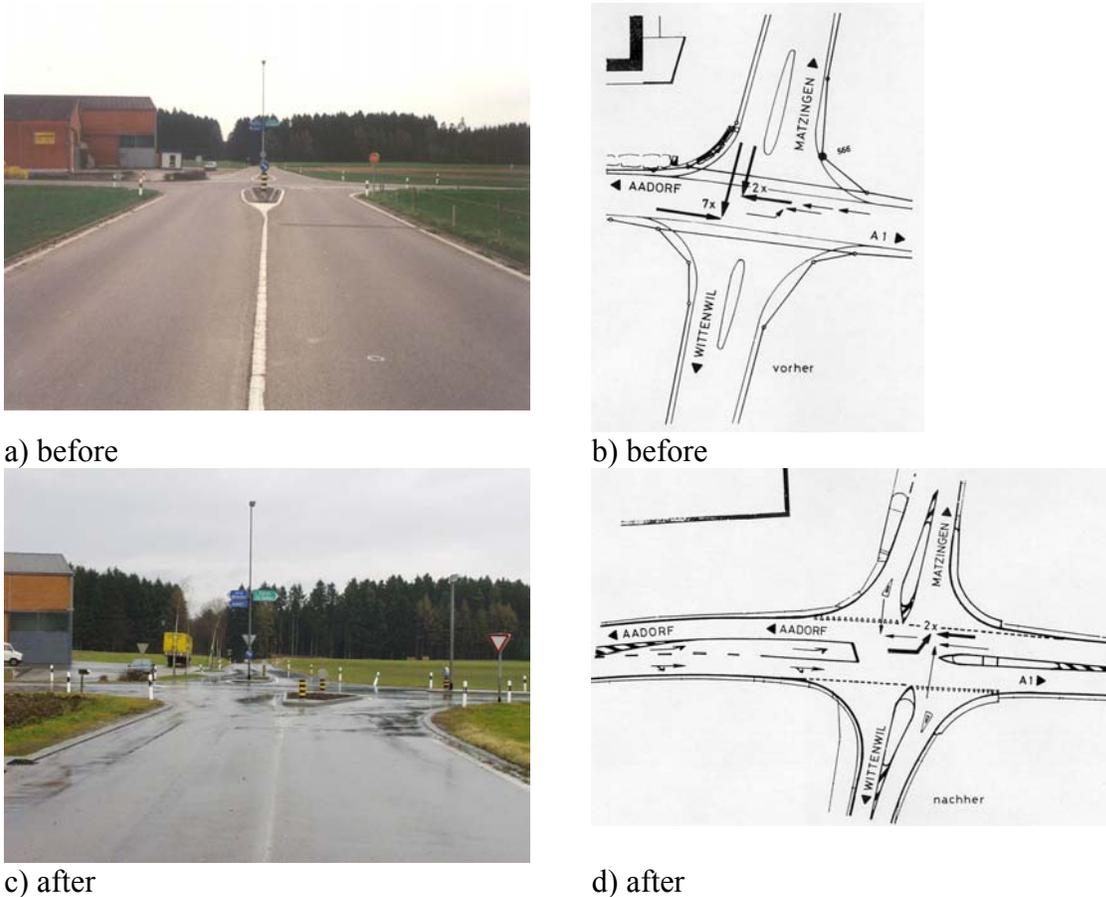


Figure 54. A blackspot intersection in Switzerland before and after treatment [61]. a) Photograph before treatment. b) scale drawing before treatment. c) photograph after treatment. d) scale drawing after treatment.

6.6 Offset Driving in Switzerland

In Switzerland drivers are told to drive with their vehicles slightly offset or staggered from the car ahead to improve visibility [62]. Drivers can see further ahead in congested situations and are thus better able to drive defensively and avoid or at least mitigate collisions. A diagram of this is shown in Figure 55. This practice could be encouraged in Ohio through various public education measures such as including a picture and explanation in the driver handbook, putting it on the driver's license exam, teaching it in driver's education courses, or signs encouraging the practice in frequently congested areas, including but not limited to CMSs. Note that this may not work as well in work zones with narrow lanes, though it can still be used in the approach areas with full-width lanes.

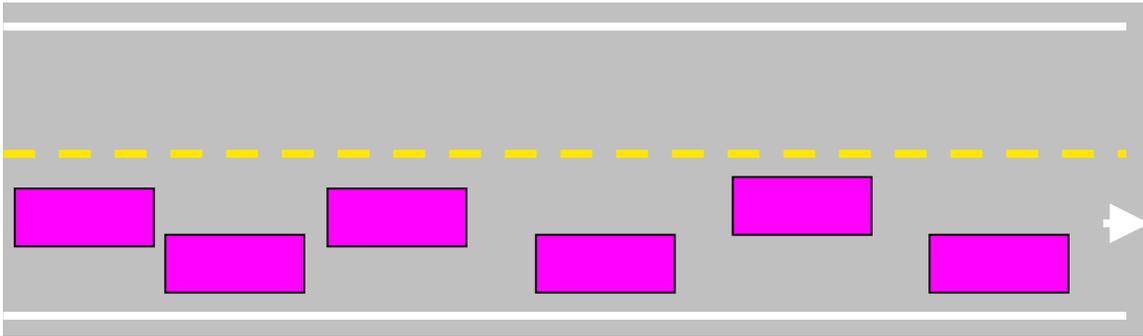


Figure 55. Offset driving as practiced and encouraged in Switzerland.

6.7 Road Safety Audit Reviews

Another technique called the Road Safety Audit Review was tested in rural areas in Arizona, South Dakota, and Wyoming and studied by Wilson [63]. The road safety audit review is an independent analysis by a qualified team of auditors that includes the following steps:

- Classify road network by function
- Recruit independent auditors (for a county, use neighboring 3-5 county engineers or state DOT personnel)
- Prioritize improvements based on road classification and nature of safety problem – factor in urgency and resources available
- Use an incremental approach
- Document audit findings and address issues identified
- Study all roadways over 4-5 year period

Road Safety Audits can also be conducted on planned roadways not yet built.

This method appears to have a similar aim to Ohio's hot spot program; however the road safety analysis is based more on an analysis of road conditions rather than on an analysis of road accidents.

The same study also listed types and causes of intersection crashes [63]:

- Types:
 - Crossing collisions (sideswipe)
 - Rear end collisions
 - Lane change collisions
 - Collisions with pedestrians or bicycles
- Causes:
 - Poor design of intersection and/or approaches
 - Inadequate traffic engineering, e.g. improper signing
 - Poor driver education and training
 - Drivers disregarding traffic control

6.8 Pennsylvania DOTs for tailgating

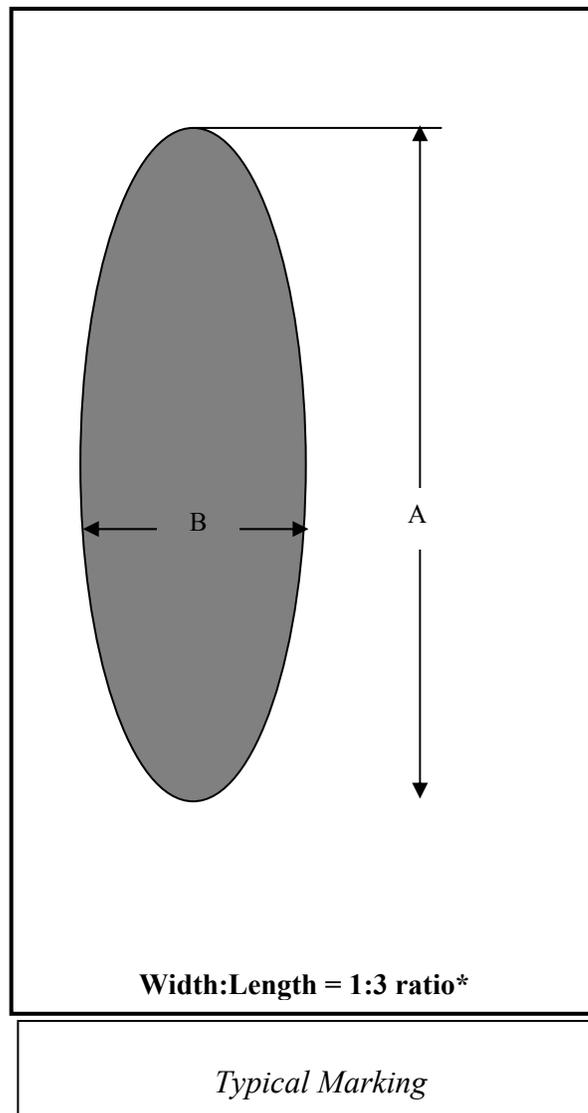
Pennsylvania has a safety initiative program which is directed at reducing crashes and lowering fatalities by 5% in 2002 and 10% in 2005 statewide [64]. As part of this program, they have been experimenting with “DOTs”, which are white spots marked at regular intervals on a segment of freeway. They are spaced so that traffic moving at the speed limit needs to keep a space of two dots from the car ahead to maintain an adequate clearance. The concept is similar to the chevrons used on European roads [64]. The dots are being evaluated in 4 locations in Pennsylvania, selected for having higher than average numbers of tailgating or aggressive driving accidents but where congestion is not anticipated [65]. Each installation is accompanied by “Don’t Tailgate” and “Maintain Safe Following Distance” signs 1000 ft (304.8 m) before and after the dots. Each installation consists of 11 dots per lane spaced 145 feet apart for a 55 mph (88.55 kph) road, as shown in Figure 56. The total average cost an installation at a site in South Centre Township in Columbia County was \$1892. The installation was coupled to local media events and to local law enforcement programs. Similar media/signing/enforcement initiatives without DOTs show a 25% reduction in fatalities for 40% of the targeted segments. In the South Centre Township DOTs installation, crashes from November through March went from 34 in 1999-2000 to 12 in 2000-2001, a reduction of over 60%. The township has requested more of these installations [65].

These dots could be evaluated in rural sections of Ohio roads with heavy tailgating activity for potential more widespread adoption.



Figure 56. Pennsylvania's DOTs are installed to ensure vehicles maintain an adequate following distance [64].

A picture of a single DOT is shown in Figure 57 [66]. An overhead diagram of the full treatment is shown in Figure 58 [66], and written guidelines are reproduced in Figure 59 [67]. A table giving recommended dot spacing is given in Table 22 [68].



Alternative	A (ft, m)	B (ft, m)	Area (sq ft, sq m))
Two Lane Highway	7.5, 2.29 m	2.5, 0.76 m	14.71, 1.37
Interstate	12, 3.66 m	4, 1.22 m	37.68, 3.5

*Refer to Guidelines for more information

Figure 57. Diagram and measurements of a single dot in Pennsylvania's DOT tailgating treatment [66].

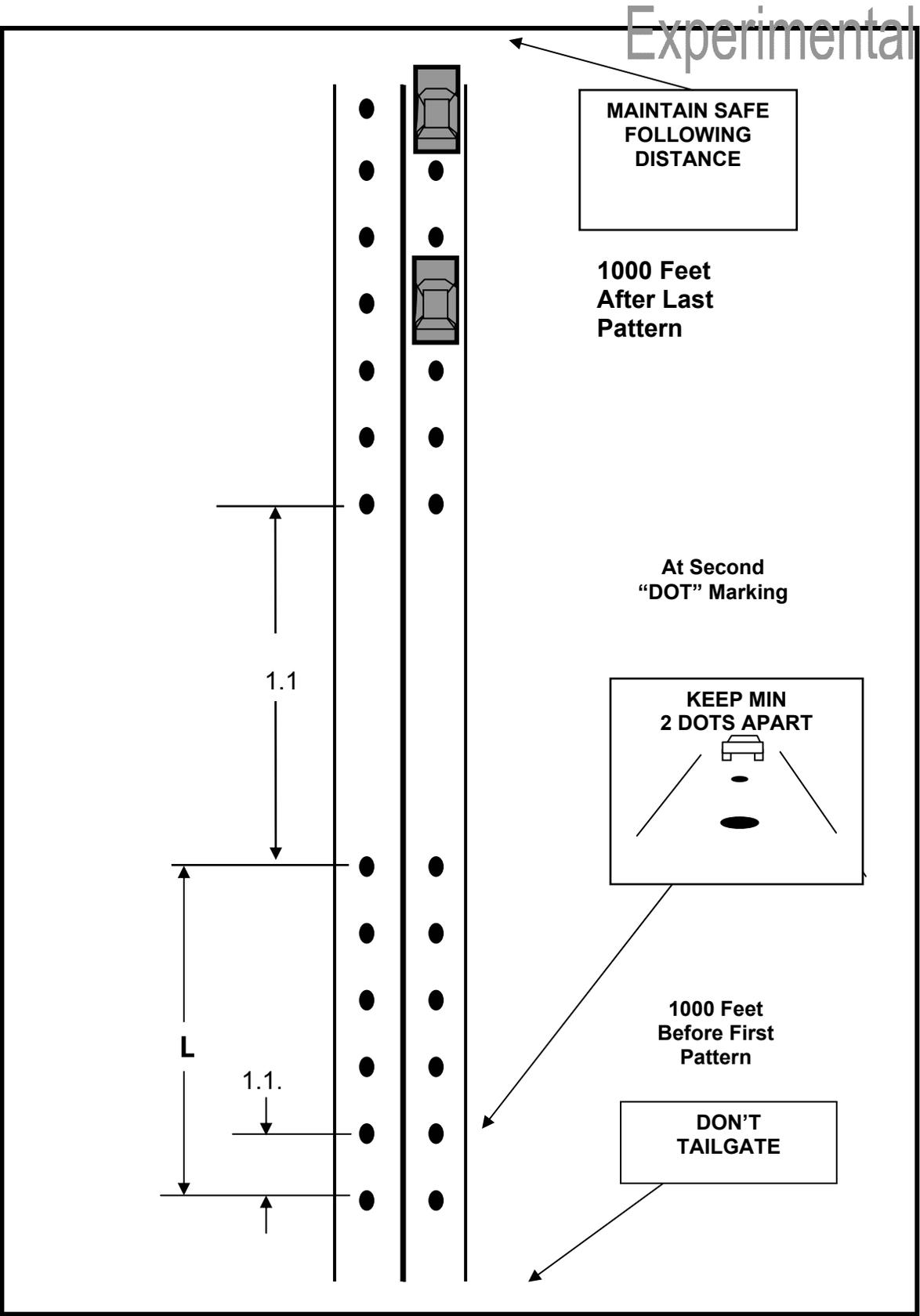


Figure 58. Schematic of Pennsylvania's DOT tailgating treatment [66].

Guidelines for installation of Pennsylvania “DOT” Tailgating Treatment

1. The “DOT” markings are shown to be effective for assisting the motorist in establishing safe following distance. Use this treatment in areas where there is a high concentration of aggressive driving or tailgating related crashes. Markings are spaced such that safe distance is kept between vehicles when a minimum of two markings separates them. Safe distance is defined based on a two second following rule. Areas with significant grade differences should generally be avoided.
2. **Marking** - The marking consists of a series of ellipses (DOTs) marked in all lanes at equal spacing according to the posted roadway speed (see Table 1, Spacing ‘S’). Marking is to be centered in the travel lane. The ratio of width to height for the elliptical mark is 1:3 based on standard oblong pavement markings referenced in the MUTCD. Markings should be applied according to Figure 1.
3. **Spacing** - The pavement markings should be placed such that the spacing is according to Table 1. Spacing is based on posted speed for any given roadway.
4. **Pattern Spacing** - The distance between successive series of “DOT”s is also based on posted speed and can be found in the Table 1. This distance should be adjusted as appropriate to meet field conditions.
5. **Signing** - There should be placed a minimum of three signs as follows:
 - “Don’t Tailgate” should be placed 1000 feet before the first pattern.
 - “Keep Min 2 Dots Apart” sign should be placed at the second marking in each set of DOTs.
 - “Maintain Safe Following distance” sign 1000 feet after the last pattern.

For signing layout, see Figure 3. Place signs in accordance with Sign Foreman’s Manual, Pub 108.
6. Refer to attached Specification for Epoxy Pavement Marking for selection of material and construction.
7. “DOT” pavement markings can be installed via projects initiated exclusively for this purpose.
8. Deviation from the above specifications and guidelines may be considered by Districts; however, they require approval by the Bureau of Highway Safety & Traffic Engineering prior to implementation.

Figure 59. Guidelines for Pennsylvania's DOT Treatment [67].

Table 22. Spacing guidelines for Pennsylvania's DOT treatment [67].

Pennsylvania "DOT" Tailgating Treatment

Comprehension
 Time : 5 sec
 P/R Time : 2.5 sec
 Adjustment
 Time : 20 sec
 Following Time
 : 2 sec
 Effective Time : 60 sec
 Vehicle
 Correction : 15 ft

Posted Speed (mph)	Posted Speed (kph)	Distance Traveled (ft, m)	S Marking Spacing (ft, m)	Minimum # Markings in Pattern	L Min Pattern Length (ft, m)	X Pattern Spacing (ft, m)
25	40	73, 22	60, 18	18	1020, 311	2200, 671
30	48	88, 27	75, 23	18	1275, 389	2640, 805
35	56	103, 31	90, 27	17	1440, 439	3080, 939
40	64	117, 36	105, 32	17	1680, 512	3520, 1073
45	72	132, 40	115, 35	17	1840, 561	3960, 1207
50	80	147, 45	130, 40	17	2080, 634	4400, 1341
55	88	161, 49	145, 44	17	2320, 707	4840, 1475
60	96	176, 54	160, 49	17	2560, 780	5280, 1609
65	104	191, 58	175, 53	16	2625, 800	5720, 1743

6.9 Pennsylvania Utility Pole Delineation

Another safety initiative used in Pennsylvania is to mark utility poles that are within the clearance area of a route with a band of 4 in (0.1 m) yellow high intensity retroreflective material, placed 4 feet above the road level, as shown in Figure 60. An example is illustrated in Figure 61. This is one part of a general method to remedying pole crashes. The decision tree, shown in Figure 62, begins with finding a location with enough pole crashes to warrant attention. If the lines can be buried, they are. If not, they are relocated if possible. If not, they are shielded with guardrails where possible. If not, then either the road is relocated or the poles delineated.

Utility poles are to be marked if they are within the required clear distance shown in Table 23, but not if they are already protected by a guardrail, on a high slope where they would not be hit, or in cases where the line of poles deviates from the road direction [68].

The system works by making the poles more visible at night. This delineation system is really a simple commonsense measure that could be implemented in Ohio whenever the state is ready. However it would need to be implemented consistently so that no pole that needs marking is left out.

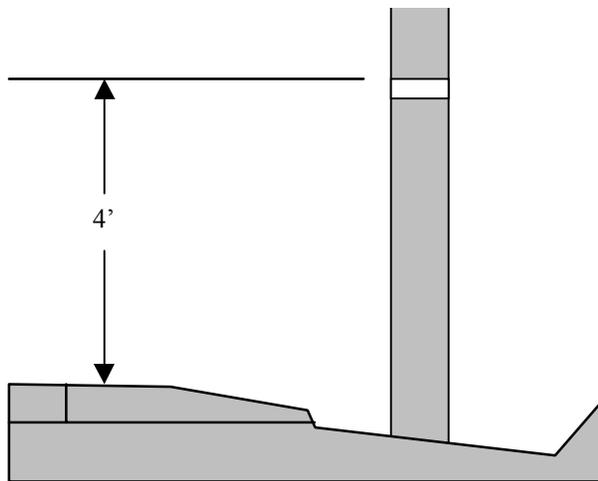


Figure 60. Sketch of utility pole delineation method used in Pennsylvania [68].



a)



b)

Figure 61. Utility pole delineation with 4" band of retroreflective material used in Pennsylvania[70]. a) daytime. b) nighttime.

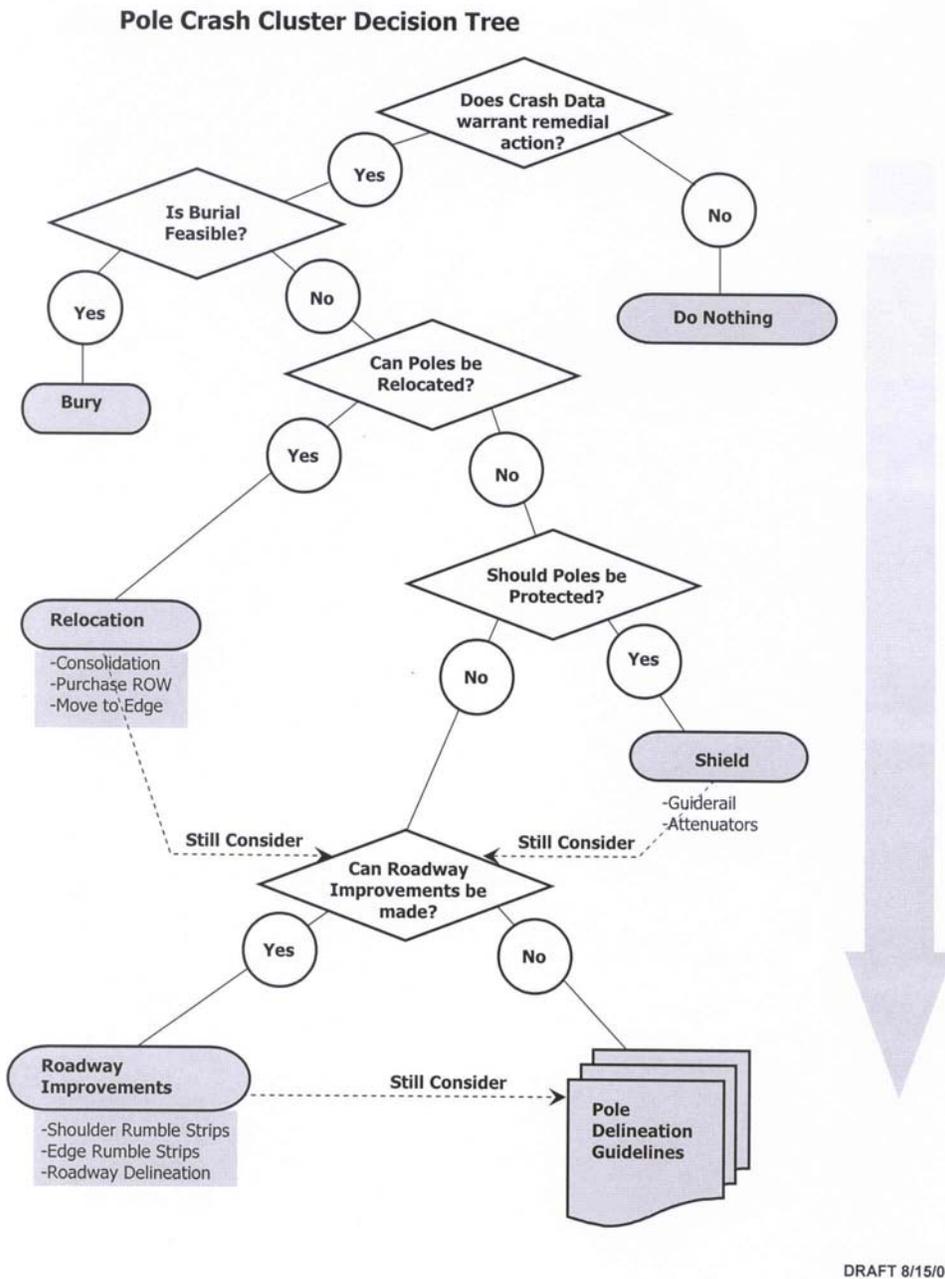


Figure 62. Pennsylvania Pole Crash Decision Tree [71].

Table 23. Required clear distance standards used in Pennsylvania [68]. Utility poles closer than this to the road may pose a hazard.

Posted Speed Limit	Required Clear Distance
≥ 50 mph (80 kph)	30 ft (9.14 m)
45 mph (72 kph)	22 ft (6.71 m)
≤ 40 mph (64 kph)	15 ft (4.57 m)

6.10 Pennsylvania Stop Intersection Gap Warning System

A third Pennsylvania low-cost safety measure being used on a pilot basis is to mark pavement with crosses and erect warning signs at approaches to a stop intersection to aid drivers in judging whether there is adequate clearance to make a turn. The system is depicted in Figure 63, and an overhead view is given in Figure 64 [70]. The size and placement of the markings depends on the posted speed, as shown in Table 24 [72]. The first sign is placed 80 feet (24.4 m) before the 7 second distance to the intersection, and the markings begin 80 feet before the 5 second distance. Dimensions of a single cross marking are shown in Figure 65 [73] and of the written legend are shown in Figure 66 [72].

It should be noted that as this is a pilot program, a full evaluation would need to be done before this treatment can be applied in Ohio.



Figure 63. Digitally enhanced photograph showing marking treatment for stop intersection approaches [70]. Note the crosses on the road surface in front of the car and the "Wait if vehicle in marked area" sign. Actual experimental treatment is given in Figure 64.

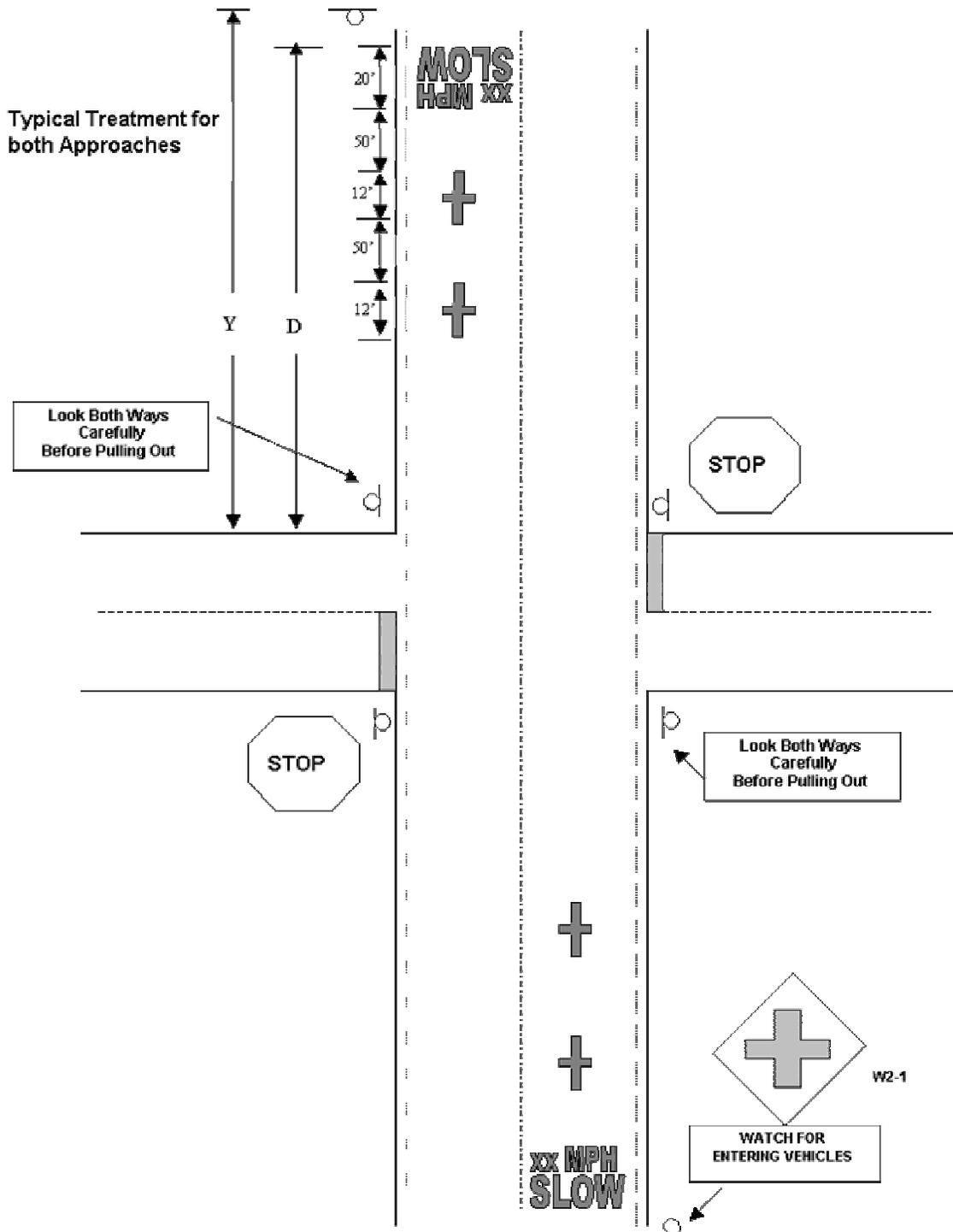


Figure 64. Overhead diagram of stop intersection gap warning system used in Pennsylvania [70].

Table 24. Distances for placing gap warning markings and signs in Figure 64 [72].

VV	D	Y
Posted Speed (mph, kph)	Pattern Length (ft, m)	Distance to Sign (ft, m)
25, 40	265, 81	340, 104
30, 48	300, 91	380, 116
35, 56	340, 104	450, 137
40, 64	375, 114	500, 152
45, 72	410, 125	550, 168
50, 80	450, 137	600, 183
55, 88	485, 148	650, 198
Posted speed	5 second distance + 80 feet	7 second distance + 80 feet

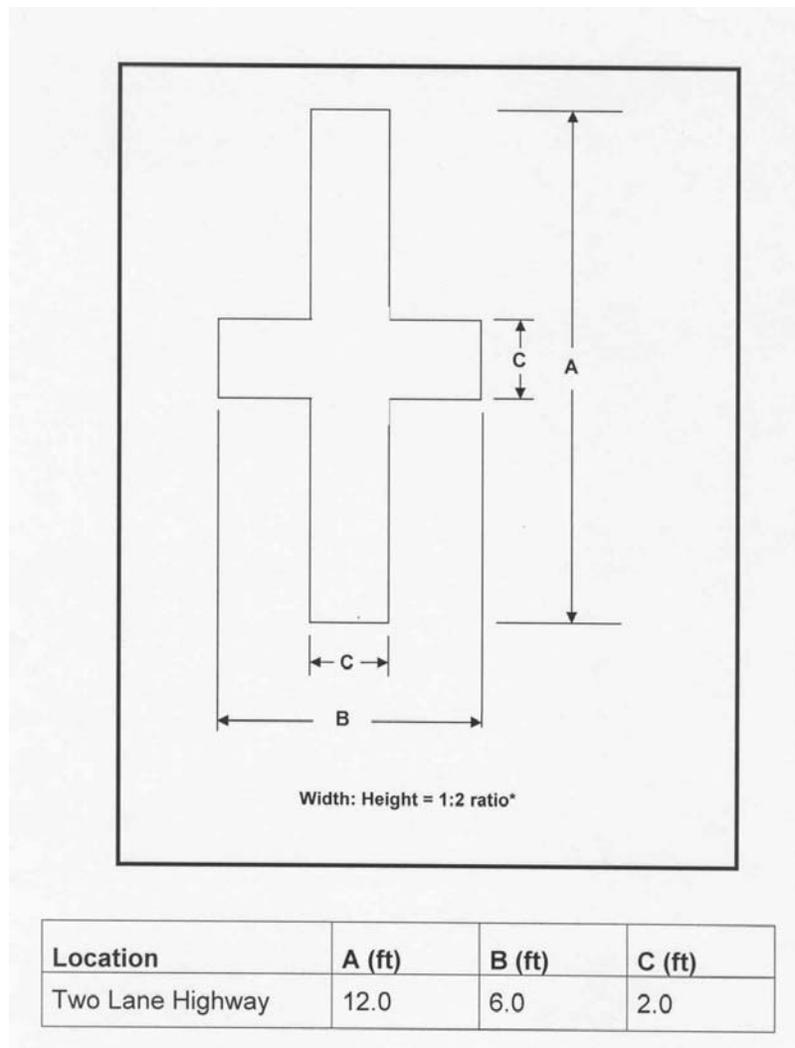


Figure 65. Drawing of one of the crosses used in the Pennsylvania stop intersection gap warning system [73].

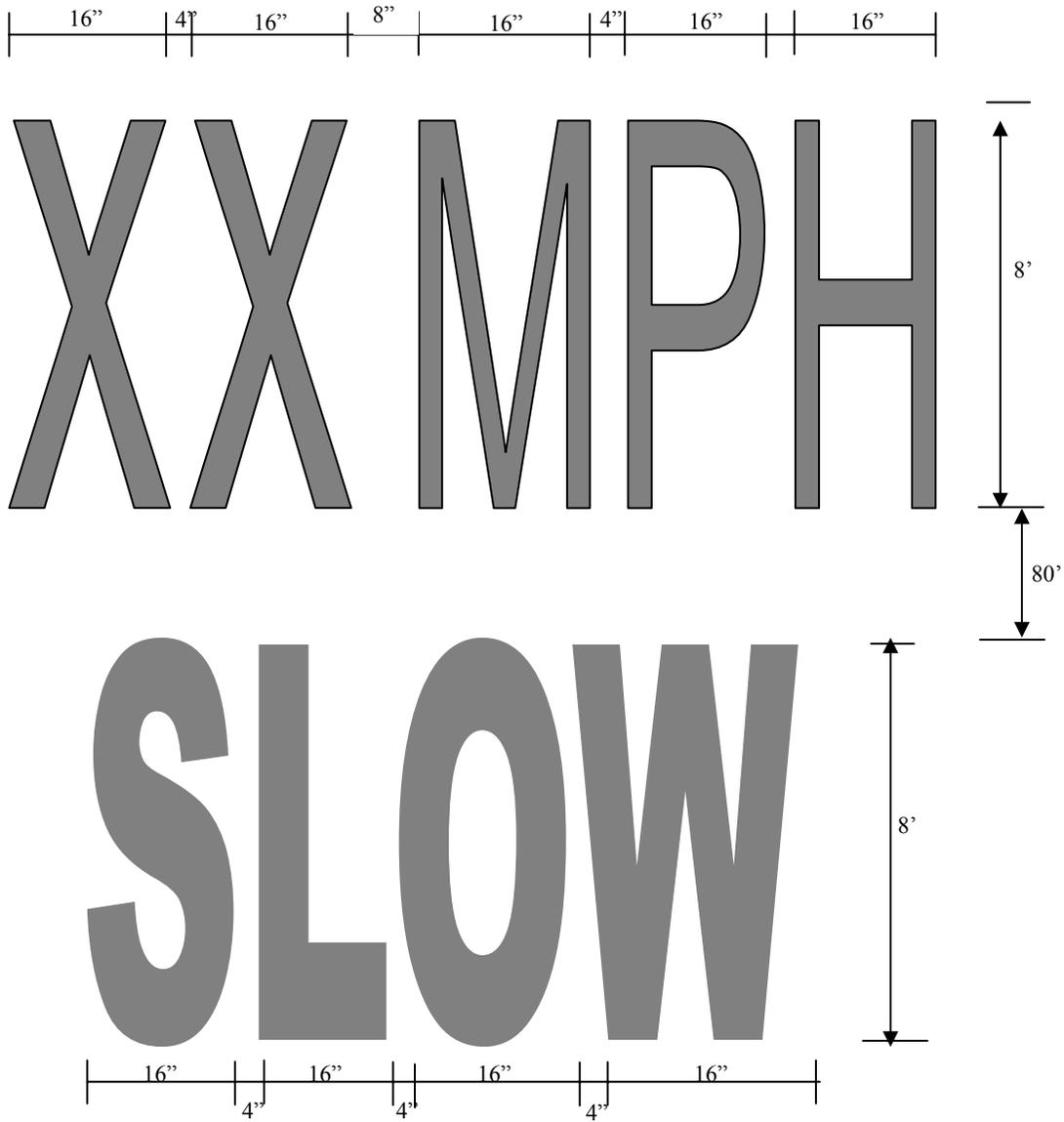


Figure 66. Legend for pavement markings in Pennsylvania Intersection Warning Treatment [73]. Dimensions are given but note that drawing is not to scale.

6.11 Deer-Vehicle Crash Mitigation

6.11.1 Deer Fences

Deer-vehicle crashes are increasing at alarming rates all over the country, including in Ohio. The best estimates indicate that there were 1.5 million deer-vehicle crashes nationwide in 2002, causing 150 human fatalities, 1.5 million deer fatalities, and \$1.1 billion in damages, according to a study reviewed by the Insurance Institute for Highway Safety (IIHS) [74]. The study looked at several possible countermeasures such as active, passive, and animated signs, deer whistles, in-vehicle warning systems, lowered speed limits, roadside reflectors, increasing lighting, adding road clearance, public education (e.g. Iowa's "Don't Veer for Deer" campaign [75]), and deer fences with overpasses, underpasses, or at-grade deer crosswalks. Fences combined with overpasses and/or underpasses for deer were the only method proven to be effective. Promising but untested methods included herd reduction, roadside clearing, temporary signs (active or passive), and deer detection systems in vehicles. Deer crosswalks may be useful with mule deer in Western states that follow well-defined migration paths, but not white-tail deer in Ohio. The other methods have either limited or no effect. A similar study by the Deer-Vehicle Crash Information Clearinghouse (<http://www.deercrash.com>) at the University of Wisconsin reached similar conclusions [76].

A fence height of 2.4 m (7.8 ft) was found effective, while 2.2 m (7.4 ft) was not [74]. Chain-link fencing can be expensive to build and maintain, costing about \$42,000 per mile to build in Iowa. Plastic fencing material costs under \$300 for 330 feet (100.58 m), and electric fences are also manufactured [77] and are being evaluated in Michigan as an alternative to chain-link fencing. An extensive review of deer fencing studies is available via the Deer-Vehicle Crash Information Clearinghouse [78].

Deer fencing can be implemented whenever the state wants. One precaution is that at the ends of long fences there may be increased deer traffic by deer crossing the road. One study reviewed in [74] noted that by increasing fence length from 6.7 miles (10.78 km) to 7.8 miles (12.55 km) substantially reduced end runs by deer. One-way gates can also be installed to give deer that do manage to enter the roadway area an escape route out. Fencing works best when deer movements are studied and taken into account, thus underpasses or overpasses at selected locations are desirable, despite their considerable cost.

6.11.2 Deer Crosswalks

Unfortunately, erecting fencing does not keep deer from wanting to cross the road, and fences may actually just transfer the problem rather than reduce it. Utah has experimented with combining fencing with deer crosswalks [79]. Crosswalks represent a cheaper option than animal overpasses or underpasses, which have also been used in some locations, particularly in Europe. A crosswalk is installed at a gap in fencing where the fence is about 1m high, which deer can easily jump but which blocks most small animals. Overhead schematics of deer crosswalks are shown in Figure 67. Once the deer crosses over the short fence, it enters a funnel defined by more of the 2.3m (7.55 ft) fence used to keep deer off other sections of the highway and planted vegetation. At the mouth of the funnel 30 ft (9.1 m) from the highway, there begins a narrow path with unfriendly cobblestones laid to either side. The stones mark the edge of the path for the deer. At the highway, there are painted cattle guard lines to mark the path to the tip of a second funnel at the other side of the road which leads towards the land

on the other side of the deer fence on that side of the road. The painted cattle-guard lines mark a path for the deer and indicate to motorists where the deer are to be expected. However it appears that deer can still cross these markings and get off the path. Perhaps conventional cattle gate style installations can be used to keep deer on the path, assuming that a model exists that can be driven over at highway speeds.

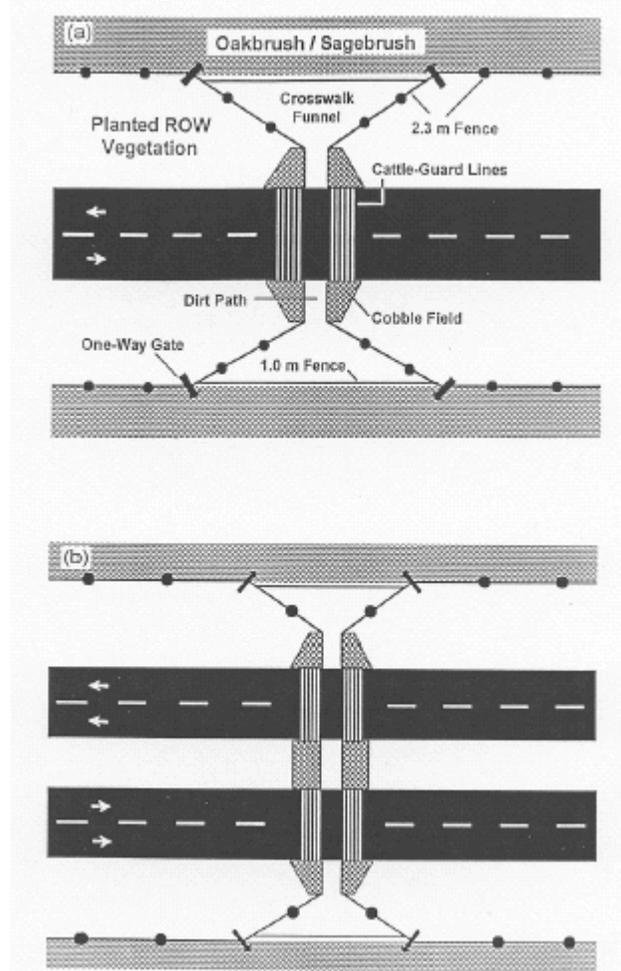


Figure 67. Deer crosswalks as installed in Utah on a) two-lane highways and b) four-lane divided highways [79].

6.11.3 Deer Reflectors

The Streiter Corporation makes Streiter-Lite roadside reflectors that reflect and scatter light from approaching vehicles and frighten deer from approaching the roadway until the traffic has passed. A study by Robert H. Greiner commissioned by the company indicated that the Streiter-Lite installations reduced deer-vehicle crashes by 78-90% [80]. This result was obtained by studying number of accidents per mile per year before and after installation at 53 sites using a Wilcoxon matched-pairs signed-rank test to determine whether the reduction in crashes was statistically significant, which it was to a very large degree ($p=0$ was cited in the report; $p=0.0625$ for a small subsample of 4 sites in Washington state).

This was one of the alternative methods studied in the IIHS report [74]. The IIHS study reviews several studies and finds conflicting results. Some studies show a similar 70-90% decline in deer-vehicle crashes, while others show little reduction. Some researchers claim that the effectiveness of the reflectors decreases over time as deer become accustomed to them – one study found that about 99% of deer fled low-intensity lights on the first night after a reflector installation, but by 15 days later 40% of the deer did not react even to higher-intensity reflected beams. It may be that there are some tricky points of the installation that are not fully considered, meaning that some ineffective installations were actually improper. Or it may be that the designs of some of the studies were flawed. Or perhaps the reflectors themselves don't work or only certain kinds work.

It may be worth further evaluating this technology as the cost of reflector installations is considerably less than fence installations, about \$8,000-\$10,000 per mile for reflectors, plus maintenance to replace missing or damaged reflectors [74]. The Streiter-Lite system costs about \$2700-\$3590 per mile, \$6000-\$9000 with installation costs, and lasts 12 years [81]. This method also has the advantage of allowing deer to cross the road when there is no traffic. The IIHS study also noted that these devices have been in existence for 30 years and have been used in 22 states.

6.12 Wrong Way Pavement Arrows

One way to reinforce wrong way messages in addition to “Do Not Enter” and “Wrong Way” signs is to use half-size pavement arrows indicating the proper direction of travel. The virtues of using two half-size arrows instead of one full-size arrow are discussed elsewhere in a separate report on half-size arrows. The arrows would serve as an additional alert that drivers are going in the wrong direction. They could be placed on entrance and exit ramps and other junction areas where vehicles can enter in the wrong direction. These arrows would present no problems with distracting drivers heading in the correct direction, but will need to be evaluated to assess their effectiveness at preventing wrong-way traffic on freeways.

6.13 X-Boxes for railroad crossings

Sanders and Long report on “X-box” pavement markings used when there is a short distance between a signalized intersection and a railroad crossing, where traffic may back up past the railway during a red phase [82]. An X-box is a rectangular box with two crossed diagonals placed on the road just beyond the railroad tracks on the approach to the intersection, as seen in Figure 68. The box is about one car length, and a driver may use the box to gauge if there is enough space to move across the tracks to wait for the signal. Similar markings have been used in many places in Europe, though they have not been evaluated for effectiveness. The box is 25 feet (7.62 m) long, which is long enough to accommodate most passenger cars; drivers of buses and large trucks are presumed to be professionals with better capacity to judge space available. The closest edge of the box is 10 feet (3.05 m) from the nearest track. The authors tested these markings at one urban and one rural location in Florida for one and a half years. A before and after study of hazardous stopping rates revealed that the rural location saw a 42% reduction in stopping on the tracks, which became a 60% reduction after seven months. Stopping on or near the tracks declined by 36-39%. The urban site did not experience such a significant reduction, instead one lane saw a reduction in stoppage on the

tracks of 72%, while another lane saw a reduction of only 6%. The authors conclude that X-box markings are beneficial in rural applications where the driver information load is lower and there are fewer other signs. In urban areas with greater clutter and denser traffic, the X-boxes may not be of great value, but they did no harm, either. The X-boxes may prove more effective if the driving public becomes more aware of their purpose. One noted source of possible confusion is with spaces in parking lots with an X marked in them where cars are allowed to park.



Figure 68. X-box marking between a railroad track and signalized intersection. From [82].

6.14 Mitigating Accidents Involving Pedestrians and Bicycles

Various measures can be adopted to reduce the incidence of accidents involving pedestrians and bicycles.

6.14.1 Using an island for pedestrians in crosswalks:

Having a center island in the middle of a crosswalk provides a platform for pedestrians to wait until traffic in the opposite direction has cleared. When such an island is provided pedestrians do not have to cross both the lanes at once, but can cross one lane and wait until the traffic in the next lane is cleared to walk across. The island could simply be marked with paint or can be a raised concrete platform that is 5-6 in (0.13-0.15 m) high. Some examples are shown in Figure 69.

Such a pedestrian island was created, in addition to increased signage, in one of the streets running through Ohio University after an accident in which a student pedestrian was seriously injured [86]



(a) In England [83]



(b) In University Place, WA [84]

Figure 69. Islands for Pedestrians

6.14.2 In-pavement Lights to Increase Visibility of Crosswalks

In-pavement lights and roving or animated eyes are also being used at crosswalks to alert motorists to the presence of pedestrian crossings. The in-pavement amber lights are embedded in the crosswalk and are activated when the pedestrian pushes the button or through an automated detection device. The driver is alerted by these flashing amber lights that are directed towards oncoming traffic. Such lighting would be useful, particularly in rural roads and other situations where the visibility is low. An example is shown in Figure 70. Such systems are currently being used in Kirkland, Washington [84]. However, it must be noted that such an installation costs between \$25000 and \$35000.



Figure 70: In-pavement Lights [84]

6.14.3 Bicycle Lanes

Separate lanes for use by bicyclists in situations where there is a high amount of bicycle traffic can help reduce the accidents involving motorists and bicycles. Such bicycle lanes are widely used in Europe and in some cities in the United States as well. The most commonly used method is to demarcate the bicycle lane with pavement marking materials, such as shown in Figure 71(a), (b), and (c). Studies conducted in Sweden, Denmark, and England [85] have revealed that when colored pavements, such as shown in Figure 71(d), are used they are easily seen by drivers and help reduce the conflicts in identifying the correct lane and thereby avoiding bicycle-vehicle collisions.



(a) Switzerland

(b) The Netherlands



(c) Portland, OR



(d) Copenhagen, Denmark

Figure 71: Different Methods used to Demarcate Bicycle Lanes

6.15 Recommendations to ODOT

Based on the analysis of literature and practices of other states and countries, the following recommendations can be made to ODOT to reduce the incidence of accidents on Ohio's road system.

- Use tailgating 'DOTs', such as those used by PennDOT to encourage drivers to keep the required distance with the vehicle ahead and maintain adequate clearance. They could be evaluated in road sections with heavy tailgating for potential implementation statewide later.
- Delineation of utility poles to ensure they are more visible at night. This is a commonsense measure that can be implemented statewide but, must be adopted consistently so that no pole that needs marking is left out.
- A stop intersection gap warning system can be applied at intersections to aid drivers in judging whether there is adequate clearance to go past the intersection. Since this is only a pilot program, further evaluation is required before it can be implemented in Ohio.
- Use half-size pavement arrows to indicate proper direction of travel to motorists. This will reduce the number of motorists traveling in the wrong direction on highways and will help reduce the number of accidents.
- Use X-boxes to inform drivers of railroad crossings when there is a short distance between a signalized intersection and the crossing.
- Use pedestrian islands in crosswalks so pedestrians can cross traffic flowing in one direction at a time. Separate bicycle lanes can be demarcated in areas where there is high bicycle traffic.
- In addition to the above, the following general practices can be adopted to make Ohio's roads more safer to the driving public.
 - Realign roads to increase vertical sight distance and improve horizontal alignment to meet or exceed the requirements and policies described in Traffic Engineering Handbook [89] when the roads are being re-paved.
 - Replace signalized intersections with roundabouts whenever possible. When roundabouts can not be used construct shifted intersections to reduce the incidence of accidents
 - Improve signing in general (more redundant signing, larger signs, higher retroreflectivity, etc.) and on arterial roads leading to interstates. Also diagrammatic road signs can be used on arterial roads to make proper lane selection easier for drivers.
 - Provide drivers with lane information at the earliest possible time to allow more time for decision making and to make switching/changing lanes easier.
 - Increase the use of retroreflective materials system wide. Zwahlen et al. [47] found that Type VII reflective sheeting is best for use when increased nighttime legibility is required from a longer distance. Based on photometric evaluation they concluded that for guide signs either white Type VII or Type IX legends on

green beaded Type III backgrounds provide adequate appearance, conspicuity, and legibility.

- In collaboration with the Department of Public Safety conduct programs to educate and update all motorists periodically on traffic signs, traffic control devices, and traffic rules. This can be done for example by having TV spots designed to educate drivers or distributing pamphlets that has the relevant information at the time driver licenses are renewed.
- Provide more efficient and timely winter maintenance services. For example, applying brine treatments just before winter storms can help reduce accidents when the storm strikes.
- Make law enforcement personnel more visible to drivers during the day/night time. The dark grey clothing worn by highway patrol officers is difficult to see at night and can be made more conspicuous through the use of fluorescent colors and retroreflective materials. E.g.: by wearing a yellow band on the sleeve
- Increase the conspicuity of road maintenance workers and equipment
- Older drivers usually have degraded visual capabilities and this must be accommodated for when designing traffic control devices. Therefore use better and more conspicuous signing e.g.: larger legends, symbols, fluorescent materials etc can be used.

6.16 Recommended evaluations

Further evaluations must be carried out before some of the above recommendations can be adopted.

- Evaluate the use of ‘DOTs’ in rural sections of Ohio roads which have high tailgating traffic to study their effectiveness in reducing tailgating. If found effective ODOT could consider widespread implementation.
- The stop intersection gap warning system has only been tested through a pilot program and will need to be further evaluated if ODOT is interested in implementing the strategy.
- There is only a single study that has evaluated the effectiveness of X-box pavement markings at railroad crossings. The size of the X-box used and the distance between the nearest track and the box are some issues that must be resolved before implementation.

More information regarding accident mitigation can be found in section 15 and 16 of this report.

7 ACCOMODATING OLDER DRIVERS

The number of Americans 65 years of age and older is expected to double between 2000 and 2030. Americans are living longer and driving longer. Together these trends suggest that the number of older drivers killed on U.S. streets and highways will grow. Drivers in the three older age categories, compared with drivers aged 55–64, were found to be more likely to die in injury crashes: drivers 65+ years of age were 1.78 times as likely to die, 75+ years of age were 2.59 times as likely to die and, 85+ years of age were 3.72 times as likely to die [87]. Figure 72 shows the fatality rate per 100 million vehicle miles traveled compared to the driver age groups. The most common crash type that older drivers are involved in is the intersection and crossing-path situation, where older drivers must make complex maneuvers and decisions as they interact with opposing traffic [88].

According to the Traffic Engineering Handbook the limitations and most common deficiencies of older drivers were due to failing sensory and information processing capacities [89]. This resulted in an increase in reaction time, decreases in both static and dynamic visual acuity, decrease in color perception, increased glare sensitivity and longer glare recovery time, poor contrast sensitivity, reduced night vision, slower eye movements, reduced peripheral field, reduced movements and force, and reduced other sensory modalities such as hearing.

The driver fatality rates for 1996 as reported by the National Highway Traffic Safety Administration [90] are shown in Figure 72 below. A steady increase can be observed for categories in age range 60+ years.

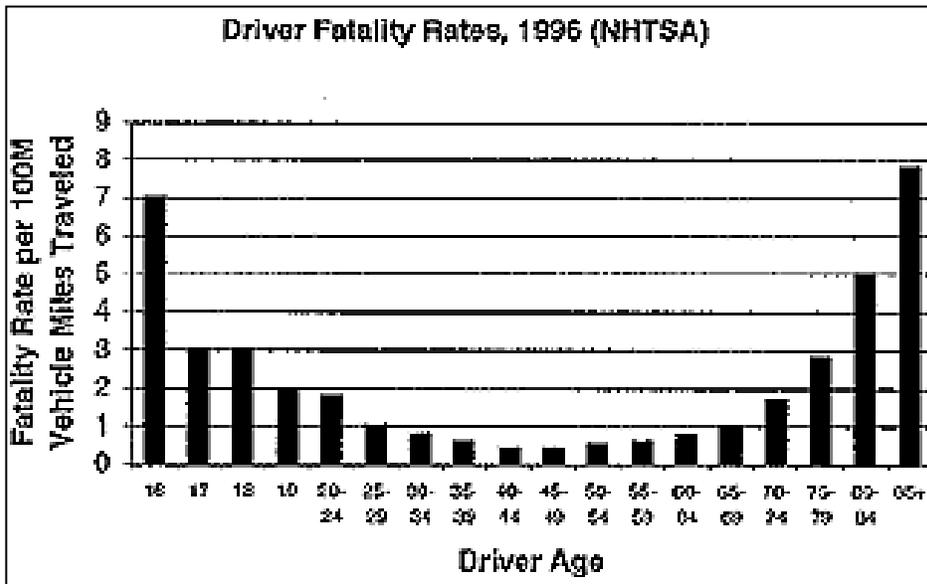


Figure 72: Driver Fatality Rates for 1996

In a study conducted by Burkhardt et al. [91], the projection of fatalities involving older drivers in the United States between 1995 and 2030 is given. Figure 73 shows the projection of fatalities involving older drivers (65 and older). With the increasing number of older driver population in traffic, the number of crashes involving older drivers will grow, and since the physical vulnerability increases by age the number of serious injuries and fatalities among older drivers will increase.

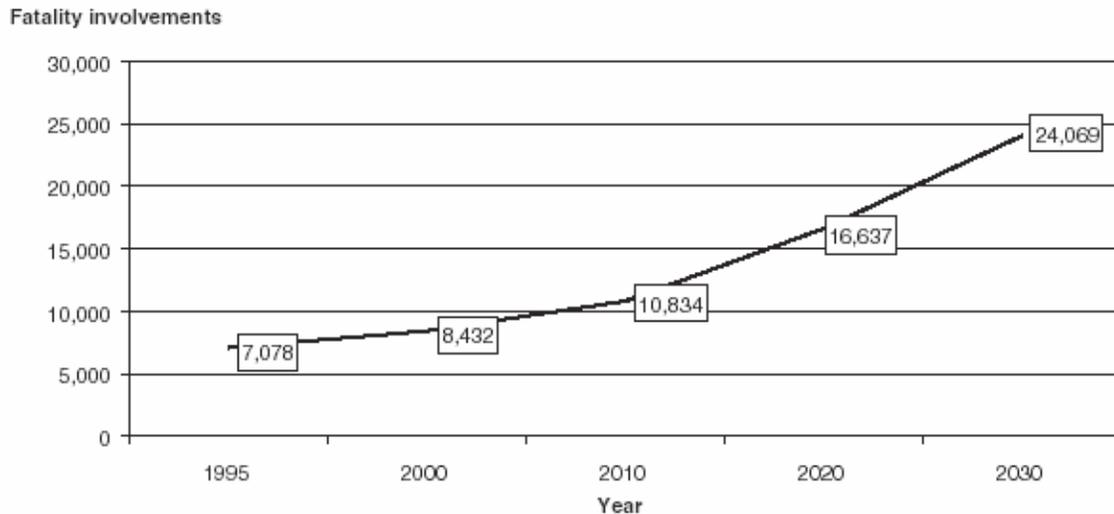


Figure 73. Projection of Fatalities Involving Older Drivers in the United States, 1995-2030 [adapted from Burkhardt et al. (91)].

In a survey conducted by Alicandri [92], older driver freeway needs and capabilities are investigated. Nearly 1400 members of the American Association of Retired Persons were surveyed from 39 states; their mean age was 72.2 years.

- About one-quarter of the drivers indicated that they avoided freeways, with no differences between the younger and older drivers. The most common reasons for avoiding freeways included heavy traffic, high travel speeds, trucks, difficulties merging or changing lanes, and a preference for a more leisurely/scenic route.
- More than half of the survey respondents indicated that they drove less at night, during rush hour, and in snowy or foggy weather.
- Eleven percent of the respondents indicated that signs on the freeway were too small and 20 percent said signs were not bright enough.
- Three-quarters of the drivers indicated a preference for overhead signs as opposed to shoulder-mounted signs. They also preferred signs that indicated distances to several (as opposed to one) approaching exits. About half of the drivers indicated that sign messages (words and symbols) were either “sometimes” or “often” confusing.
- Lane-changing is difficult for older drivers. They indicated that they sometimes (60 percent) or frequently (17 percent) slowed down and followed a slower vehicle rather than pass it. They also never (17 percent) or almost never (23 percent) passed a slow-moving vehicle in the fast lane.

- Almost half of the drivers indicated that they either occasionally (45 percent) or often (3 percent) became fatigued while driving. Older drivers indicated that they sometimes (42 percent) or often (32 percent) used rest areas.
- Toll plazas created difficulties for some older drivers.
- Headlight glare from oncoming and following vehicles caused problems for half of the drivers.
- About a fifth of the drivers reported problems around construction zones.
- Drivers reported that they had problems staying in their lane because of worn or faded lane markings (56 percent), barriers or construction (25 percent), and large trucks (24 percent).
- Almost three-quarters of the drivers indicated that more lighting was needed at exit ramps (45 percent), rest stops (37 percent), construction areas (31 percent), and interchanges (26 percent).
- Drivers indicated that many highway features “help a lot,” including painted lane lines (90 percent), raised pavement markers (RPMs) (78 percent), guardrails (68 percent), post-mounted reflectors (68 percent), and rumble strips (50 percent).
- Some drivers had difficulties entering and exiting freeways: 25 percent said they actually stop before merging into traffic and 52 percent slow down before reaching the exit lane.

7.1 Older Driver Countermeasures

7.1.1 Increasing Sign Visibility

Advanced age, in combination with the requirement an acceptable “true” preview time (PT) of 3.0s, requires fairly large letter-heights to achieve adequate legibility performance (Figure 74). It is also observed that higher background luminance values help considerably to reduce the minimum required letter or numeral heights [93].

More information regarding larger and better-illuminated signs is given in section 15.1.6 of this report. Specific recommendations regarding size and retroreflectivity increases cannot be made without first conducting an evaluation and considering the cost/benefit ratios of such increases.

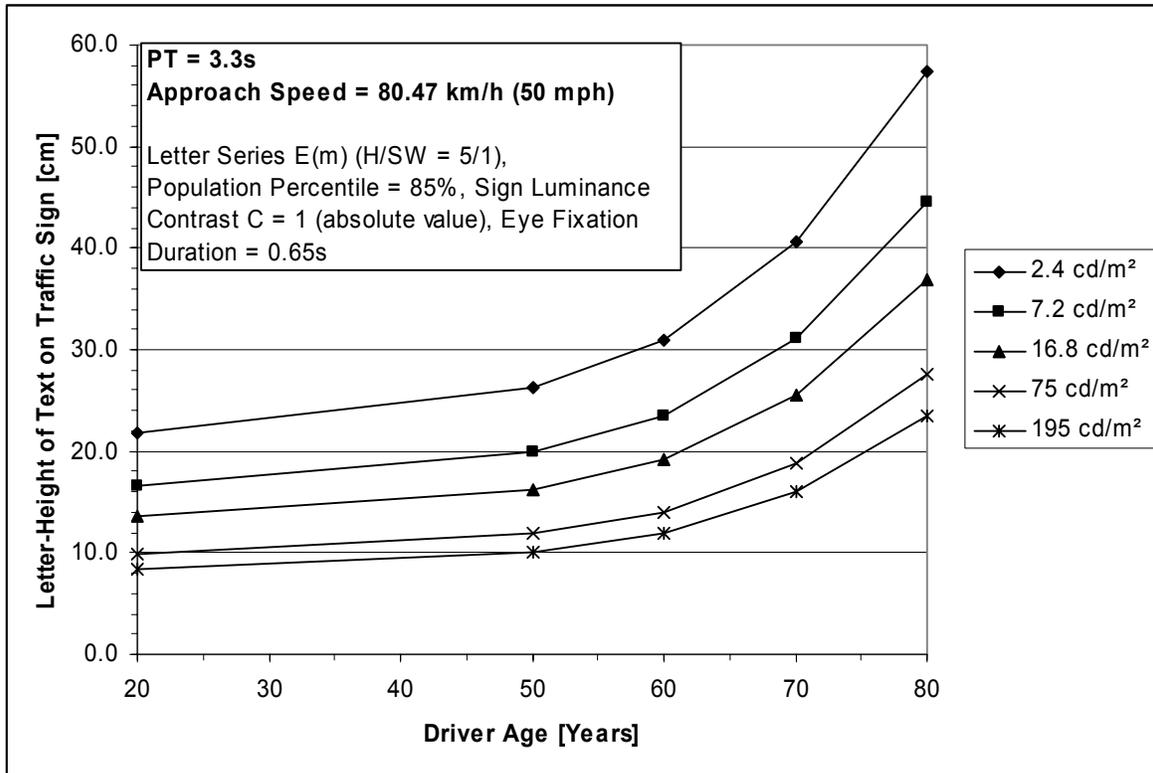


Figure 74: Minimum Letter Height Required on Traffic Signs as a Function of Driver Age [93]

Age in combination with an acceptable minimum “true” PT of 3.0s requires fairly bright pavement markings to achieve the required visibility distances, and therefore fairly high coefficients of retroreflected luminance [$\text{mcd}/\text{m}^2/\text{lx}$], especially at higher speed values (Figure 75). It should be noted that recently introduced pavement marking materials (adhesive pavement marking tape, new liquid applied pavement markings) are close to meeting or actually meet the “true” PT of 3.0s requirement even for older drivers and also possibly under wet nighttime low-beam driving conditions.

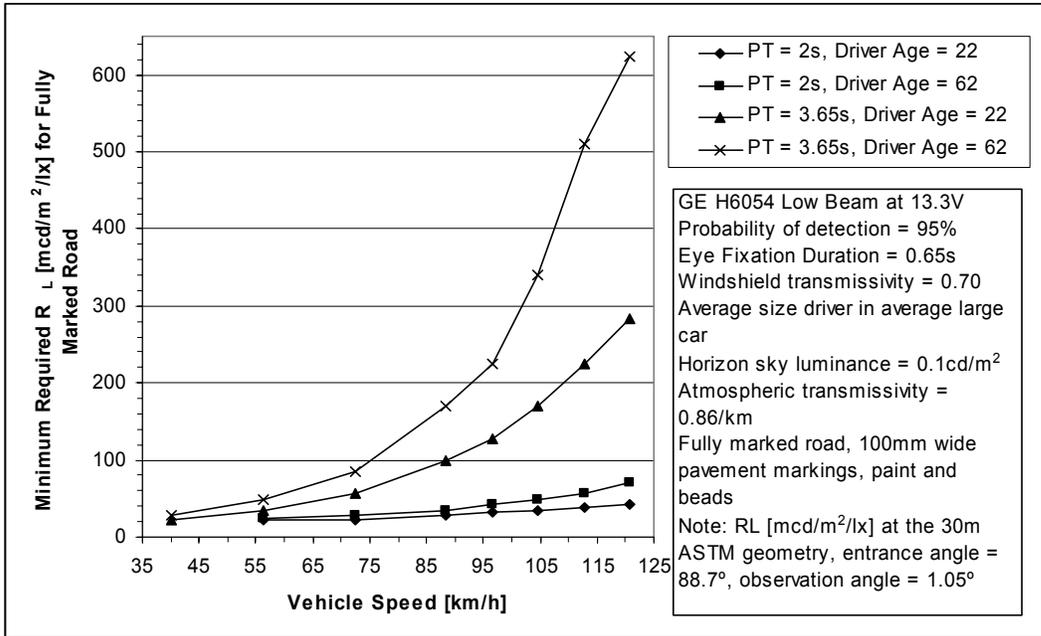


Figure 75: Minimum Required Retroreflected Luminance as a Function of Vehicle Speed [93]

The daytime legibility distance of different sign types as a function of driver age as reported by Dewar et al [94] is shown in Figure 76 below. One-way ANOVA on each type of sign showed a significant increase in legibility distances with increased driver age for warning, guide, regulatory, and recreational/cultural signs, but not for the school signs.

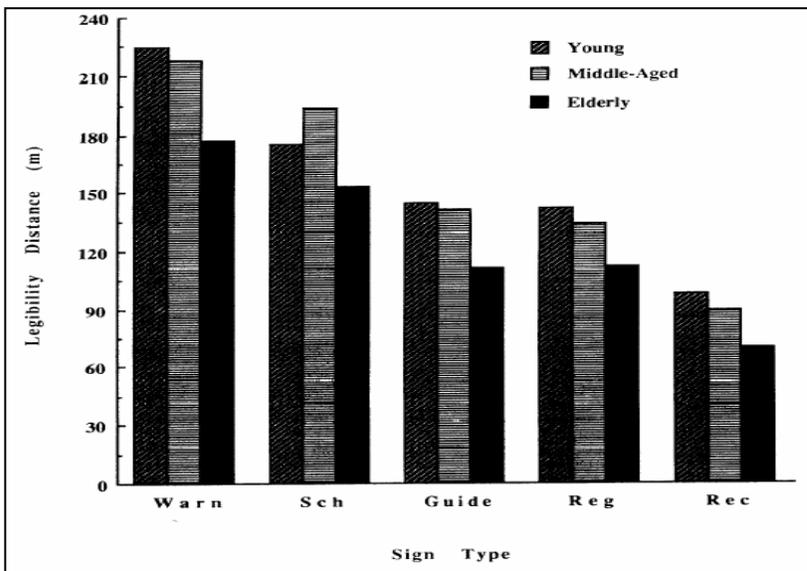


Figure 76: Legibility Distance for Different Sign Types for Daytime Legibility (adapted from [94])

The mean nighttime legibility distances of different sign types as a function of driver age are shown in Figure 77 [94]. Driver age was closely related to legibility distance for all three types of signs (Best, Intermediate, and Worst), with the legibility distances for the older drivers being about half those observed for the young drivers.

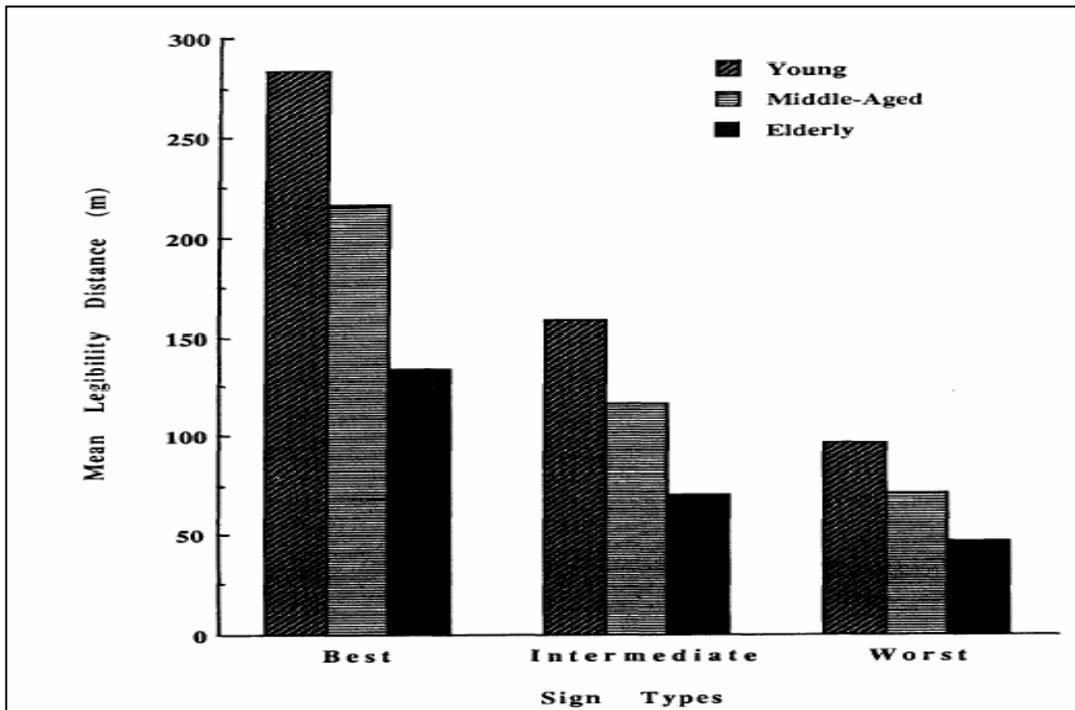


Figure 77: Legibility Distance for Different Sign Types for Nighttime Legibility (adapted from [94])

In the Transportation Research Board Safe Mobility for Older Persons Committee Newsletter, findings from a recent study by American Association of State Highway and Transportation Officials (AASHTO) are discussed [95]. In this study the researchers conducted telephone interviews with representatives of the transportation planning staffs of 10 State Department of Transportations (DOTs) and 9 Metropolitan Planning Organizations (MPOs) to evaluate how the transportation planning responds to the particular needs of seniors.

The interview included a set of 14 questions. Among the state DOTs the highest rated programs included more visible and easily readable road signage, and driver licensing programs for older drivers. Driver retraining programs and alternative transportation systems for older drivers were given the lowest ratings in the interviews

7.1.2 Longitudinal Pavement Markings

Pietrucha et al [96] conducted a series of engineering studies to evaluate the efficacy of available retroreflective treatments for improving the nighttime lane visibility distance of older drivers. On the basis of a review of the literature and a preliminary simulation-based study, they identified 11 treatment combinations that showed potential for improving the nighttime visibility of older drivers without negatively affecting the performance of young drivers. Treatment combinations are listed in Table 25.

Table 25. Delineation Treatments in Field Study on Age Differences in Nighttime Visibility Distance (adapted from [96])

No.	Treatment Description	Grade	Relative Cost
1	4-in. yellow centerline (baseline control)	F	—
2	4-in. yellow centerline and a 4-in. high-brightness white “profiled” edge line	F	—
3	4-in. yellow centerline with widely spaced yellow RPMs	F	—
4	4-in. yellow centerline with widely spaced yellow RPMs and widely spaced white edge line RPMs	F	—
5	4-in. yellow centerline with high-intensity chevrons at standard height and spacing	B	1.15
6	4-in. yellow centerline, 4-in. white edge line, and high-intensity chevrons at standard height and spacing	A	1.52
7	4-in. yellow centerline and standard flat post delineators at standard spacing	C	1.63
8	4-in. yellow centerline, white edge line, and standard post delineators	C	2.00
9	4-in. yellow centerline and fully retroreflectorized flat post delineators at standard spacing	A	1.05
10	4-in. yellow centerline and high-intensity T-post delineators at standard spacing	A	1.00
11	4-in. yellow centerline with yellow RPMs at standard spacing and high-intensity T-post delineators at standard spacing	A	2.72
12	4-in. yellow centerline, 4-in. white edge line and engineering-grade T-post delineators at standard spacing	A	2.03

— = cost was not calculated for treatments receiving a failing grade. 4 in. = 10.16 cm.

The study showed that six treatments resulted in the greatest curve recognition distances and statistically were indistinguishable from one another. Their recognition distances are shown in Figure 78. Each of these six treatments afforded a visibility distance that exceeded the 5 second driver preview criterion established by Rumar and Marsh.

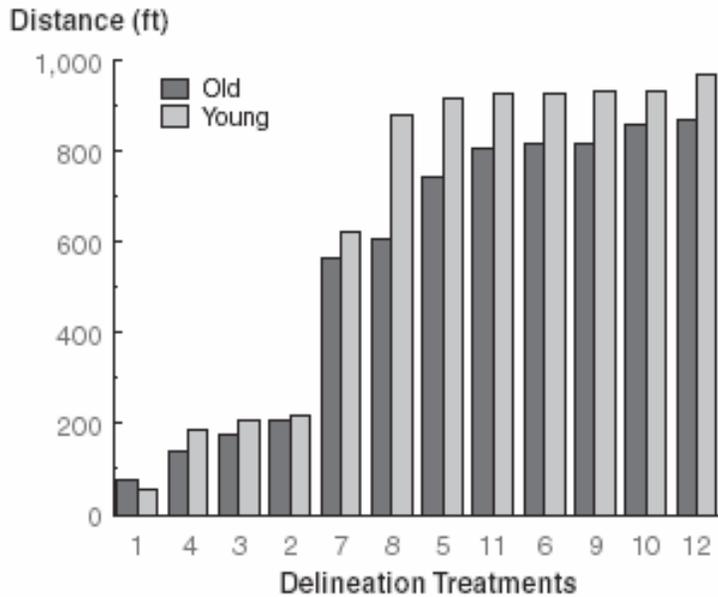


Figure 78. Visibility Distance of Nighttime Delineation Treatments as Function of Age (adapted from [96])

In a study conducted by the Texas Transportation Institute, the effectiveness of the use of wider pavement markings is analyzed [97]. Based on a review of the technical literature and agency survey responses, wider markings provide improved long-range detection under nighttime driving conditions (older drivers benefit the most), improved stimulation of peripheral vision, improved lane positioning and other driver performance measures and, improved driver comfort.

Mostly due to increased amounts of materials used, wider markings cost more to implement than 4-inch (0.1016 m) markings. Increased cost was the only drawback cited by agencies and is dependent on marking width, contract size, materials used and striping procedure. The use of different sized pavement markings by the various states is shown in Figure 79.

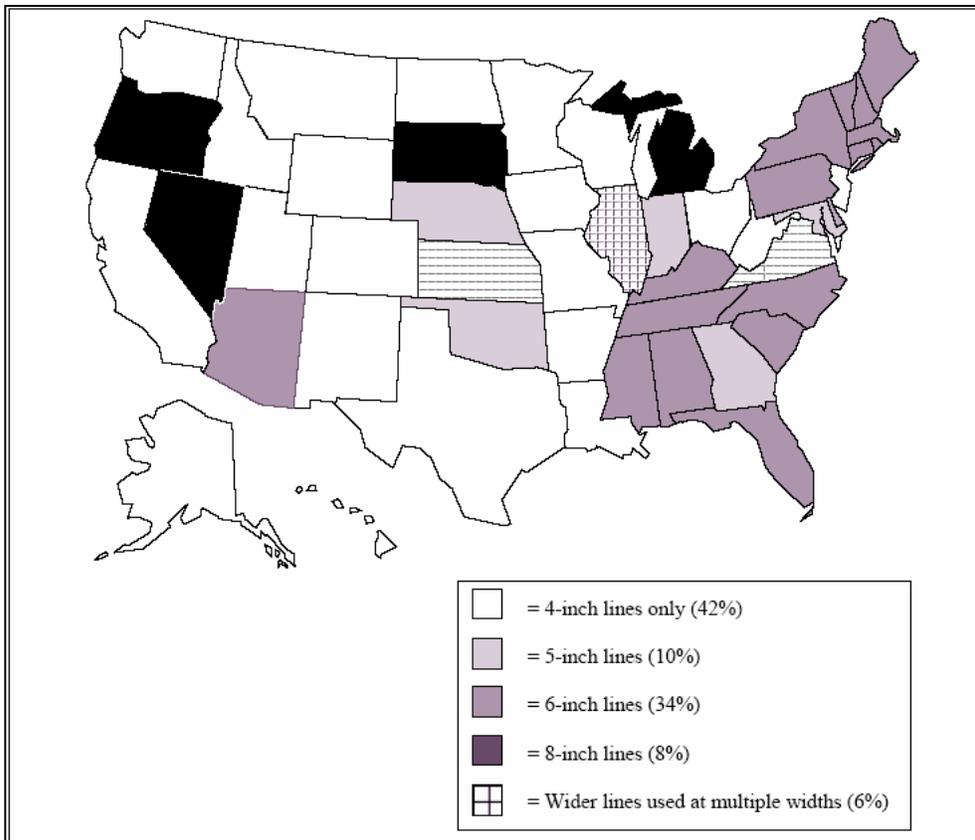


Figure 79: Pavement Marking Width used by Different State DOTs [97]

In a study conducted by Miami University for the Florida Department of Transportation, various traffic control devices are evaluated to determine the effectiveness for older drivers [98]. Overhead and advanced street name signs with 6", 8", 10", and 12" (0.1524, 0.2032, 0.254, and 0.3048 m) letter sizes, pavement markings of 4" (0.1016 m) and 6" (0.1524 m) in width, raised pavement markers, and offset left turn lanes are tested.

The authors evaluated two types of enhanced traffic control devices: a new Clearview font and new pavement marking materials (3M 380I and 820).

The results of the study showed that there were very definite advantages in the use of larger lettering on signage and in the use of wider pavement lines. They also found it advantageous to use raised pavement markers. The Clearview font was found to yield significantly greater legibility distances than the other fonts for advanced street name signs but not for ground-mounted street name signs. No significant differences were found in the absolute or comparative visibility with the new lane markers tested.

7.1.3 Intersections

Studies showed that older drivers have a higher risk of being in a crash at intersections [99]. Older drivers when turning are affected more likely by limited intersection sight distance. In 2001, 50 percent of all older driver fatalities occurred at intersections, while only 23 percent of younger driver fatalities (those 69 and under) occurred at intersections, making older drivers more than twice as likely to be killed while driving through an intersection than younger drivers (Figure 80).

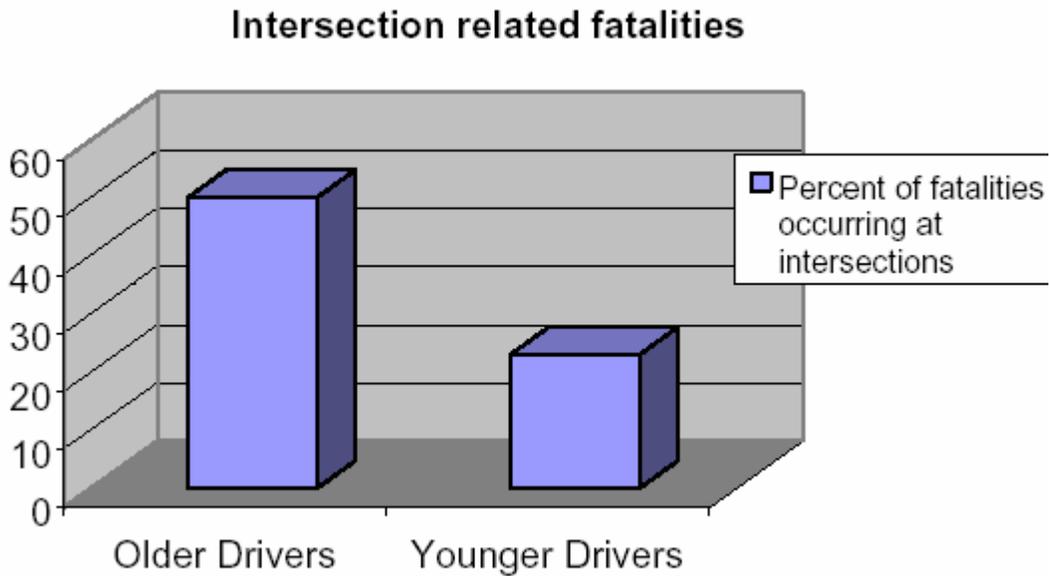


Figure 80. Percentage of 2001 Fatal Accidents Occurring at Intersections for Older and Younger Drivers (adapted from [99])

In a study by Staplin et al. [100] the appropriate offset of opposing left turn lanes to improve the conditions for older drivers is analyzed. The study showed that the appropriate offset improved the performance of drivers' perception of the size of the critical gap of the opposing traffic stream, especially for older drivers.

Staplin et al. also examined the effects of intersection lane geometry on age differences in driving behavior when the driver turns right [100]. This study focused on the right-turn-on-red maneuver because previous investigations had demonstrated that older drivers also have a high risk of being in a crash when executing a right turn. The results of the study indicated that the implementation of an exclusive right turn lane, established through lane channelization, significantly contributed to the mobility of the drivers in the age group of 25-45. Drivers in the age groups of 25-45 and 65-74 executed right turns at speeds from 3 to 5 mph (4.8-8.1 kph). Faster at intersections with channelized right turn lanes than at intersections without channelization. Also channelization significantly increased the probability of a driver completing a right turn on red maneuver without first coming to a complete stop. Finally the study showed that the presence of an acceleration lane on the receiving road had little effect on right turn driver behavior, regardless of age.

7.1.4 Freeway Entrance and Exit Ramps

Reilly et al. [101] conducted an observational field study of 35 freeway sites to investigate the relationship between driver gap-acceptance and acceleration–deceleration behavior when entering and exiting the freeway. Having developed a model of driver freeway entry and egress behavior, they concluded that the Green Book Guidelines for freeway speed-change lanes did not provide sufficient distance for merge or diverge maneuvers. This conclusion suggests that freeway entry and egress lanes may fall short in meeting the needs of many older drivers.

7.1.5 Public Education and Conditional Licensing

The California Department of Motor Vehicles has added a section in its handbook for older drivers [102]. In the section on safety for the aging driver, it is stated that the older drivers, over the age of 70, have more crashes than any other group except teenagers and young adults. In cases where a person's driving must be restricted, DMV may issue a conditional driving license rather than revoking the person's driving privilege. In addition California DMV published a list of recommendations for older drivers. Do not drive at night, at dusk, or in bad weather conditions.

In addition to the California's effort for conditional licensing, other states' efforts are listed below in Table 26. Most of the states do not accept drivers' license renewal after certain ages, and they require vision test, medical reports, or in some states on-road driving tests [102]. The studies evaluating the efficacy of various requirements for license renewal showed mixed results.

Table 26. Licensing Requirements: Distinctions for Older Drivers (adapted from [102])

<i>State or Province</i>	<i>Licensing Requirements: Distinctions for Older Drivers</i>	<i>Age</i>
Alaska	No renewal by mail, vision test required	70
Alberta	Medical report every 2 years at age 70, every year at age 80	70, 80
Arizona	Reduction of interval between renewal (from 12 years to 5 years at age 55), no renewal by mail for age 70 or older	55, 70
British Columbia	Medical report at age 75, every 2 years at age 80	75, 80
California	No renewal by mail, vision test required, written knowledge test required	70
Connecticut	Reduction of interval between renewal from 4 years to 2 years	65
District of Columbia	Medical report plus reaction test; optional knowledge, and road tests at age 75	70
Hawaii	Reduction of interval between renewal from 6 years (age 18–71) to 2 years	72
Idaho	No renewal by mail	69
Illinois	Reduction of interval between renewal from 4 years (age 21–80) to 2 years (age 81–86); reduction of interval between renewal to 1 year (age 87 or older); no renewal by mail, vision test required, and on-road driving test required (age 75 or older)	75, 81, 87
Indiana	Reduction of interval between renewals from 4 years to 3 years, required on-road driving test.	75
Iowa	Reduction of interval between renewal from 4 years to 2 years	70
Kansas	Reduction of interval between renewal from 6 years (age 16–64) to 4 years	65
Maine	Reduction of interval between renewal from 6 years to 4 years at age 65; vision screening test at renewal for age 40, 52, and 65; every 4 years after age 65	40, 52, 65
Manitoba	Medical report for renewal	65
Maryland	Medical report for new drivers over age 70	70
Montana	Reduction of interval between renewal from 8 years (age 21–67) to 6 years (age 68–74) and to 4 years at age 75	68, 75
Nevada	Vision test and medical report required to renew by mail	70
New Mexico	Reduction of interval between renewal from 4 years to 1 year	75
New Hampshire	Road test at renewal	75
Newfoundland	Medical report every 2 years at age 70, every year after age 80	70, 80
Ontario	Medical report for renewal	65
Oregon	Vision screening test every 8 years (every other license renewal)	50
Pennsylvania	Random physical examinations for drivers age 45 or older; most are over age 65	45
Quebec	Medical report every 4 years at age 70, 2 years at age 74–80, and every year at age 80	70, 74, 80
Rhode Island	Reduction of interval between renewal from 5 years to 2 years	70
Yukon	Medical report and renewal every 2 years at age 70	70
Wisconsin	No renewal by mail	70

7.2 Recommendations to ODOT

Based on the research that has already been conducted by various agencies the following conclusions can be made with respect to older driver accommodation in roadway design.

In the placement of traffic signs, in addition to the guidelines specified in Sign Design Manual [103], it is also important to avoid placing signs which are similar in regard to color, features, or message in close proximity. Reaction time required can be decreased by making symbols as easily understandable and by using familiar symbols.

In critical situations, drivers should be given a longer response time by providing advance warning through early and, if needed, multiple signs. The use of twice as many half size arrows rather than one full-size arrow would provide redundancy and increase the overall recognition distance, which would increase the reaction time of older drivers. In the study conducted by Texas Transportation Institute, the researchers found that use of wider pavement

markings would improve long-range detection under nighttime driving conditions especially for older drivers [97].

In a study conducted by Staplin [104], recommendations for highway enhancements for various conditions are given:

- For nighttime driving, a better indication of lane and road boundaries the proper use of proper lanes would give large benefit to motorists. This indication may be accomplished in most cases through a more effective use of painted markings on the road surface and raised delineation treatments. The selective use of larger and brighter signs also is recommended. Although the most expensive to implement, a fixed lighting installation may represent the only viable solution for certain high-crash or - conflict locations.
- In the area of traffic control and intersection operations, countermeasures deemed most effective to accommodate older drivers' diminished capabilities are promote consistency, facilitate correct expectations about permitted and prohibited movements, reduce attentional demands or other information-processing requirements during intersection approach and negotiation, and aid comprehension and decision making.
- The high speeds at which drivers enter, travel, and exit freeway facilities require a rapid and efficient search for guidance cues, recognition, and comprehension of traffic-control elements, as well as effective decision making under a high information load and divided attention conditions, to accomplish maneuvers safely and without disruption to other traffic. Acceleration lane lengths specified in the Green Book guidelines do not provide sufficient distance for merge and diverge maneuvers. Freeway entry and egress lanes may fall short in meeting the needs of older drivers. Longer acceleration and deceleration lanes should be provided to accommodate older drivers. To better accommodate drivers who rely on mirrors because of a difficulty in turning the head to look over the shoulder during merging operations, implement a parallel, as opposed to a taper, design for entrance ramp geometry.

In a study conducted by National Highway Cooperative Research Program [105], the timeframe and cost for implementing the strategies to reduce collisions involving older drivers are given in Table 27. However, the costs for the implementation of the strategies might show differences between agencies according to their specialization topics.

Table 27. Classification of Strategies

Timeframe for Implementation	Relative Cost to Implement and Operate			
	Low	Moderate	Moderate to High	High
Short (Less than a year)	Provide advance warning signs			
	Provide advance guide signs and street name signs			
	Increase size and letter height of roadway signs			
	Provide all-red clearance intervals at signalized intersections			
	Provide more protected left signal phases at busy intersections			
	Improve roadway delineation			
	Increase seatbelt use of older drivers and passengers			
Medium (1-2 years)	Improve traffic control at work zones	Replace painted channelization with raised channelization	Provide offset left-turn lanes at intersections	
	Establish a broad-based coalition to plan for addressing the transportation needs of older adults	Update procedures for assessing medical fitness to drive	Improve lightning at intersections, horizontal curves, and railroad grade crossings	
		Provide educational and training opportunities to the general older driver population	Reduce intersection skew angle	

7.3 Recommended Evaluations

A more comprehensive evaluation on the design of the appropriate offset for left-turn lanes could be performed. Effects of advance lane guidance using two consecutive half size pavement markings could be evaluated for older drivers.

The effectiveness of the use of larger pavement markings and larger traffic signs could be evaluated. A comparative study could be performed to identify the most favorable sizes of pavement markings and signs.

One objective of a future study would be determination of an appropriate length for acceleration and deceleration lanes that meets the needs of both older and younger drivers.

More information regarding accommodating older drivers is given in section 15 of this report.

8 TRAFFIC SIGNAL OPERATIONS

8.1 Countdown Ped Heads

Countdown ped heads are pedestrian crossing signals that add a countdown in seconds until the steady “don’t walk” phase. Federal MUTCD [7] Section 4E.07 Countdown Pedestrian Signals states the standards for the use of countdown ped heads. Countdown pedestrian signal shall display the number of seconds remaining until the termination of the pedestrian change interval. Countdown displays shall not be used during the walk interval nor during the yellow change interval of a concurrent vehicular phase. They are offered by several vendors, including Ecolux, Polara, and Tassimco. They have been installed in several cities, such as Alexandria VA, Arlington VA, Charlotte NC, Spartanburg SC, Kingston Ontario, and now in Athens, OH. In Florida, their NUTCD specifies a countdown only during flashing “don’t walk” period [106], though others have a countdown during the “walk” phase. These may also come with sound capabilities to accommodate blind pedestrians, but the pedestrian advocacy website Walkinginfo.org suggests that the countdown should not be made audible [107]. The three phases of a signal installed in Spartanburg SC are shown in Figure 81 [108].

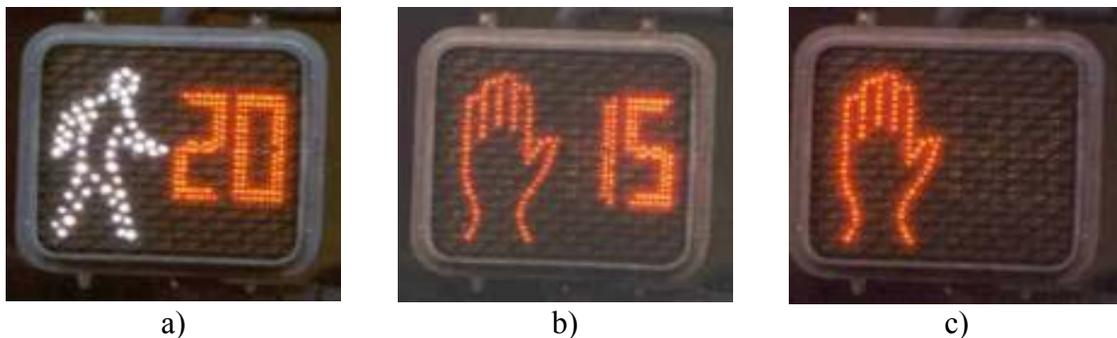


Figure 81. Countdown ped head installed in Spartanburg SC [108]. a) When walk starts, count down gives number of seconds to cross; b) Countdown continues during flashing hand phase; c) cycle ends with solid hand “don’t walk”.

8.1.1 Minnesota Marketing Evaluation

Farraher of the Metro Division of the Minnesota Department of Transportation conducted a study entitled *Pedestrian Countdown Indication - Market Research and Evaluation* in 1999 [109]. She evaluated countdown ped heads at 5 locations in the Twin Cities of Minneapolis-St. Paul, interviewing pedestrians over age 16 before (372 subjects) and after (535 subjects) installation. The countdown occurred only during the flashing “don’t walk” phase to avoid a truncation of countdown during the walk phase when the signal was preempted by emergency vehicles. After 11 months of use the range of responses received ranged from, no complaints and no comments at some intersections to numerous compliments at others. No maintenance was required during these first 11 months once the system was up and running.

Successful service, defined as starting during walk or flashing don’t walk phase and finishing during the walk or flashing don’t walk, increased from 67% to 75% of pedestrians.

The number of violators, those pedestrians in the intersection during the steady don't walk phase stayed about the same: 15% before versus 13% after. 78% of respondents found the new signals easier to understand. 79% preferred the new signals, with the age breakdown favoring younger pedestrians: 91% of younger pedestrians vs. 59% of older ones. 92% of pedestrians found the signals more helpful in crossing.

Farraher recommends using countdown ped heads in these situations:

- Long crossing distances
- Crossing to median
- Nearby school or senior center generating high pedestrian traffic
- High percentage of pedestrians with disabilities
- Heavy pedestrian traffic

However, she adds that countdown ped heads should not become standard because of the extra cost and maintenance expense; the additional information is not always needed.

8.1.2 *San Jose Study*

Botha, Zabyszny, and Day performed an experimental evaluation of countdown ped heads in San Jose CA in 2002 [110]. Their literature review mentions other studies in Sacramento, Monterey, and Quebec City that indicate that the number of people in the intersection during the steady don't walk phase decreased, but the number of people entering intersection during flashing don't walk phase may increase. Pedestrians may cross more quickly with the countdown. Pedestrians were often confident they understood what the signal meant, even though their idea was wrong, for example they thought it was legal to begin crossing during the flashing don't walk phase.

In the San Jose study, 4 intersections were used. The investigators assessed pedestrian compliance, walking speeds, and motorist behavior to find rates of noncompliance and erratic maneuvers. They also observed vehicle-pedestrian conflicts.

The study authors observed that the number of people beginning to cross during the flashing don't walk increased at 3 of 4 intersections. The percentage of pedestrians waiting for the next walk signal decreased from 11.6-41.8% to 2.9-11.9% while the percentage of pedestrians entering on flashing don't walk increased but not significantly at all intersections. The percentage of pedestrians entering on the steady don't walk phase decreased slightly but not significantly at 3 of the 4 intersections. The percentage of pedestrians finishing crossing during the flashing don't walk phase increased significantly, by 2.0-7.9%, while percentage finishing crossing during the steady don't walk phase decreased significantly, by 2.2-4.4%.

Their overall observations indicated that for erratic behavior no pattern of change was observed. The same was true for conflict situations. Walking speeds also did not change significantly. Pedestrians' average perceived crossing time for an intersection was 3-10 seconds less than their actual time; pedestrians are not good judges of crossing time.

Pedestrians' perception of the flashing don't walk phase is different: 76% thought it meant "don't cross" before installation of countdown ped head, while only 59% thought it meant "don't cross" after installation. 80% of pedestrians thought that countdown meant that you

could cross if you would finish crossing before countdown finished. Thus the likely cause of increase in pedestrians entering intersection during the flashing don't walk phase with countdown ped heads is this perception that it is legal to cross so long as you finish before the countdown ends.

8.2 TTI Guidelines to reduce red light running

Bonneson, Zimmerman, and Brewer of the TTI investigated the effect of various countermeasures to red light running [111]. The measures investigated and their effects in terms of percent reduction in red light running are:

- Extending yellow interval – 50-70% reduction
- Providing green extension (advance detection) – 45-65% reduction
- Improving signal coordination – varies
 - Red light running likely to increase at each intersection, but longer signals likely to mean fewer red lights per trip
- Improving visibility of signal with yellow LEDs – 13% reduction
- Increasing conspicuity of signal with backplates – 25% reduction
- Adding advance warning signs with flashers – 29-67% reduction

It should be noted that combinations of these strategies were not investigated.

8.2.1 Engineering countermeasures to reduce red light running

A more comprehensive toolbox of engineering strategies to reduce red light running is published by the Institute of Traffic Engineers (ITE) and made available by the FHWA on their web site at <http://safety.fhwa.dot.gov/rlr/rlrreport/chap3.htm> [112]. The list of countermeasures is quite extensive and effectiveness measures are often provided. Many of the countermeasures are such basic engineering issues that they don't really qualify as human factors innovations, such as adhering to the MUTCD, ensuring adequate sight distance, adjusting timing and signal coordination, favoring overhead signals over pole-mounted signals which can often be blocked by vehicles, and others. Among the suggestions are the addition of supplemental signals for redundancy (and to place signals over the center of each lane for improved visibility) or to compensate for limited sight distances (e.g. on curves), use of larger 12-inch (0.3048 m) signal heads (at least for red), adding a second red signal head for redundancy (see Figure 82), use of LEDs (which have service times 6-10 times that of regular bulbs), black backplates for higher contrast between signal light and surrounds (note that additional weight and wind load must be accounted for in design), addition of strobe lights (as a last resort), addition of signal ahead signs, advanced warning flashers, rumble strips, left-turn signal signs, and the use of roundabouts instead of signalized intersections.

All red interval is another countermeasure to reduce red light running. An all-red interval is a portion of a traffic signal cycle where all approaches have a red-signal display. The purpose of the all-red interval is to allow time for vehicles that entered the intersection during the yellow-change interval to clear the intersection before the traffic-signal display for the conflicting approaches turns to green [111]. In federal MUTCD it is stated that the all-red clearance interval is optional and the duration of the all-red interval shall be predetermined but it should not exceed 6 seconds. Various studies have shown that providing a red interval does have a positive effect on the safety of the intersection. Four studies performed in the

1970s in various states and cities indicated more than a 40 percent reduction in right angle accidents at the study locations.

Figure 82 shows a signal with two red heads and a back backplate for contrast. When two-red-head signals were installed at 9 intersections in Winston-Salem NC, a decrease of 33% in right-angle crashes was observed [112].



Figure 82. Signal with two red signal heads [112].

In a study conducted by Sayed et al [113], the safety impact that can be expected by providing a retroreflective border on the backboard of traffic signal displays was investigated. They installed 75 mm (2.95 in) of yellow microprismatic reflective sheeting along the outer edge of the signal display to increase the conspicuity of the signal displays. Figure 83 shows a traffic signal display with yellow microprismatic reflective sheeting along the outer edge of the display.

The evaluation of the treatment showed that the treatment was effective in reducing the total number of collisions and this kind of improvement was therefore effective in enhancing safety at signalized intersections and consideration should be given to enhancing its use.



Figure 83. Signal with Retroreflective Border during Daytime and Nighttime (adapted from [113])

Advanced warning flashers have been shown to reduce red light running [112]. In a before and after study conducted at an intersection in Bloomington MN, the installation was effective in reducing the number of red light violators, and number and speed of violating trucks. There was still a reduction after a year, but some increase over the period immediately after installation. Another study of 106 intersections was conducted in British Columbia, 25 of which included advanced warning flashers. The intersections with the flashers had lower accident rates; however the difference was not statistically significant. A correlation was found between minor street traffic volumes and the accident reduction capacity of the flashers; benefits were found at intersections with moderate to high minor approach traffic volumes ($\geq 13,000$ ADT).

The Advanced Warning for End of Green Phase System (AWEGS) at high-speed rural intersections is a similar research project [114]. The two sites selected for study were the intersections of FM 518 with SH 6 in Waco, TX and FM 577 with US 290 in Brenham, TX. The results were expressed in three different rates of per 100 cycles, per 1,000 vehicles, and per 10,000 vehicle-cycles. Brenham showed a maximum of 51 % reduction in Red Light Running (RLR) using a per 100 cycle Measure of Effectiveness (MOE). RLR was reduced by up to 60% in Waco using RLR per 10,000 vehicle cycles.

The ITE report also mentions the use of transverse rumble strips to alert drivers of an upcoming signal [112]. No figures on effectiveness are given, but a picture of such an installation is given, reproduced here as Figure 84. The installation depicted may be in a residential area, and the noise from the rumble strips would most likely disturb nearby residents.



Figure 84. Transverse rumble strips and pavement markings to warn drivers on an upcoming signal [112]

While the length of yellow and all-red intervals has been researched since the 1970s, a more recent development is dilemma zone protection, where the onset of the yellow interval begins when no vehicle is in the dilemma zone [112]. A vehicle detector, and also a speed detector, is used to determine if there is traffic in the dilemma zone at the time of a signal change. A before-after study of three intersections in Kentucky showed a reduction of 54% in accidents after detectors were installed. Dilemma zone protection is discussed elsewhere in this report; see the section entitled “Detection System for Rural Signalized Intersections”.

Roundabouts solve the red light running problem by eliminating the signal [112]. A roundabout is shown in Figure 85. The ITE report does not give much information on roundabouts, but does note that they are widely used internationally and their benefits widely studied. Such benefits include reduced frequency and severity of accidents, vehicle emissions, noise, fuel use, delays, electricity costs, and maintenance costs. Good candidates for roundabout conversion include locations with significant delay on minor roads, lots of left turns, more than four legs or other unusual geometry, or where U-turns are desirable. There are also some disadvantages to roundabouts: they are not as accommodating to pedestrians, require a greater right of way, and can handle only a limited amount of traffic. Roundabouts are much more thoroughly discussed in an FHWA report [115].



Figure 85. Roundabout installed in Colorado [112].

8.3 Video Imaging Vehicle Detection Systems (VIVDS)

Another TTI study looked at Video Imaging Vehicle Detection Systems (VIVDS) as a replacement for traffic loops [116]. These systems use video technology to detect the presence of vehicles in travel lanes on intersection approaches. The authors conclude that VIVDS supplies reliable presence detection when detection zone is long (over 40 ft or 12.19 m), but does not detect gaps between stopped vehicles well. VIVDS negatively affects volume-density control and adaptive protected-permissive left turn phasing and should not be used to monitor vehicles at distances over 300 feet (91.44 m) as their capability decreases with distance.

VIVDS are cost effective:

- Where more than 12 stop line detectors are needed.
- Where inductive loop life is shortened by poor soil conditions
- When extensive intersection reconstruction will last for one year or more
- Where a loop is physically impractical
 - E.g. because of bridge decks, railroads, underground utilities
- Where pavement will be resurfaced within three years
- When intersection will be resurfaced and the cost of new loops is more than the cost of VIVDS

Single-camera VIVDS can also be used to partially replace loops at intersections where some but not all loops have failed. It should be noted that VIVDS can be affected by weather and light conditions. On the other hand, VIVDS are more adaptable to changing conditions such as lane reassignments, construction, etc. The authors recommend that new installations should be checked at morning, evening, and night to make sure they work correctly under all conditions.

A similar study by TTI involved taking snapshots of red light runners using cameras placed at intersections [117]. Cameras were found to reduce violations by up to 40 percent at these intersections with the added advantage of having a ‘halo’ effect on nearby intersections where cameras are not installed.

8.4 Dilemma Zone Protection

TTI has also developed a new vehicle detection system for use on fully-actuated rural signalized intersections [118]. This is basically a form of dilemma zone protection as mentioned previously. The system uses vehicle detection loops placed 700-1000 ft (213.4-304.8 m) in advance of the signal. Information from the loops is sent to a computer that uses the speed and vehicle type to determine the dilemma zone for each vehicle. The computer then schedules the end of the green phase when all vehicles have gone through or when there is a gap in traffic so that no vehicle will be in the dilemma zone when the light changes. If the volume of traffic is high enough to sustain flow in a green phase for 30-40 seconds and there is waiting traffic on the minor road, the controller will relax the criteria and end the green phase when there is at most one car in the dilemma zone (not a truck). This allows the system to end the phase when there is the least likelihood of a rear-end collision given the level of traffic, rather than waiting for the phase to “max out” and end abruptly. It should also be noted that the system identifies a dilemma zone based on the measured speed of the approaching vehicle, rather than being tied to the posted speed or an 85th percentile speed derived from it. This allows the system to work without change even if the speed limit on the major road is changed.

The system was installed at two intersections in Texas and its capabilities measured extensively [118]. The benefits of the system include having the dilemma zone tailored to each specific driver, not just those in the 15-85 percentile range. The system also uses the relaxed end of phase criterion after 30-40 seconds to reduce the incidence of “max-out”. Cost reduction appears in the system’s “one-size-fits-all” approach that eliminates or reduces the need for expensive site-specific engineering for the system; older systems had design elements and controller settings that were dependent on a single approach speed. Another cost reduction is that the system does not need to be reprogrammed to work with a change in speed limit. It is also anticipated that the system will reduce overall delay by effectively shortening some phases, both by using the relaxed ending criterion before a “max-out” is reached and also by ending a phase when there are no vehicles in the open lane, eliminating “wasted green time”.

The researchers recommend the use of their system at all isolated high-speed (>45 mph (72.42 kph) 85th percentile speed or speed limit) full-actuated intersections with left-turn bays on each major road approach. The system should also be considered as a replacement for older systems when the design life of the old system has expired. As of January 2004, the Texas DOT is implementing the design guidelines and specifications [118]. From a human factors point of view, this system adapts itself to the user rather than the other way around. It considers the driver’s speed in determining the end of the green phase.

McCoy and Pesti evaluated two kinds of dilemma zone protection in Nebraska [119]. They studied three sites with advance detection and three sites with advance detection and advance

warning flashers with signs that said “prepare to stop when flashing”. The sites were all high-speed sites – 55 mph (88.55 kph) design speed except for two with warning flashers which were 65 mph (104.65 kph). The study examined the number of vehicles in the dilemma zone, the number of max-out green intervals, the number of vehicles running the red light, the number of vehicles stopping abruptly, and the number of vehicles accelerating on yellow. Max-out occurs when the signal has been green for a hard maximum time and the signal changes regardless of the presence of vehicles in the dilemma zone; in essence the dilemma zone protection is turned off when there is too much traffic. The two systems were judged to be comparable. The design with flashers did have fewer vehicles in the dilemma zone when the yellow phase began, and more vehicles began stopping before the yellow phase. This was countered somewhat by the narrower speed range at which the flasher design provided dilemma zone protection.

The same authors then reevaluated the dilemma zone protection provided by the advance detection accompanied by advance warning flashers [120]. This time they reduced the maximum allowable headway, which reduced the likelihood of max-out. There are two speed ranges in which dilemma zone protection, a lower speed range and an upper one. The design change was to lower the various limits so that the upper speed range began close to the average approach speed; equivalently the design speed for the intersection was taken as 10 mph (16.1 kph) below the 85th percentile speed rather than being equal. The probability of vehicles being in a speed range given dilemma zone protection went from about 0.15 to 0.8 for a normal speed distribution with a standard deviation of 5 mph (8.1 kph), and from 0.23-0.37 to 0.48-0.53 for a normal speed distribution with a standard deviation of 10 mph (16.09 kph).

Martin, Kalyani, and Stevanovic studied dilemma zone protection at two intersections in Utah [121]. One intersection had advance warning signals only, while the other had advance warning signals and traffic detection; a third intersection was used as a control. The advance warning signal only intersection had 1.15% more drivers in the dilemma zone than did the control intersection, while the intersection that also had advance detection had 1.4% fewer vehicles in the dilemma zone. Though 90% of drivers did reduce their speeds when the sign flashed, most waited before making an actual decision to stop until they were close to the intersection, and the reductions were less if drivers could see the signal was still green. The researchers recommend more intensive study before making further installations.

8.5 Red light strobes

Another device that has been proposed and experimented with is a strobe instead of the red face of a traffic signal. Two examples are depicted in Figure 86 and Figure 87. The first figure shows a separate strobe unit mounted in addition to a standard dual signal head installation in Greenville SC. The second depicts the Barlo Safety Traffic Signal Strobe, which has a strobe light built into the red light head.



Figure 86. At center is a red strobe light to direct attention of driver to the presence of a traffic light in Greenville SC [108].



Figure 87. The Barlo Safety Traffic Signal Strobe [122].

The use of strobe lights is discussed in the ITE report mentioned above [112]. Their typical strobe rate is once per second. The guidelines for the use of red light strobes in Maryland are [123]:

- At locations with approach speeds greater than 45 mph (72.45 kph) that have a documented accident problem
- On the approach to the first signal in a series
- On long and flat unobstructed approaches that alter perception at high speeds
- At isolated intersections
- Only after other standard traffic control devices have failed.

A limited study of six intersections in Virginia in 1994 indicated that some intersections had increases and others decreases in rear-end and angle accidents [124]. Since no clear benefit has been determined for strobes, the FHWA will no longer approve the devices for experimentation. This, plus the fact that strobes are not listed in the MUTCD, means that a DOT using strobes may be subject to liability in crash-related litigation [112].

8.6 Recommendations to ODOT

Countdown ped heads could be installed at places where there is a heavy pedestrian traffic. They are especially useful for pedestrians with disabilities and for older drivers. The users of countdown ped heads found them easier to understand. However, countdown ped heads should not become standard because of the extra cost and maintenance expense; the additional information is not always needed.

In order to reduce the red light running the yellow interval might be extended, the visibility of signals with yellow LEDs might be improved, conspicuity of signals could be increased with backplates and retroreflective strips, and advance warning signs with flashers could be installed.

New vehicle detection system developed for use on fully-actuated rural signalized intersections [118] by TTI can be implemented on Ohio's transportation system. It is recommended to be used at all isolated high-speed (>45 mph (72.42 kph) 85th percentile speed or speed limit) full-actuated intersections with left-turn bays on each major road approach. The system should also be considered as a replacement for older systems when the design life of the old system has expired. As of January 2004, the Texas DOT is implementing the design guidelines and specifications [118].

Roundabouts should be installed at locations with significant delay on minor roads, lots of left turns, more than four legs or other unusual geometry, or where U-turns are desirable. They solve the red light running problem by eliminating the signal. They also help to reduce frequency and severity of accidents, vehicle emissions, noise, fuel use, delays, electricity costs, and maintenance costs.

Recommendations should be reviewed for conformance to the existing federal and state standards and guidelines.

More information regarding traffic signals can be found in section 15 and 16 of this report.

9 HIGHWAY LIGHTING

9.1 Solar Powered Highway Lighting

Eagle-1 Manufacturing makes solar powered highway lighting in two models [125]: HLS-35E/12 with a 12-hour light time and HLS-35E/07 with a 7 hour light time. A solar powered light is shown during daytime in Figure 88 and during nighttime in Figure 89. The lights use xenon gas discharge lighting technology that produces 3600 lumens of light with a lifetime of 5000 hours. They illuminate starting at sunset and shut off after 12 hours or at sunrise. The system requires 4 hours of direct bright sunlight to recharge.



Figure 88. Eagle-1 solar powered highway light in daytime [125].



Figure 89. Eagle-1 solar powered highway light working at night [125].

9.2 Pedestrian Area Lighting

Lighting reduces crime in inhabited areas. A before and after study conducted in Dudley and Stoke, UK is documented by Painter [126]. Lighting was changed so that illumination increased from 1 lux mercury vapor 6 lux average (2.5 lux minimum) to high pressure sodium. Crime was significantly reduced, and the fear of crime decreased substantially as well, resulting in more use of streets at night by pedestrians. The benefit to cost ratios of the lighting were computed at 4.45 in Dudley and 1.36 in Stoke based on first year crime reduction [126].

9.3 Swiss Crosswalk Lighting

Proper lighting of pedestrian areas can also save the lives of pedestrians by reducing accidents. For instance Switzerland reduced pedestrian fatalities by 2/3 with an improved lighting system as shown in Figure 90. Patrick Hasson et al. evaluated this system on two pedestrian crossings in Madison, Wisconsin [127].

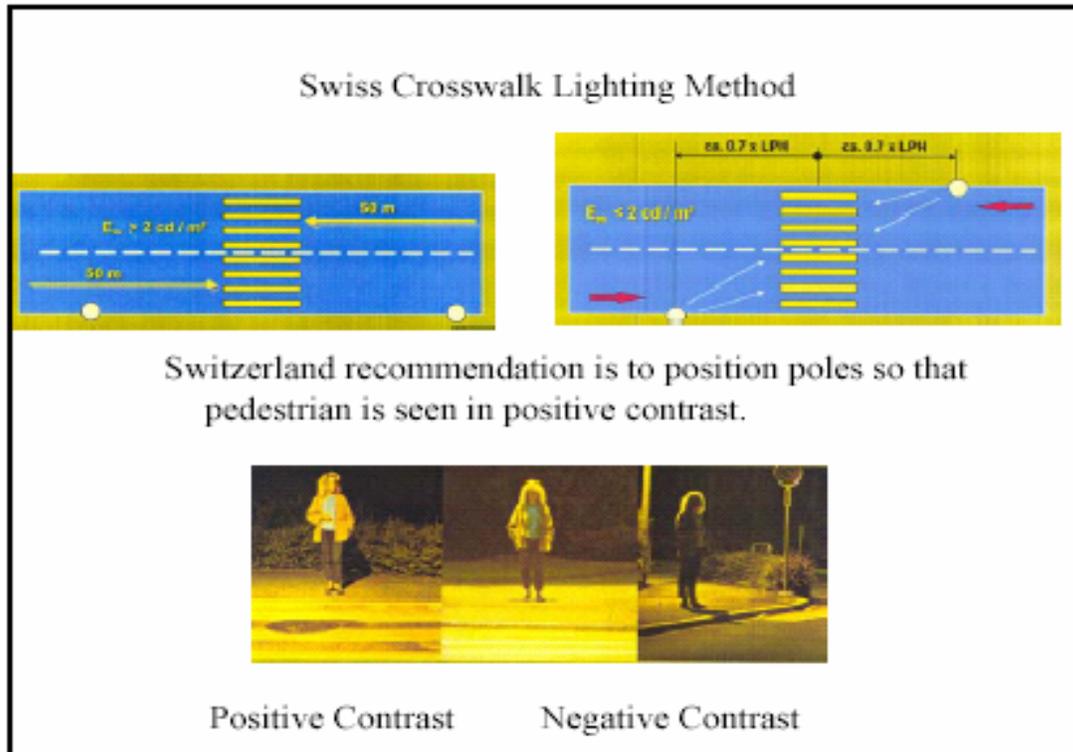


Figure 90. The Swiss pedestrian crosswalk illumination system places lights so they illuminate the pedestrian in the direction of travel. The Swiss system is shown at top right, the American system at top left [127]

The study objective was to set up the two crosswalks so that they could be illuminated either American or Swiss style. Then a group of pedestrian-sized and shaped cutout targets were set up in the roadway at night. Each subject was seated in the passenger seat of a stationary 2002 Dodge minivan parked in the left-most traffic lane, which was closed to traffic. A shade in

front of the subject obscured his or her view out the front windshield. It was raised for 2 seconds then lowered, and the subject was asked how many cutouts were seen. Then the process was repeated applying the other lighting style; the styles were presented randomly. One of the intersections with the American style lighting is shown in Figure 91, and the same intersection with Swiss style lighting is shown in Figure 92.

9.3.1 Study Results

The percentage of cutouts recognized at the first site was 72.1% for US lighting versus 93.9% for Swiss lighting, which was statistically significant at the 0.01 level. At the second site the percentage was 92.3% with US lighting and 94.9% with Swiss lighting, which was not a statistically significant difference. At the first site 50% of the subjects saw fewer than the actual number of cutouts with US lighting, while only 10% had the same result with Swiss lighting. Only 33% of the subjects saw the correct number of cutouts with US lighting, and 80% saw the correct number with Swiss lighting. 17% of the subjects saw more than the actual number of cutouts with US lighting; only 10% saw more with Swiss lighting. At the second site, 20% of the subjects saw fewer than the actual number of cutouts with US lighting; only 13% did with Swiss lighting. 73% of the subjects saw correct the number of cutouts with US lighting; 87% saw correct number with Swiss lighting. And 6.7% of the subjects saw more than the actual number of cutouts with US lighting, while none saw more with Swiss lighting.

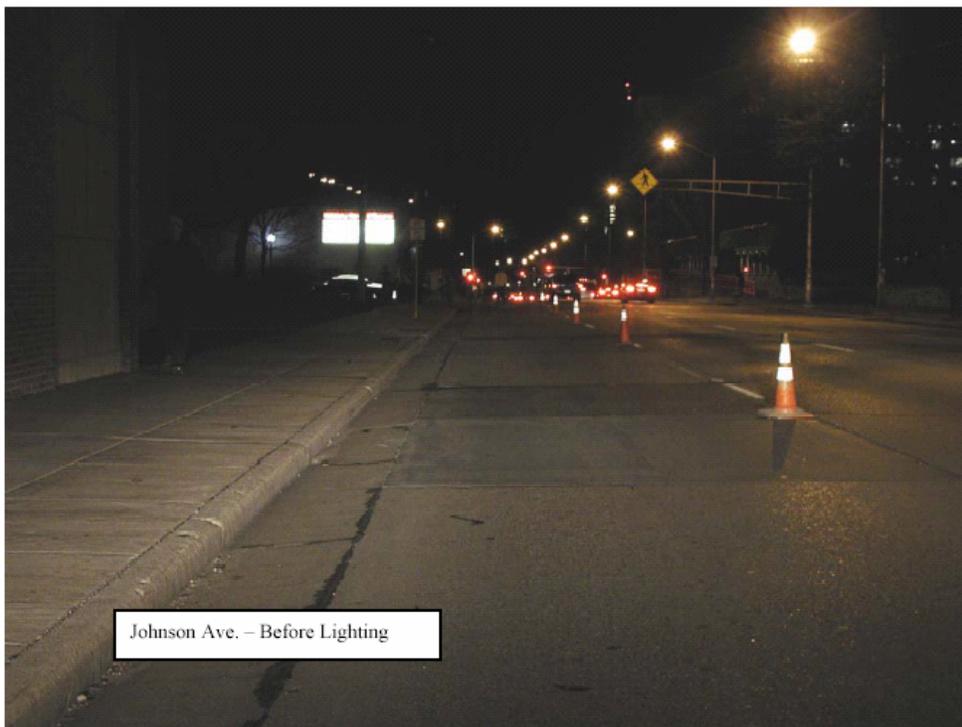


Figure 91. A test intersection with pedestrian cutouts with American style lighting [127].

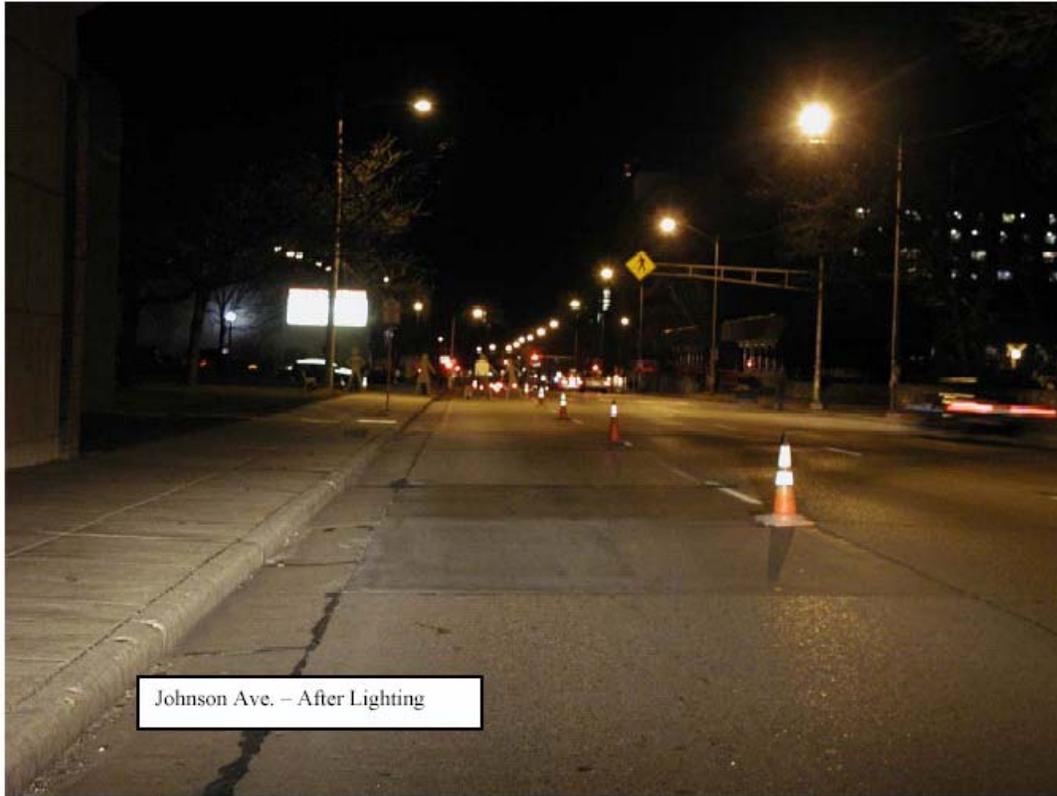


Figure 92. A test intersection with pedestrian cutouts with Swiss style lighting [127126].

9.4 Small Target Visibility study

Mace and Porter have been conducting a study on *Fixed Roadway Lighting to Benefit Older Drivers* [128]. Some preliminary results were generated as of 2002. The study involved 36 older drivers (65-80 years old) and 24 younger drivers (20-40 years old), who were asked to detect small targets along a roadway under three different illumination conditions plus no external lighting. At the same time, they were also given a secondary task of identifying reflectorized markings. Preliminary results indicate that the visibility level of individual targets does not correlate with the small target visibility (weighted average of visibility level of all objects in system). Thus small target visibility simulation programs do not predict the visibility level of targets, but do indicate the possible existence of problem areas.

9.5 Roadway lighting

Most arterial highways in urban areas if not all require fixed lighting [129]. Conventional highways which depart from urban areas pose a problem as to where the lighting should be dropped. This largely depends on the visual complexity of the scene, the ambient lighting level provided by curbside businesses and advertising, the number of curb cuts and driving lanes, etc. In the case of limited access roadways, lighting would depend on the number of lanes in each direction, the frequency of ramps, and the traffic volume. Lighting can greatly help in areas where there are frequent changes in geometry especially when they are

unexpected, such as in construction areas and where there are lane drops. There are several existing studies that generally show that lighting is better than no lighting.

Sixty-two lighting and accident studies, from 15 countries, have been rigorously analyzed [130]. About 85 per cent of results show lighting to be beneficial, with about one third of these having statistical significance. It can be concluded that road lighting on traffic routes will reduce the incidence of night accidents. Depending on the road conditions and the accident classification involved, the statistically significant results show reductions of between 13 and 75 per cent.

9.6 Recommendations to ODOT

Illuminated highways extend the automobile beam of light, which provides better visibility and increased preview times for drivers. It also improves conspicuity especially of non-retroreflective objects including pedestrians.

High pedestrian traffic areas should be adequately illuminated. Adequate lighting of pedestrian areas would increase the visibility of the pedestrians and reduce the number of accidents. Study results recommend that a Swiss pedestrian crosswalk type of illumination be used wherein the lights illuminate the pedestrian in the direction of travel with a positive contrast.

More information regarding highway lighting can be found in section 15 of this report.

10 IMPROVED CURVE DELINEATION

Pavement striping, pavement markers, reflectors, and other devices are used to indicate to drivers the roadway alignment and the intended travel path [131]. The main idea behind an adequate curve delineation system is to provide guidance for motorists driving through curves (especially at night) by providing visual cues using equally spaced retroreflective curve delineation devices such as chevrons or post delineators [132].

Chevron alignment sign is one of the alternatives which may be used for the curve delineation. It may be used to provide additional emphasis and guidance for a change in horizontal alignment. The standard for the installation of chevron alignment sign is given in Section 2C.10 of OMUTCD [5]. The sign shall be a vertical rectangle. The drawing of the Chevron Alignment sign (W 1-8) is given in Figure 93. The spacing criteria for the alignment of chevron signs is specified that the road user always has at least two signs in view, until the change in alignment which eliminates the need for the signs.



W1-8

Figure 93. Chevron Alignment Sign (W 1-8) (Ohio Manual of Uniform Traffic Control Devices, pp.2-96)

Chevrons are also used in some European countries. In Switzerland, white on black chevrons are placed at the beginning of a curve [133]. The drawing for the chevrons used in Switzerland is given in Figure 94 and the typical application of chevrons in curve delineation is given in Figure 95.

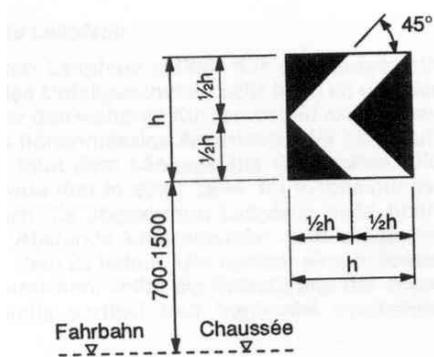


Figure 94. Chevron Design used in Switzerland [133]

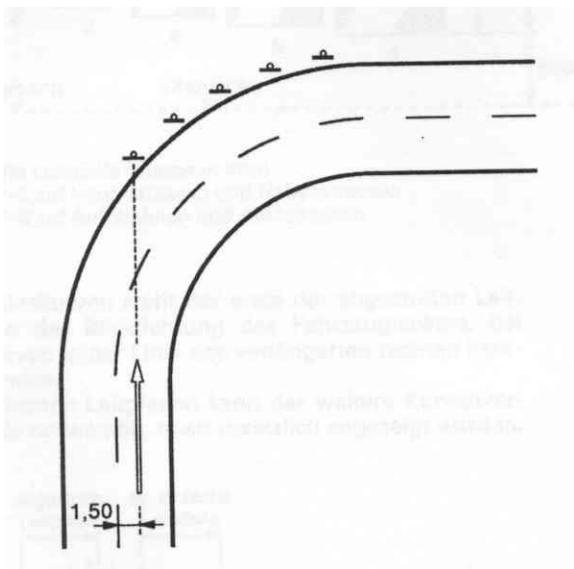


Figure 95. Typical Application of Chevrons in Curve Delineation in Switzerland [133]

Another sign which may be used for curve delineation purposes is the One-Direction Large Arrow Sign (W 1-6). The One-Direction Arrow sign shall be a horizontal rectangle with an arrow pointing to the left or right. The drawing for the One-Direction Large Arrow sign is given in Figure 96. In Section 2C-09 of OMUTCD the standards and guidance for the use and installation of the One-Direction Large Arrow sign is given [5]. The sign should be installed on the outside of a turn or curve approximately at a right angle to approaching traffic. The sign should be visible for a sufficient distance to provide the road user with adequate time to react to the change in alignment.



W1-6

Figure 96. One-Direction Large Arrow Sign (W1-6) (Ohio Manual of Uniform Traffic Control Devices, pp.2-96)

In Section 3D.04 of Ohio Manual of Uniform Traffic Control Devices, information on delineator placement and spacing are given.

Delineators should be mounted on suitable supports so that the top of the highest retroreflector is 1.2 m (4 ft) above the near roadway edge. They should be placed 0.6 to 2.4 m (2 to 8 ft) outside the outer edge of the shoulder, or if appropriate, in line with the roadside barrier that is 2.4 m (8 ft) or less outside the outer edge of the shoulder.

Delineators should be placed at a constant distance from the edge of the roadway, except where a guardrail or other obstruction intrudes into the space between the pavement edge and the extension of the line of the delineators. In such cases the delineators should be transitioned to be in line with or inside the innermost edge of the obstruction. Delineators should be spaced 60 to 160 m (200 to 530 ft) apart on mainline tangent sections.

Delineators should be spaced 30 m (100 ft) apart on ramp tangent sections. When uniform spacing is interrupted by such features as driveways and intersections, delineators which would ordinarily be located within the features may be relocated in either direction for a distance not exceeding one quarter of the uniform spacing. Delineators still falling within such features may be eliminated. Delineators may be transitioned in advance of a lane transition or obstruction as a guide for oncoming traffic.

The spacing of delineators should be adjusted on approaches to and throughout horizontal curves so that several delineators are always simultaneously visible to the road user. The approximate spacing is given in Table 28.

Table 28. Approximate Spacing for Delineators on Horizontal Curves (OMUTCD pp.3-82)

(Distances in feet were rounded to the nearest 5 feet (1.524 m).)

Radius (R) of Curve (meters)	Approximate Spacing (S) on Curve (meters)	Radius (R) of Curve (feet)	Approximate Spacing (S) on Curve (feet)
15	6	50	20
35	8	115	25
55	11	180	35
75	13	250	40
95	15	300	50
125	18	400	55
155	20	500	65
185	22	600	70
215	24	700	75
245	26	800	80
275	27	900	85
305	29	1000	90

The minimum spacing should be 6 m (20 ft). The spacing on curves should not exceed 90 m (300 ft). In advance of or beyond a curve, and proceeding away from the end of the curve, the spacing of the first delineator is 2S, the second 3S, and the third 6S but not to exceed 90 m (300 ft). S refers to the delineator spacing for specific radii computed from the formula:

S=1.7 for metric units, and

S=3 for English units.

Typical delineator installation application is given in Figure 97 adapted from OMUTCD.

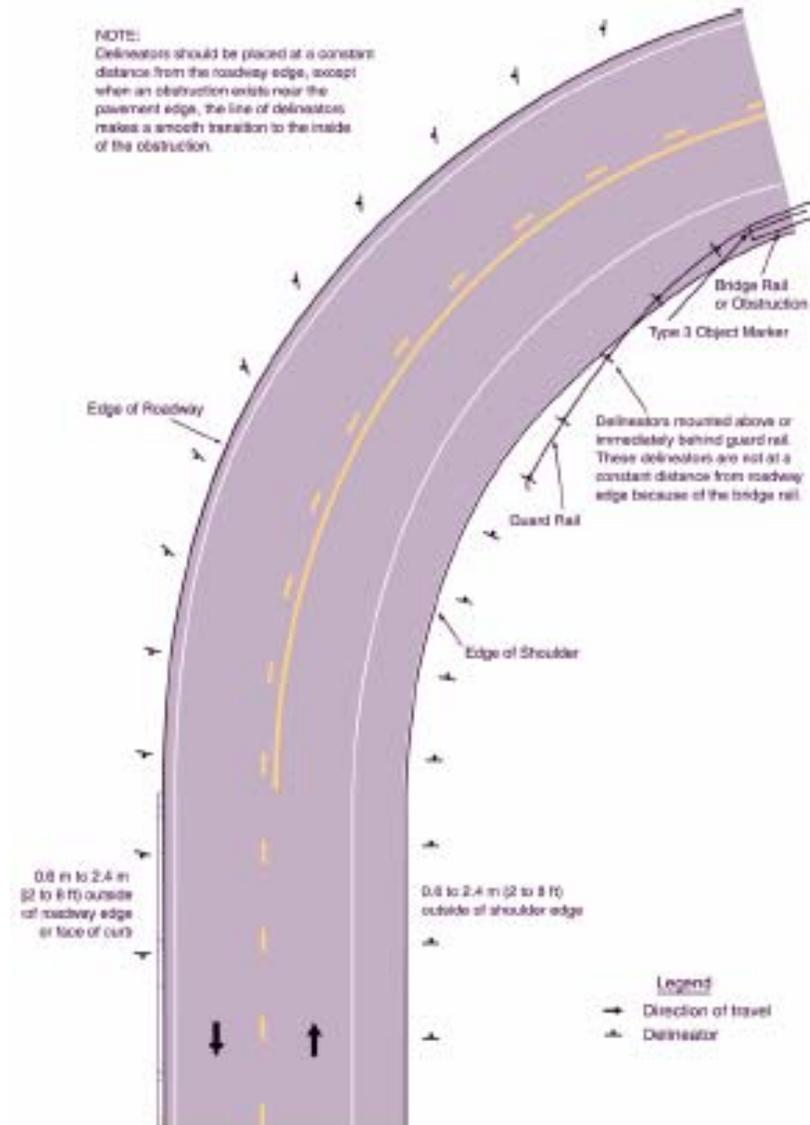


Figure 97. Typical Delineator Installation (adapted from Figure 3D-1, pp3-81, OMUTCD, 2003 Edition)

10.1 General Concept of Curve Delineation

In the study conducted by Zwahlen and Schnell [132], the evolution of the curve warning system for drivers in the U.S. is described. Figure 98 describes the evolution of the curve delineation concept, and its standardization, application, and placement.

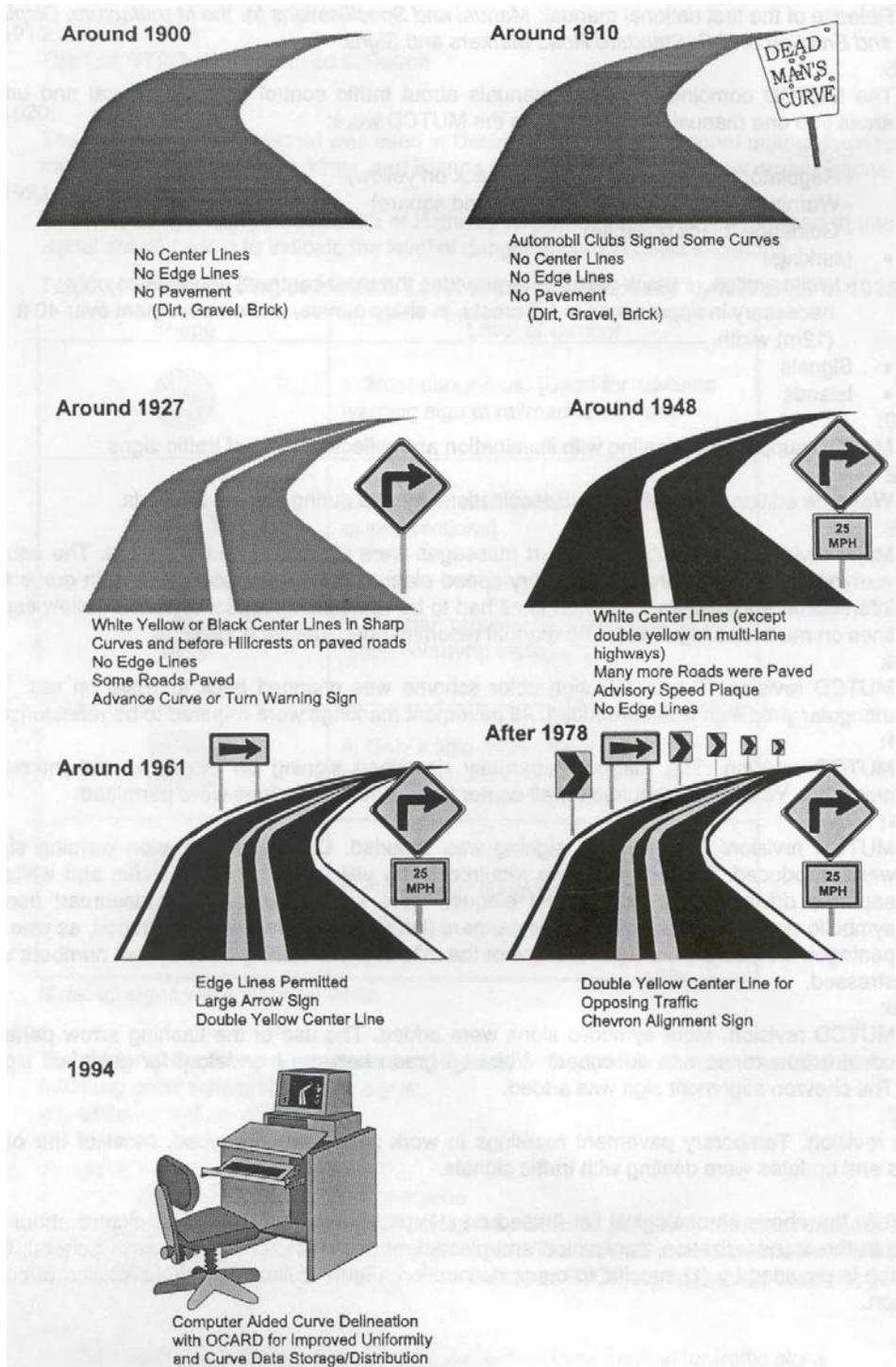
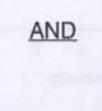


Figure 98. Evolution of Curve Delineation in U.S. [132]

In Table 29, an example of an overall curve delineation concept is given.

Table 29. Example of an Overall Curve Delineation Concept [132]

Safe Speed	Advance and Center Location	Approach Speed ≥ 55 MPH (88 km/h) (high)	Approach Speed ≤ 55 MPH (88 km/h) but above Safe Speed	Approach Speed Near Safe Speed (low)
Is Equal or Below Critical Speed of 28 MPH (45 km/h)	Always  AND 	 High Acc. Severity and Freq.	 High Acc. Severity and Freq.	 High Acc. Severity and Freq.
Is Slightly Above or Above Critical Speed of 28 MPH (45 km/h)	Always at least 	 High Acc. Severity and Freq.	 High Acc. Severity and Freq.	 High Acc. Severity and Freq.
Close to Approach Speed of 55 MPH (88 km/h)	NONE	 High and Low Acc. Severity and Freq.	 High and Low Acc. Severity and Freq.	 High and Low Acc. Severity and Freq.

In another study by Zwahlen and Schnell [134], a knowledge-based PC software package was developed for the application and placement of curve delineation devices. The OCARD (ODOT Computer Aided Curve Delineation) PC software package was developed to assist the user in the curve delineation task and treat similar or equal curves with the same traffic characteristics in the same, consistent, and uniform way. An adequate number of roughly equally spaced delineation devices in a curve provide an unfamiliar driver with curvature information which may be helpful in the curve speed selection thus resulting in fewer run-off-the-road accidents.

10.2 Curve Delineation Applications in Other States

10.2.1 Texas

In a study performed by the Texas Transportation Institute (TTI), Carlson, Rose, and Chrysler developed an instrument called the radiusmeter, shown in Figure 99, for measuring the radius of a curve [135]. This device will reduce the danger of the curve radius measurement operations by the field crew. The device will give more accurate measurements (3% accuracy), and the effects of human error in the measurement process will be reduced. TTI researchers also developed a Chevron spacing table that can be integrated into the existing delineator spacing table.



Figure 99. The Radiusmeter is mounted on a vehicle's dashboard (Texas Transportation Researcher, Volume 40, No.1, 2004)

Carlson and Rose [136] developed delineator and chevron spacing values for field personnel and engineers based on the speed values. The research showed that having more than two chevrons in view on a curve provides a small reduction in mean speeds. Carlson and Rose recommended making three chevrons visible on curves. Table 30 shows the TTI recommended spacing for delineators and chevrons.

The researchers also developed another procedure for the spacing of delineators and chevrons using the curve radius values for engineers. The curve radius is determined using the radiusmeter shown in Figure 99. The recommended spacing for delineators and chevrons based on curve radii for engineers is given in Table 31.

Table 30. Delineator and Chevron spacing values based on the advisory speed for field personnel (adapted from [136])

Advisory Speed Value (mph, kph)	Delineator Spacing = S (ft, m)	Chevron Spacing = S (ft, m)
15, 24.14	35, 10.67	40, 12.19
20, 32.19	40, 12.19	80, 24.38
25, 40.23	50, 15.24	80, 24.38
30, 48.28	55, 16.76	80, 24.38
35, 56.33	60, 18.29	120, 36.58
40, 64.37	70, 21.34	120, 36.58
45, 72.42	75, 22.86	160, 48.77
50, 80.47	85, 25.91	160, 48.77
55, 88.51	100, 30.48	160, 48.77
60, 96.56	110, 33.53	200, 60.96
65, 104.6	130, 39.62	200, 60.96

Note: Approach and departure delineation on horizontal curves should be spaced at 2S using 3 delineators or 1 chevron.

Table 31. Delineator and Chevron spacing values based on the curve radius for engineers (adapted from [135])

Degree of Curve	Radius (ft, m)	Delineator Spacing = S (ft, m)	Chevron Spacing = S (ft, m)
1	5730, 1747	225, 68.58	400, 121.9
2	2865, 873.3	160, 48.77	280, 85.34
3	1910, 582.2	130, 39.62	200, 60.96
4	1433, 445.6	110, 33.53	200, 60.96
5	1146, 358.4	100, 30.48	160, 48.77
6	955, 297.03	90, 27.43	160, 48.77
7	819, 252.21	85, 25.91	160, 48.77
8	716, 218.2	75, 22.86	160, 48.77
9	637, 194.2	75, 22.86	120, 36.58
10	573, 174.7	70, 21.34	120, 36.58
11	521, 158.8	65, 19.81	120, 36.58
12	478, 145.7	60, 18.29	120, 36.58
13	441, 134.4	60, 18.29	120, 36.58
14	409, 124.7	55, 16.76	80, 24.38
15	382, 116.4	55, 16.76	80, 24.38
16	358, 109.1	55, 16.76	80, 24.38
19	302, 92.05	50, 15.24	80, 24.38
23	249, 75.9	40, 12.19	80, 24.38
29	198, 60.35	35, 10.67	40, 12.19
38	151, 46.02	30, 9.144	40, 12.19
57	101, 30.78	20, 6.096	40, 12.19
Note: Approach and departure delineation on horizontal curves should be spaced at 2S using 3 delineators or 1 chevron.			

10.2.2 Pennsylvania

The Pennsylvania Department of Transportation has developed and implemented “The Advanced Curve Warning Initiative” [137]. The Advanced Curve Warning treatment was installed at 5 locations in 5 counties. There were 8 sets of markings installed at these locations. Each marking was made up of a curved arrow and a “SLOW” legend enclosed with transverse bars (Figure 100). Based on the evaluation of the original pilot program, there is expected to be a reduction of the 90th percentile speed. This translates into an estimated 25% reduction in curve-related deaths at each of the locations where installation is planned.



Figure 100. PennDOT Advanced Curve Warning Treatment [137]

10.2.3 Colorado

The Colorado Department of Transportation installs rumble strips before curve approaches [138]. They install 3 clusters, each of which is 11 ft 4 in (3.454 m) wide. The first cluster is placed 700 ft (213.4 m) before the start of the curve. The distances between the clusters are 200 ft (60.96 m), and 100 ft (30.48 m) starting from the first rumble strip cluster. The last cluster is placed 400 ft (121.9 m) before the start of the curve. The drawing for the installation of rumble strips before curve approaches is given in Figure 101.

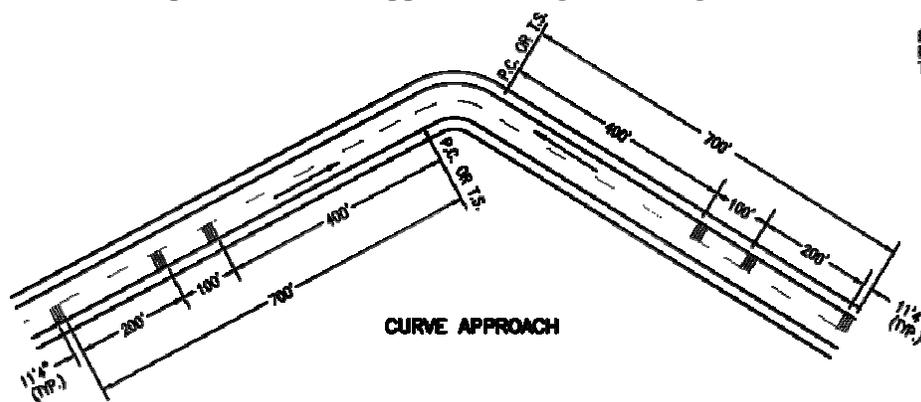


Figure 101. Installation of Transverse Rumble Strips before Curve Approaches in Colorado.

10.3 Recommendations to ODOT

In a report prepared by Torbic et al. [139], strategies to improve the safety at horizontal curves to achieve the overall goal of AASHTO's strategic highway safety plan, significant reduction in highway fatality crashes, were identified. The main objectives for improving safety along horizontal curves are identified as to reduce the likelihood of a vehicle leaving its lane and either crossing the roadway centerline or leaving the roadway at a horizontal curve and to minimize the adverse consequences of leaving the roadway at a horizontal curve. Objectives and strategies for improving safety at horizontal curves are also provided in the study (Table 32). The treatments given in the table are presented in the order from short term, low cost strategies to high cost, long term strategies.

Table 32. Objectives and Strategies for Improving Safety at Horizontal Curves [139]

Objectives	Strategies
Reduce the likelihood of a vehicle leaving its lane and either crossing the roadway centerline or leaving the roadway at a horizontal curve	Provide advance warning of unexpected changes in horizontal alignment.
	Enhance delineation along the curve
	Provide adequate sight distance
	Install shoulder rumble strips
	Install centerline rumble strips
	Prevent edge drop-offs
	Provide skid-resistant pavement surfaces
	Provide grooved pavement
	Provide lighting of the curve
	Provide dynamic curve warning system
	Widen the roadway
	Improve or restore superelevation
	Modify horizontal alignment
	Install automated anti-icing systems
	Prohibit/restrict trucks with very long semi-trailer on roads with horizontal curves that cannot accommodate truck off-tracking
Minimize the adverse consequences of leaving the roadway at a horizontal curve	Design safer slopes and ditches to prevent rollovers
	Remove/relocate objects in hazardous locations
	Delineate roadside objects
	Add or improve roadside hardware
	Improve design and application of barrier and attenuation systems.

10.4 Recommended Evaluations

A more comprehensive instrument based on the TTI curve radiusmeter could be developed. This new device could not only provide curve radius information, but also the beginning and the end points of the curve, the curve length, the curve superelevation, and the grade (uphill or downhill) of the curve. These measurements could be directly fed into a program like the ODOT OCARD program which would then automatically compute the safe speed, the advisory speed, the advance distance for the advance warning sign, the type of advance warning sign, the type of curve delineation elements, the locations of all delineation elements, and the bill of materials. Such a system would not require any workers to endanger themselves while making curve measurements on the road.

In addition such a system would provide more accurate and more consistent curve delineation practices throughout the state by reducing the human error and automating the curve delineation decisions and practices. This uniformity could also potentially reduce the state's liability exposure.

An evaluation study would also help to identify the benefits and effectiveness of the developed system, software, and practice.

More information regarding curve delineation can be found in section 15 and 16 of this report.

11 WET / DARK DELINEATION

11.1 Wet/Dark Delineation Introduction

Retroreflective pavement marking materials historically have performed poorly in wet weather. The rainwater on the markings sharply reduces their visibility. Special wet weather marking tape using enclosed lenses instead of glass beads have been developed to remedy this problem. Another solution is to use raised pavement markers. A third is the rumble stripe, where edgelines are laid over a rumble strip; rumble stripes are discussed in the section of this report on rumble strips.

11.2 Comparing Wet Weather and Standard Tapes

Schnell, Aktan, and Lee conducted a comparative evaluation of nighttime visibility of different pavement marking materials under dry, wet, and rainy conditions [140, 141]. The three materials tested were:

- Commercially available polymer preformed flat marking tape incorporating 1.5 index beads
- Commercially available preformed patterned (structured) tape incorporating 1.75 index ceramic beads (patterned tape)
- Commercially available wet weather tape with enclosed lens design

Under these three conditions were tested at a test track in Minnesota: dry (ASTM E-1710), wet recovery (just after rainfall) (ASTM E-2177), and simulated rain (ongoing 1in/hr rainfall) (ASTM E-2176).

11.2.1 Study method

Eighteen subjects, 7 male, 11 female, were recruited for the study. Their age range was 55 – 74 yrs, average 62.5 yrs, thus representing a group of generally older drivers. The participants drove the experimental vehicles, a 1996 Ford Taurus with conventional headlights and a 2001 Ford Taurus with Visually Optically Aimed (VOA) headlights, along the pavement marking treatments on the test track. Eye movements were tracked electronically. The task of the participants was to state the earliest point when they were able to see the end of the pavement markings. Additionally the retroreflectance of each pavement marking material was measured with handheld retroreflectometers under the three weather conditions. The reflectance values were correlated to the detection distances so that the ability of the ASTM standards to predict visibility under each condition could be assessed.

11.2.2 Study results

The wet weather tape performed best, followed by the patterned tape, and the flat tape performed the worst. Flat tape performed poorly under both wet conditions and had very short detection distances even when dry (75.46 ft (23 m), preview time of about 1 s at 55 mph (88.51 kph)). Patterned tape was about as poor as flat tape under the simulated rain condition, but was better in wet recovery (154.2 ft (47 m)). Wet weather tape performed best under all conditions (180.4 ft (55 m) even in rain). Dry retroreflectivity was highest for all materials, followed by wet recovery and simulated rain. Flat tape showed a 70% decrease in retroreflectivity in going from dry to wet recovery. Patterned tape showed a 49% decrease, and wet weather tape showed a 35% decrease. The wet weather tape did show a retroreflectivity decrease of 52% for simulated rain compared to dry values.

11.3 Wider Pavement Markings

Schnell and Ohme examined flat paint and beads, patterned ceramic markings, and enclosed lens wet weather material detection distances when new and after one year of wear under dry and wet conditions [142]. The potential benefit of wider pavement markings to accommodate older drivers was also examined.

Schnell and Ohme found that the use of wider pavement markings 7.87 in (0.2 m) versus 3.94 in (0.1 m)) improved detection distances slightly but not significantly when markings were new, and this advantage was completely lost after a year of wear. However, wider markings were viewed more favorably by subjects. Wider markings may improve near visibility of markings, or perhaps during fog. The observed detection distance appeared to be a function of retroreflectance. Pavement markings supplemented with Raised Pavement markers and delineator posts provided the longest detection distances.

11.3.1 TTI study on Wider Pavement Markings

Gates and Hawkins surveyed states using or evaluating wider longitudinal pavement markings in the spring of 2001 [143]. They surveyed departments of transportation in the United States and Canada, and they conducted a literature review. The authors found that 29 of the 50 states were using wider pavement markings, though at varying levels of implementation and for varying reasons, as indicated in Figure 102. Crash data supporting the use of wider pavement markings had not been sufficient, so alternative justifications based on motorist surveys or visibility measurements were made. The most common wider marking width used was 6 in (0.1524 m) (see Figure 102) though Maryland has experimented with widths as large as 10 in (0.254 m) [143]. The most common reasons given for using wider pavement markings was the improvement in visibility, cited by 57% of the DOTs surveyed. The second most common justification was the improvement for older drivers (19%), then crash reduction (14%), and driver comfort and aesthetics (8%). Most agencies indicated that they were satisfied with the performance of wider pavement markings and would continue their use despite the increased costs. The cost is estimated to be 20% more for 5 inch (0.127 m) lines (Oklahoma) to 50% more for 8 inch (0.2032 m) lines (Nevada) compared to 4 in (0.1016 m) markings. Agencies that did not use wider markings cited the lack of conclusive crash reduction evidence. Benefits of wider markings cited by agencies included favorable public response (by 30% of agencies) and improved visibility (also 30%), improved driver comfort and aesthetics (5%) and crash reduction (3%). Most states had not conducted a study of crash reduction; 22% saw no significant results, and 3% cited a significant crash reduction. The literature reflects this lack of objective measures of effectiveness.

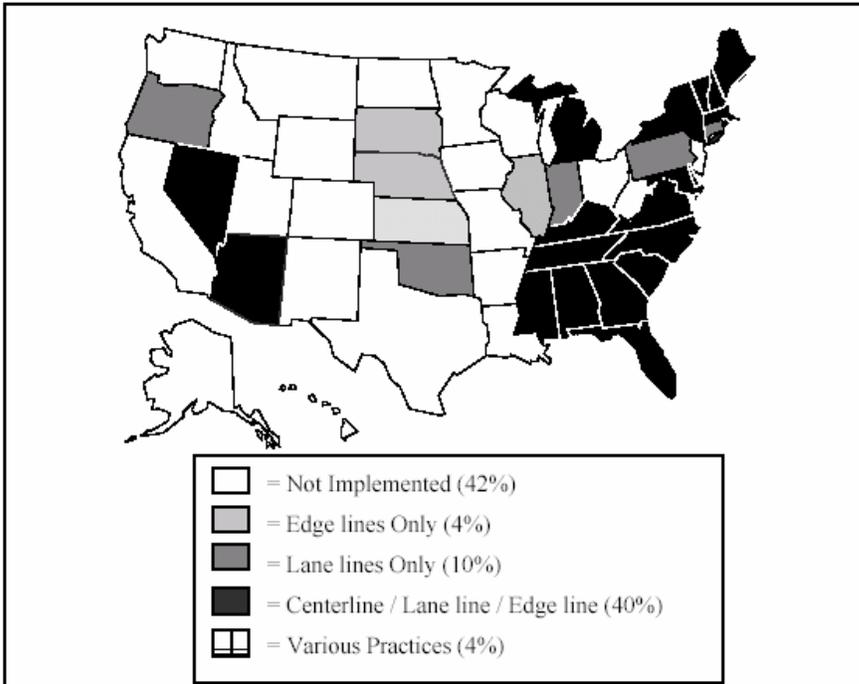


Figure 102. States using wider longitudinal pavement markings as of spring 2001[143].

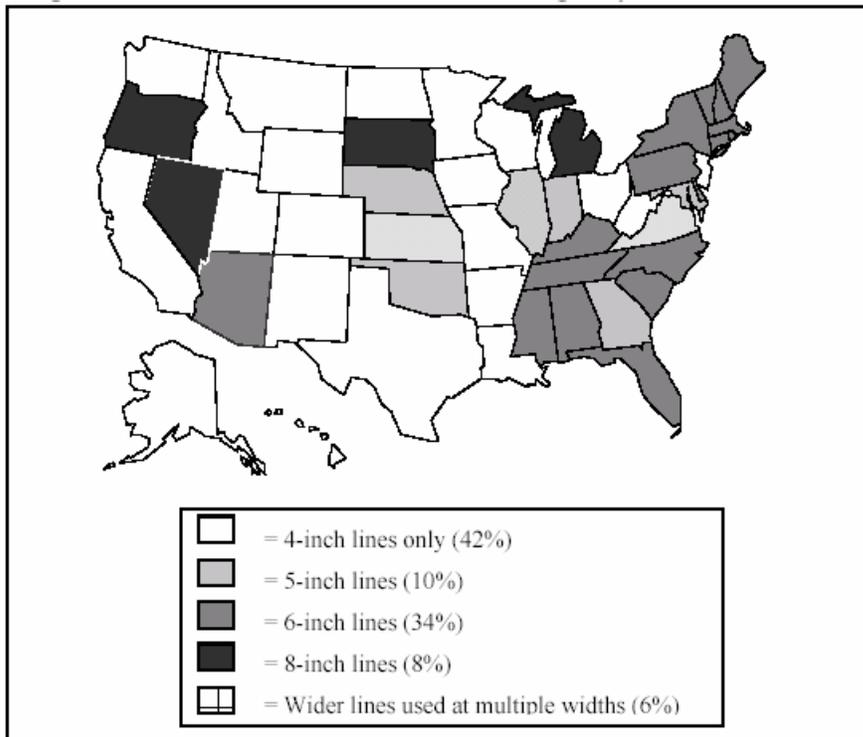


Figure 103. Longitudinal pavement marking widths used by various states [143].

11.3.2 Alternative Measures of Effectiveness of Wider Pavement Markings

Because most evaluations of wider pavement markings are based on qualitative assessments, or on measurements of end detection distance that may depend more on the retroreflectivity of the material than on the width, Gates, Chrysler, and Hawkins [144] suggest that new alternative measures of effectiveness would be needed. They suggest that wider pavement markings may increase driver comfort by improving peripheral visibility leading to reduced driver workload. New measures of effectiveness will need to be devised to determine the answer to this question, and may be found in the cognitive sciences. Any nonstandard measures will also need to be validated in simulators and on the field before use [144].

11.4 No Passing Zone Pennant Signs

Several states mark the beginning of no passing zones with a triangular pennant shaped sign on the right hand side of the road. This is in addition to the standard centerline indications. This sign reinforces the indication given by the change in centerline pattern and helps counter the effect of wet weather reducing the visibility of centerline markings.

11.5 Recommendations to ODOT

The use of wet weather tape with enclosed lens design as a pavement marker material performed significantly better than the patterned and the flat type in a comparative study at nighttime under wet, dry and rainy conditions. The use of additional signs as adopted by other states to mark the beginning of no passing zones is also recommended. The No Passing Zone Pennants are especially useful at night.

11.6 Recommended Evaluations

An evaluation including driver visibility, driver performance, cost/benefit analysis considerations is recommended to determine where to use wet weather tape with enclosed lens design and where to employ wider pavement markings.

The use of wider pavement markings especially for older drivers is discussed in Section 7 Accommodating Older Drivers.

More information regarding wet / dark delineation can be found in section 15 and 16 of this report.

12 RAISED PAVEMENT MARKER SPACING

12.1 Ohio Department of Transportation Guidelines

In Section 3B-11 of the Ohio Department of Transportation Manual of Uniform Traffic Control Devices, information on raised pavement markers is given [5]. Raised pavement markers should be at least 10 mm (0.4 in) high and mounted on or in a road surface. The color of raised pavement markers under both daylight and nighttime conditions shall conform to the color of the marking for which they serve as a positioning guide, or for which they supplement or substitute.

There are two types of raised pavement markers specified in ODOT guidelines: Type A markers and Type B markers [145]. Type A markers are intended to provide high visibility both day and night. Their daytime visibility shall be assured by size, shape and color. The markers shall be a high visibility yellow or white color which will not degrade substantially due to traffic wear and which will match the color of reflector. When viewed from above, the markers shall have a visible area of not less than 14 sq. inches (9030 sq. mm). When viewed from the front, parallel to the pavement, as from approaching traffic, the marker shall have a width of approximately 4 inches (0.1016 m) and a visible area of not less than 1.5 sq. inches (0.00096 sq. m). Type B markers are intended to provide high visibility at night by retroreflecting light from automotive headlights back to the driver.

The typical spacing for raised pavement markers when required to supplement pavement marking as given in ODOT guidelines is shown in Table 33. The typical spacing for pavement markers when used to substitute for pavement marking is given in Table 34.

Table 33. Typical Spacing for Pavement Markers When Required to Supplement Pavement Marking [145]

LINE	TYPE	SPACING
EDGE LINE	A or B	20' (6 m) C/C
LANE LINE	A or B	40' (12 m) C/C*
CENTER LINE (SINGLE BROKEN)	A or B	40' (12 m) C/C*
CENTER LINE (DOUBLE/SOLID)	A or B	2 UNITS SIDE BY SIDE 4" (100 mm) APART 20' (6 m) C/C
CHANNELIZING LINE (INCLUDES EXIT GORE NOSE)	A or B	10' (3 m) C/C

Table 34. Typical Spacing for Pavement Markers When Used to Substitute for Pavement Marking [145]

LINE	TYPE	SPACING
EDGE LINE	A	5' (1.5 M) C/C
LANE LINE	A	5 · 2.5' (0.75 M) C/C 30' (9 M) GAP [40' (12 m) CYCLE]
CHANNELIZING LINE (INCLUDES EXIT GORE NOSE)	A	5' (1.5 m) C/C
EDGE LINE (TWO COLOR) (WHITE / YELLOW)	A	BACK TO BACK 5' (1.5 M) C/C

12.2 Benefits of Raised Pavement Markers

In the study conducted by Grant and Bloomfield [146] for the Federal Highway Administration, guidelines for the use of RPMs are determined based on an extensive survey of literature. These guidelines provide more details on the use of RPMs than the Manual on Uniform Traffic Control Devices.

Use of RPMs would result in low variability for speed, deceleration rates through curves that would reflect advance warning, and a mean speed that is no greater than that achieved during clear-day good driving conditions. Also lateral position would not encroach onto the shoulder or adjacent lanes and there would be low variability in lateral position. [146]

Although it is evident that studies show RPMs are beneficial, the speed advantages of better delineation should also balance with the driver's ability to respond to emergency situations at night. The use of RPMs may allow the driver to safely control the vehicle at higher speeds, but RPMs cannot provide the same advance information about an impending collision with a road hazard (e.g., an animal or person crossing the road). Therefore, if the driver travels faster because far-delineation provides sufficient driving cues, there is a potential danger for hazard collisions to increase. [146]

In the Roadway Delineation Practices Handbook by Migletz [147] et al., the advantages of using RPMs are listed as follows:

- Retroreflective RPMs provide increased retroreflectivity under wet weather conditions.
- Both retroreflective and non-retroreflective RPMs are more durable than painted lines. Replacement is much less frequent and repainting operations under heavy traffic conditions can often be avoided.
- The vehicle vibration and audible tone provided by vehicles crossing over the RPMs creates a secondary warning.
- The capability of providing directional control of retroreflected color permits their use in conveying a wrong way message.

12.3 Raised Pavement Marker Location Guidelines

Guidelines for RPM locations [146] are as follows:

- Supplement double-yellow centerlines with RPMs on two-lane rural curves.
- Delineate center and edgelines where there are pavement width reductions at a narrow bridge.
- Use RPMs at painted gores, exits, and bifurcations.
- Install snowplowable RPMs on all freeways and interstate highways.
- Install snowplowable RPMs on State highways at locations determined by the Bureau of Traffic Engineering on the basis of accident data.
- Do not use snowplowable RPMs on interchange ramps.
- Place RPMs in line with and in gap of skip lines.
- Place RPMs between double-yellow centerlines when used on two-way, two-lane roads.
- Place RPMs outside double-yellow centerlines, on both sides of traffic, when used on two-way, multilane roads.
- Offset RPMs 50.8-76.2 mm (2-3 in) from a solid edgeline, specifically to the traffic side of left edgelines.
- Offset RPMs to the traffic side of left edgelines on exit and entrance ramps.
- Retroreflective RPMs should be placed so that the face is perpendicular to a line parallel to the roadway centerline.
- RPMs should not be placed over longitudinal or transverse joints of the pavement surface.
- Offset RPMs 50.8-76.2 mm (2-3 in) from the edge of solid paint or thermoplastic markings to avoid painting.
- Ensure that there is a 152.4-mm (6-in) space between double solid-yellow center lines instead of a 203.2-mm (8-in) space to prevent RPMs from being painted.
- Concrete joints should not be straddled by a snowplowable RPM (unless lane narrowing will occur because of the offset RPMs).
- For typical "cloverleaf" entrance/exit ramps (i.e., 4.9-m (16-ft) wide, radius ~73.2 m (240 ft), therefore about 24-degree curve), place RPMs on the outer edge of the ramp.
- Turn each RPM so that the angle between the tangent of the outer edgeline and the reference axis of the RPM is 15 degrees.
- If RPMs are used to delineate outside of the traffic lane, place at the location of the lane boundary.

12.4 Raised Pavement Marker Spacing Guidelines

Guidelines for RPM spacing [146] are as follows:

- Supplement double solid-yellow centerline on a two-lane, two-way road with RPMs spaced at 2N—24.4 m (80 ft)—placed between lines.
- Supplement centerline indicating passing in one direction, on a two-lane, two-way road with RPMs spaced at 2N—24.4 m (80 ft)—placed between skip lines.
- Supplement center skip lines indicating passing in both directions, on a two-lane, two-way road with RPMs spaced at 2N—24.4 m (80 ft)—placed between skip lines.
- Supplement centerlines indicating a transition from passing in both directions to no passing zone, on a two-lane, two-way road with RPMs spaced at 2N—24.4 m

(80 ft)—placed between skip lines, and with RPMs spaced at $N=12.2$ m (40 ft)—placed outside of double solid-yellow lines.

- Supplement double solid-yellow centerline on a multilane, two-way road with RPMs spaced at $N=12.2$ m (40 ft)—placed beside lines, specifically 50.8-76.2 mm (2-3 in) away.
- Supplement broken lane lines with RPMs spaced at $2N=24.4$ m (80 ft)—unless otherwise specified, placed between skip lines.
- Supplement solid left edgeline with RPMs spaced at $N=12.2$ m (40 ft)—placed to the inside of the lane, 50.8-76.2 mm (2-3 in) away from the line. Do not usually supplement solid right edgeline with RPMs.
- Use $2N=24.4$ m (80 ft)—when the degree of curvature is less than 3 degrees.
- Use $N=12.2$ m (40 ft)—when the degree of curvature is greater than or equal to 3 degrees but less than 15 degrees.
- Use $N/2=6.1$ m (20 ft)—when the degree of curvature is greater than or equal to 15 degrees.
- For curves greater than 20 degrees, use two RPMs.
- If right edgelines present an exceptional hazard as described below, supplement with RPMs spaced at 6.1 m (20 ft). Also supplement paint for a reasonable distance of treatment before hazard.
- If RPMs are used on center or lane boundaries, on straight tangents, the maximum spacing should be 24.4 m (80 ft).
- If RPMs are used on center or lane boundaries, on 200-m (656-ft) radius curves (this translates into curves with ~ 8-9 degrees of curvature), the maximum spacing should be 12.2 m (40 ft).

12.5 Raised Pavement Marker Applications

12.5.1 Lightguard RPMs in Crossovers

The Kansas Department of Transportation deployed Lightguard lighted raised pavement markers (RPMs) in a crossover [50]. The RPMs were evaluated with the Safety Warning System (SWS), which is designed to inform drivers of an upcoming work zone through a message encoded in a radar signal broadcast from a trailer mounted transmitter.

When the Lightguard system was turned on (the SWS remaining active), an additional decrease in mean and 85th percentile speeds occurred. The change was statistically significant at a 95% confidence level for both trucks and passenger cars during both daylight and darkness conditions, though the more dramatic change occurred at night. The percentage of passenger cars passing within 30 cm (1 ft) of the edge line decreased from 8.9 to 5.2 percent with the deployment of the RPMs, indicating that drivers were keeping closer to the center with the RPMs active. The pictures of the lighted RPMs and unlighted RPMs are given in Figure 104 and Figure 105 respectively.



Figure 104. Crossover Delineated by Lightguard Lighted RPMs



Figure 105. Crossover without Lighted Delineation

12.5.2 Recessed Pavement Markers

Another type of pavement markers used is the recessed pavement markers. Washington is one of the states using recessed pavement markers on their roads. Pavement markers are installed in the grooved pavement in this application. Washington DOT's standard plan [148] for the application of recessed pavement marker is given in Figure 106. Top of the pavement marker is 0 – 1/8 in (3.175 mm) below the pavement surface.

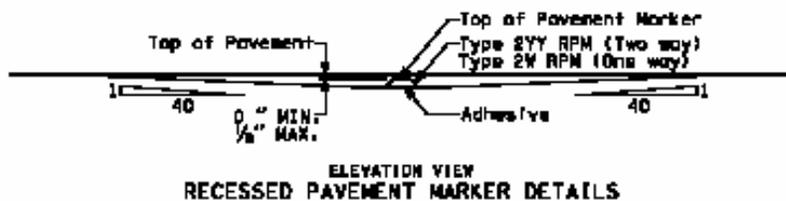


Figure 106. Recessed Pavement Marker Details [148]

In a study conducted by Oregon Department of Transportation raised and recessed pavement markers were evaluated [149]. The researchers found that the recessed pavement markers do not perform as well as raised pavement markers. The initial performance was reduced strictly because they were recessed and the slots collected debris, rain and snow and when covered recessed pavement markers were ineffective.

12.6 Evaluation of Permanent Raised Pavement Markers

In the study [150] conducted by Geni Bahar for the National Cooperative Highway Research Program, a safety evaluation of permanent raised pavement markers (PRPM) was performed. The results of the study were evaluated for two-lane roadways and four-lane freeways.

For two-lane roadways, it is stated that the purpose of PRPMs is to provide improved delineation at night. Drivers on approaches to curves need 3 to 5 seconds of preview distance in order to feel comfortable with the changes in the road path. At night, such long preview distances cannot be provided by paint, but are possible using PRPMs, post-mounted delineators, and chevrons. It is expected that the improved visibility produced by PRPMs will influence crash rates by affecting two types of driver behavior:

- Lane control and positioning: Studies of *conventional* PRPMs have found that PRPMs on curves cause drivers to shift away from the centerline at night. However, the impact on lane position during the day is not conclusive.
- Speed control: When the preview of the road ahead is reduced, as it is during nighttime with low-beam headlights, lane control becomes more difficult and driver workload increases, causing drivers to compensate by reducing their speed. Conversely, when the preview of the road is improved through delineation, driver workload decreases and drivers may compensate by increasing speeds. Studies have found that speed increases at night after the implementation of PRPMs. Improved delineation, in the form of post-mounted delineators, was associated with nighttime speed increases and increased crash frequency on roads with low design standards, but not on roads with high design standards.

Bahar summarized the expected PRPM impacts on two-lane roadways in the study. The substantial improvements in nighttime centerline visibility and the associated increase in driver comfort after the implementation of PRPMs are expected to have the following impacts on driver behavior:

- Reduced oncoming and left-lane encroachments at night,
- Increases in shoulder encroachments at night, and
- Small increases in speeds at night.

These changes in driver behavior are expected to have the following impacts in turn:

- Decreases in nighttime head-on crashes, with increasing benefits as traffic volumes increase;
- Decreases in safety benefits as the degree of curvature increases;
- Decreases in safety benefits as the vehicle moves closer to the edgeline;
- Decreases in wet weather nighttime crashes;

- Slight decreases in daytime wet weather crashes; and
- Less positive effects of PRPMs on gentle curves and less negative effects on sharp curves on roads with illumination when compared with roads without illumination.

For four-lane freeways, the purpose for the use of PRPMs is providing a comfortable driving environment and improving safety in conditions of decreased visibility (i.e., nighttime and wet weather conditions). As with two-lane roadways, the implementation of PRPMs on the lane line of freeways is expected to impact two types of driver behavior:

- Lane control and positioning: Increased delineation of the lane line is likely to cause drivers to stay better centered in lanes delineated on both sides. Where the lane line but not the edgeline is delineated, drivers are likely to position themselves farther from the delineated line toward the edgelines demarcating the median and the shoulder. The number of lane line encroachments, and therefore the potential for sideswipe crashes, will decrease. Since the possibility that a lane encroachment resulting in a crash is higher at higher traffic volumes, a measure that reduces lane line encroachments will have a proportionally greater effect at higher traffic volumes.
- Speed control: Improved visibility is likely to increase driver confidence and comfort to the extent that travel speeds will increase. Freeways have high design standards (e.g., high standards for degree of curvature, lane widths, and shoulder widths); therefore, it is unlikely that small speed increases will cause drivers to operate at or close to the margin of safety with respect to these parameters. Speed increases, however, may result in increased crash occurrence due to increased stopping, deceleration, and weaving distances required, especially during conditions of reduced visibility.

Bahar summarized the expected PRPM impacts on four-lane freeways in the study. The substantial improvements in visibility for delineation at night and during poor weather conditions, and the associated increase in driver comfort after the implementation of PRPMs are expected to have the following impacts on driver behavior at night and poor daytime weather conditions:

- Reduced encroachments over the lane line,
- Increased shoulder encroachments, and
- Small increases in speed at night.

These changes in driver behavior are hypothesized to have the following impacts on crashes in turn:

- Decreases in nighttime crashes, with increasing benefits at higher traffic volumes;
- Decreases in guidance-related crashes (e.g., sideswipes);
- Decreases in wet weather crashes.

Bahar also performed an evaluation study in six states: Illinois, Missouri, Pennsylvania, New York, Wisconsin, and New Jersey. The effects of snowplowable PRPMs on non-intersection crashes on a representative sample of two-lane roadways, four-lane expressways, and four-lane freeways were evaluated. The analysis showed that the nonselective implementation of

PRPMs on two-lane roadways, overall, does not significantly reduce total or nighttime crashes, nor does it significantly increase these crash types. The results have also showed that selective implementation of PRPMs requires a careful consideration of traffic volumes and roadway geometry (degree of curvature). At low volumes (where the annual average daily traffic is less than 5,000 vehicles per day) PRPMs can in fact be associated with a negative effect, which is magnified by the presence of sharp curvature. The installation of PRPMs at non-interchange locations on four-lane freeways showed neither a positive nor a negative overall safety effect on total and nighttime crashes. However, some significant reductions were recorded for wet weather crashes at locations on four-lane freeways, and there are indications that PRPMs are only effective in reducing *nighttime* crashes where the AADT exceeds 20,000 veh/day.

12.7 Raised Pavement Marker Maintenance Operations

Every state has different procedures for the maintenance of the RPMs. In a study by Freedman et al. [151], different maintenance practices of states are listed.

- In California RPMs are replaced when two or more consecutive markers are missing.
- In Florida RPMs are replaced when eight or more consecutive markers are missing.
- In Texas RPMs are replaced when 50 percent or more markers are missing within 1.6 km (1 mile) of highway.
- Massachusetts replaces only reflective lens if casting is intact.
- Michigan replaces only reflective lens if casting is intact.
- New Jersey replaces only reflective lens if casting is intact.
- In Massachusetts snowplowable RPMs are replaced when 30 percent or more markers are missing.
- New Jersey uses visual inspection.
- In Pennsylvania RPMs are replaced as needed, determined by visual inspection.

12.8 Recommendations to ODOT

Raised pavement markers are effective in providing visual guidance to drivers. Better visual guidance of drivers means increased preview time for drivers. More preview time provides more comfortable driving and better information processing.

Raised pavement markers also provide long preview times in wet weather conditions. RPMs are not obscured by rain water and provide adequate visibility and preview in rain.

Long preview times mean more relaxed information processing and provide longer visibility at night for drivers, which reduce the error in driving and accidents.

ODOT should continue its practice as specified in MUTCD.

12.9 Recommended Evaluations

A comparative study for the use of RPMs and rumble strip with pavement marking overlaid could be performed.

More information regarding raised pavement markers can be found in section 15 and 16 of this report.

13 INFORMATION DISSEMINATION

The objective of information dissemination is to provide information to travelers to effectively plan their trip prior to their departure; and when en-route, information to drivers to avoid congestion and/or to adjust their driving behavior (e.g., in response to unsafe conditions) [152]. Traveler information provides choices for travelers – a key attribute of mobility. They can select different routes, different modes, different times, or even different destinations. They can avoid congested or unsafe routes (e.g., due to adverse weather conditions). Their ability to choose improves their trip. Such knowledge also reduces stress and limits risk taking behavior, thus producing better travel conditions. Pre-trip information is typically disseminated to the public via websites, media broadcasts, and mobile communication devices (e.g., personal digital assistants, pagers, and cell phones). En-route traveler information has traditionally been disseminated via commercial radio; changeable message signs (CMS) and highway advisory radio (HAR). With the emergence of wireless communication technologies, en-route traveler information can also be disseminated through wireless phones, web-enabled wireless phones, and a variety of personal digital assistants (PDA) equipped with wireless communication capabilities.

Traveler information can be divided into two categories [152]: static or dynamic. Static information can be defined as planned or known events, while dynamic information can be defined as the most current available information. Real-time (dynamic) information changes continuously depending on a wide variety of events, whereas static information does not change.

Static Information includes:

- Construction and maintenance activities that reduce the number of travel lanes along a section of roadway.
- Special events that generate significant increases in traffic that can impact travel along specific roadways, and sections of roadways.
- Hours of operation of HOV lanes and carpool definition.
- Vehicle restrictions (height, weight, etc.)

Dynamic Information includes:

- Roadway travel conditions associated with travel delay, such as congestion, locations of queues, and incident locations
- Potential alternative routes which can facilitate travel, particularly in the event of a temporary roadway closure
- Weather advisories detailing snow, ice, and fog which can impact travel
- Park-n-ride lot status

Most common ways of information transfer are [152];

- Changeable Message Signs (CMS): CMSs are programmable traffic control devices that can usually display any combination of characters to present messages to motorists. These signs are either permanently installed above or on the side of the roadway or portable devices attached to a trailer or mounted directly on a truck and driven to a desired location. Portable CMSs are much smaller than permanent CMSs

and are often used in highway work zones, when major crashes or natural disasters occur, or for special events (e.g., sport events) and emergency situations.

- Highway Advisory Radio: Highway advisory radio is another way of providing information to the drivers. Information is relayed to the drivers through the AM radio receiver in their vehicles and the drivers are instructed to tune their vehicle radios to a specific frequency via roadside or overhead signs. In addition, the highway advisory radio can be used automatically by overcoming the need for the signing. In certain road regions, highway advisory system will block the other radio services and automatically tune the vehicle radio to the highway advisory radio frequency.
- Telephone-based Traveler Information: The technological growth in the cellular telephone industry provided ability to the drivers to call special hotline systems for traffic information from within their vehicle.
- Commercial Radio: commercial radio is also a good way of providing travelers with real-time traffic information both in and out of their vehicles.
- Online services, the internet also provides pre-trip information to the travelers. Most states and many local sites have websites that include traffic information with the freeway management system often providing much of the information.
- Video Display Terminals: Video display terminals are another way of providing information to the travelers in their vehicles. A video display terminal (VDT) is mounted in the dashboard and these systems can be used to provide motorists with route guidance and navigational information in two different formats. One approach is to present the driver navigation and route guidance information in the form of maps or equivalent displays and the other is using simple symbolic signals (e.g., arrows, text instructions, or a combination of both) guide the driver along a recommended route. VDTs provide continuous access to current position, routing, and navigational information to the driver, computer-generated navigational maps and displays provide route guidance and navigation information, and information can be displayed in text, graphics, or both according to the demands of the drivers. However VDTs might present complex maps and displays to the drivers, which may create information overload and may add to the visual clutter in the vehicle. The most important limitation of the VDTs is that the drivers have to take their eyes off the roadway in order to receive information.
- Head-Up Display (HUD) originally developed for the aviation industry might be a better alternative to in-vehicle VDTs for presenting visual navigational and route guidance information to motorists. Automobile manufacturers are beginning to develop HUDs for presenting vehicle status and navigational information to drivers. A wide variety of options for displaying information may be available using HUDs. Through both icons and alphanumeric text, navigation and route guidance information may be projected directly into the driver's field of view. This is expected to reduce the need for visual scanning between two information sources (the inside instrument panel and the outside environment), and the associated visual accommodation time.

The different information needs and sources for providing them discussed above can be summarized as shown in Figure 107.

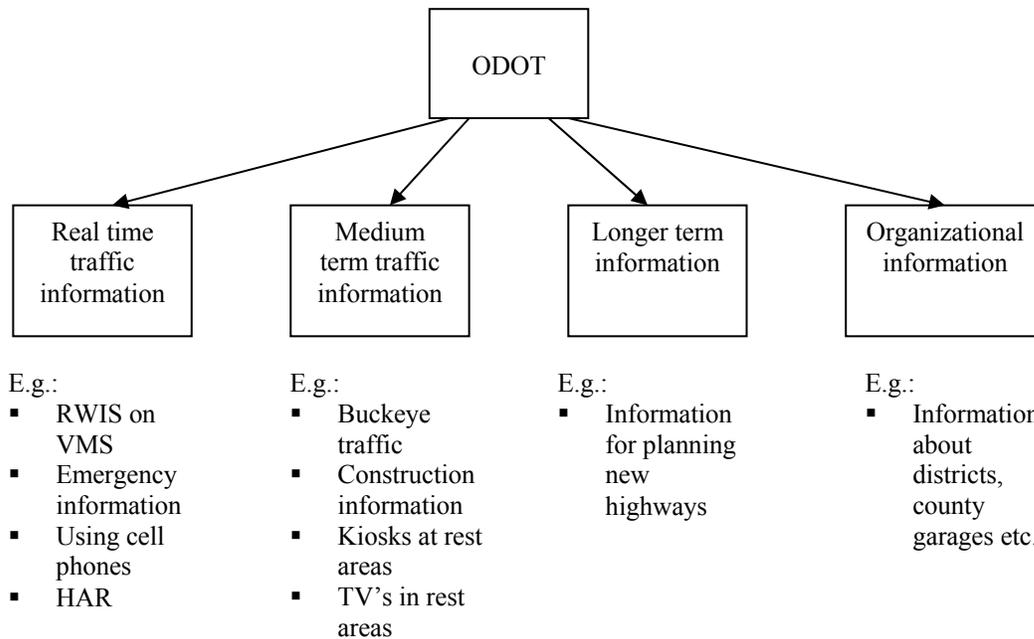


Figure 107. Information Needs and Sources

The Federal Highway Administration requires ITS projects to conform to the National ITS architecture and standards. The National ITS Architecture provides a common structure for the design of intelligent transportation systems. It is the framework around which multiple design approaches can be developed, each one specifically tailored to meet the individual needs of the user, while maintaining the benefits of a common architecture (e.g., compatibility and interoperability between systems, products, and services; without limiting design options).

Weisser and Horowitz classified the drivers into 5 categories and identified the demand for information by these drivers [153] as shown in Table 35. Commuters traveling at peak hours had the highest demand for travel information, lowest tolerance for delay, and the greatest likelihood to change the trip time. Commuters are time-sensitive, and most interested in door-to-door trip time, including parking. Shoppers have a higher interest in parking information, and a moderate interest in “whole trip” information. They are interested in perceived safety and convenience. Truck drivers have high demand for travel information, moderate tolerance for delay, and are likely to change routes if they feel that the information is accurate.

Table 35. Travel Information Demand [153]

	Travel Information Demand	Parking Information Demand	Delay Tolerance	Likely to Change Route or Time	ATIS Market Potential
Commuters	High	Low	Low	Route	High
Shoppers	Medium	Medium	Medium	Time	Medium
Special Trips	High	High	Low	Route	High
Other Trips	Low	Low	High	Neither	Medium
Truck	High	Low	Medium	Route	High

According to Weisse and Horowitz [153] drivers want more information at the right time. They want enough information to weigh their priorities and make a decision. Generally, drivers want to know if there is a problem, what the problem is, the delay, a prescribed remedy or alternate route, and how the alternate delay compares with the highway delay.

The different agencies involved in information dissemination are the ODOT central office, districts, and county garages. For each of these agencies it is necessary to determine what type of information should be made available, who will coordinate and control the information, how frequently the information will be updated, and what sources should be used for dissemination. The information to be disseminated can be broadly classified into three categories: traffic information, weather related information, and work zone or construction information. The primary sources available to communicate information to motorists include changeable message signs (CMS), kiosks, highway advisory radio (HAR), paid media, Intelligent Transportation Systems (ITS), and the World Wide Web (Internet).

Intelligent Transportation Systems (ITS) rely on advanced communication technology that enhances the existing highway infrastructure. The ITS help improve safety on the highways and make them function at a more efficient level. The main devices that are often used in ITS are closed circuit television (CCTV), surveillance cameras, and changeable message signs (CMS).

13.1 Traveler Information Websites

13.1.1 Users of Traffic Information Websites

In a study conducted by the University of Michigan Transportation Research Institute [154] it was found that the peak site usage occurred during the afternoon rush hours, but little increase was seen during the morning rush hour implying that the web site was not as effective at influencing morning travelers or traffic. The study identified six types of users. Aside from various types of commuters, the sites were used to support trucking traffic, companies that engage in on-site delivery or services, and third party traffic information providers.

The most frequently viewed web pages contained congestion overview maps or travel times. User testing also showed that most users preferred to only have to look at one web page to tell them what to expect on their trip, they did not want to “dig” through different pages to find

the details of congestion, incidents, or construction. They also found that user preferences for information types and formats may vary from city to city.

In a study conducted by Lerner et al. for the Federal Highway Administration (FHWA) 12 experiments on Advanced Traveler Information Systems (ATIS) and user surveys are used to develop guidelines for ATIS message content [155]. The research was conducted with 3 user groups: ATIS developers, ATIS service providers, and the driving public. Two axes of information were identified in the study; general traffic information vs. trip-specific information and pre-trip information vs. en-route information. Guidelines that should be followed in providing traffic and route information to drivers is outlined in a separate volume of the report [156]. The report outlines the guidelines that should be followed in determining the content, focus, and timeliness of the information provided. It is also recommended that the relative focus of the information should be tailored to the situation emphasizing incident delay, location, and suggested alternate information for pre-trip commutes. The authors also indicate that information should be time-stamped or otherwise documented so users know when the data were collected and their timeliness. A consistent, standardized set of terminology for communicating and characterizing traffic as well other information should be used. A list of the guidelines proposed in this study is provided in Appendix A.

13.2 Web Sites of Various States

13.2.1 Ohio – Buckeye Traffic

Real-time weather, traffic, and construction information which is updated frequently is available at the Buckeye Traffic website (<http://www.buckeyetraffic.org/>) [157]. Some screen shots from this website are shown below. In Figure 108 road construction activity for the state is shown. The road weather information given at the site is provided for Athens County as an example in Figure 109. The Buckeye Traffic website also provides webcams showing the road condition at given sites. The screenshot of Franklin County webcams is given in Figure 110 as an example. In Figure 111 overall construction activities for the state of Ohio are shown.

OHIO'S MACRO CORRIDOR ROUTES



OTIS - ROAD ACTIVITY

SEARCH ROAD ACTIVITY

CATEGORY	?	ALL CATEGORIES	
ROUTE	?	ALL ROUTES	
STATUS	?	<input checked="" type="radio"/> ALL <input type="radio"/> CLOSED <input type="radio"/> OPEN <input type="radio"/> RESTRICTED	
RESULTS	?	<input checked="" type="radio"/> SUMMARIZED <input type="radio"/> DETAILED	

[CLICK HERE FOR ADVANCED SEARCH](#)

Search

NOTES

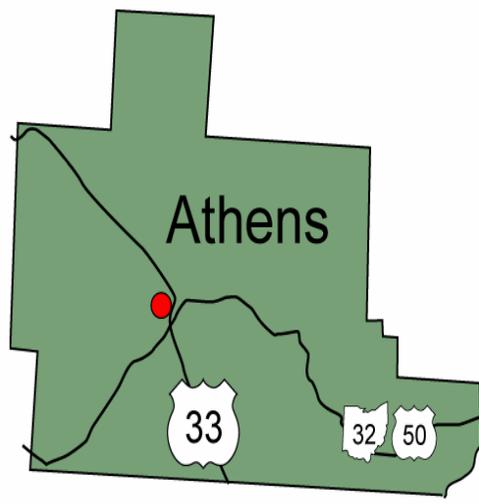
- On the **MACRO CORRIDORS** map, click a route shield to search on the route you clicked.
- On the **MACRO CORRIDORS** map, click a county to search on the county you clicked.
- You may customize your searches using the **SEARCH ROAD ACTIVITY** form.
- Contact your district Public Information Officer (PIO) for additional information. Click [this link](#) to view a district map to help identify your district PIO.
- Click [this link](#) to view more notes and disclaimers.

LOGIN STATUS	Not Logged in.	[LOGIN]	
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Figure 108. Screen Shot of the Buckeye Traffic Website Showing Road Construction Activity

www.BuckeyeTraffic.org

County: Athens
Location: Athens County



Road & Weather Sensors

SITE DETAILS	
SITE	31 - ATHENS COUNTY
LAST UPDATE	3/1/2004 5:08:42 PM
AVG WIND DIR	West
AVG WIND SPD	2 mph
MAX WIND SPD	13 mph
REL HUM	94 %
PRECIP RATE	0.07 iph
AIR TEMP	53 ° F
DEWPOINT TEMP	50 ° F
MIN TEMP	34 ° F
MAX TEMP	63 ° F
PRECIPITATION	Rain (Slight)
VISIBILITY	6562 ft.
VISIBILITY SITUATION	Clear
SUB SURF TEMP	46 ° F
PVMT SENSORS	1

Bridge Deck Simulator	
SURF STATUS	Other
SURF TEMP	57 ° F (14 ° C)

The Ohio Department of Transportation (ODOT)

Figure 109. Screen Shot of Athens County Road Weather Information on Buckeye Traffic Website

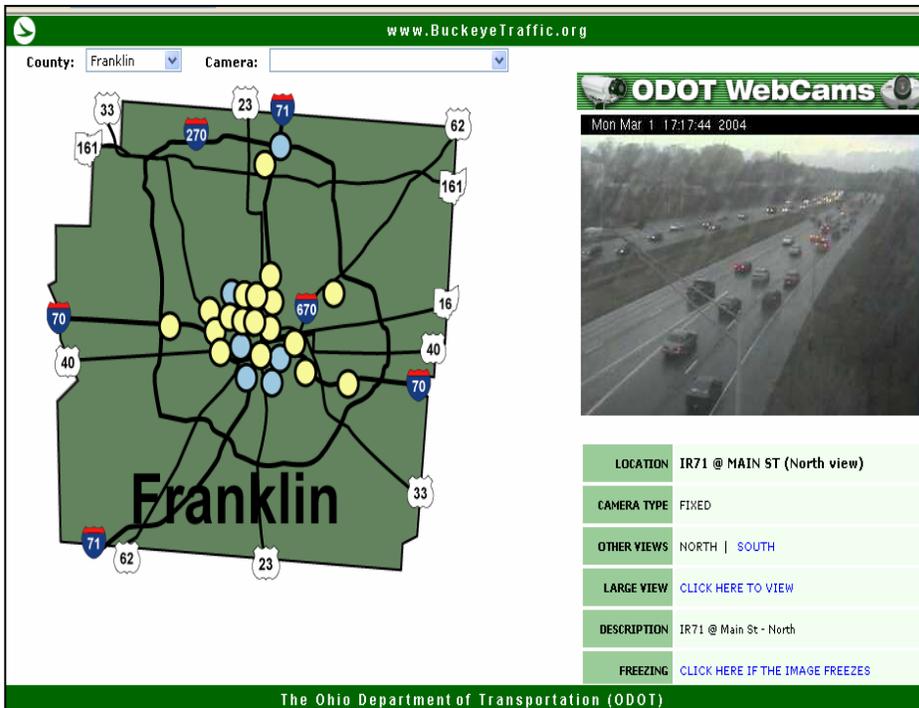


Figure 110. Screen Shot of Franklin County Webcams on the Buckeye Traffic Website

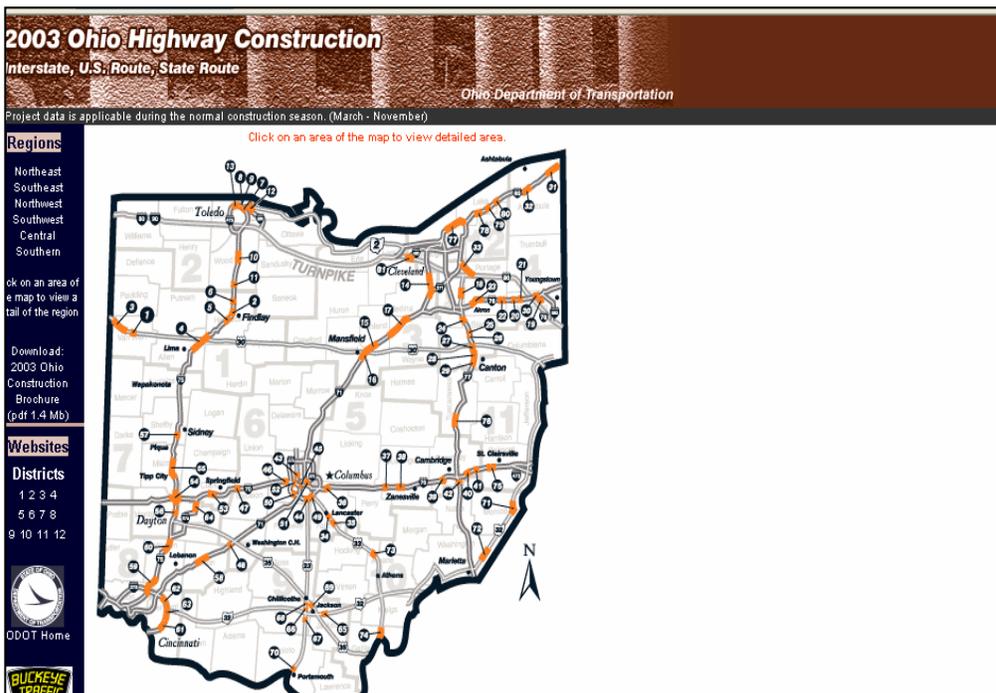


Figure 111. Screen Shot of the Buckeye Traffic Website Showing Highway Construction Projects

13.2.2 National Traffic & Road Closure Information Website

This site is linked to all state systems and is maintained by FHWA

(<http://www.fhwa.dot.gov/trafficinfo/>) [158]. In Figure 112 the screenshot of the website is given. The traffic information for all of the states can be reached using this site maintained by FHWA.

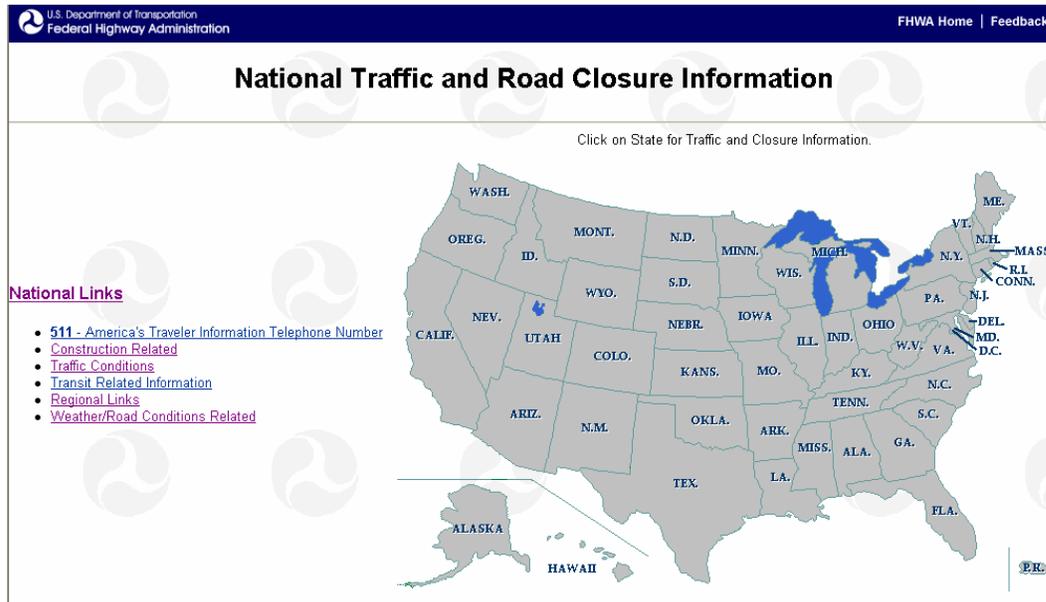


Figure 112. Screen Shot of the National Traffic & Road Closure Information Website

13.2.3 'Navigator', Georgia DOT's Intelligent Transportation System

The website (<http://www.georgia-navigator.com/>) provides information on weather, traffic and construction information on a real-time basis, updated frequently [159]. In Figure 113, a screenshot from the Navigator website shows the major and active incidents in the state. In Figure 114, a screenshot of the real time traffic information shown on changeable message signs on the roads is given. The planned construction for the 24-hour period is also provided on the Navigator website. The screenshot of the webpage is given in Figure 115.



Figure 113. Screen Shot of the Georgia Navigator Traffic Website Showing Major Traffic Incidents

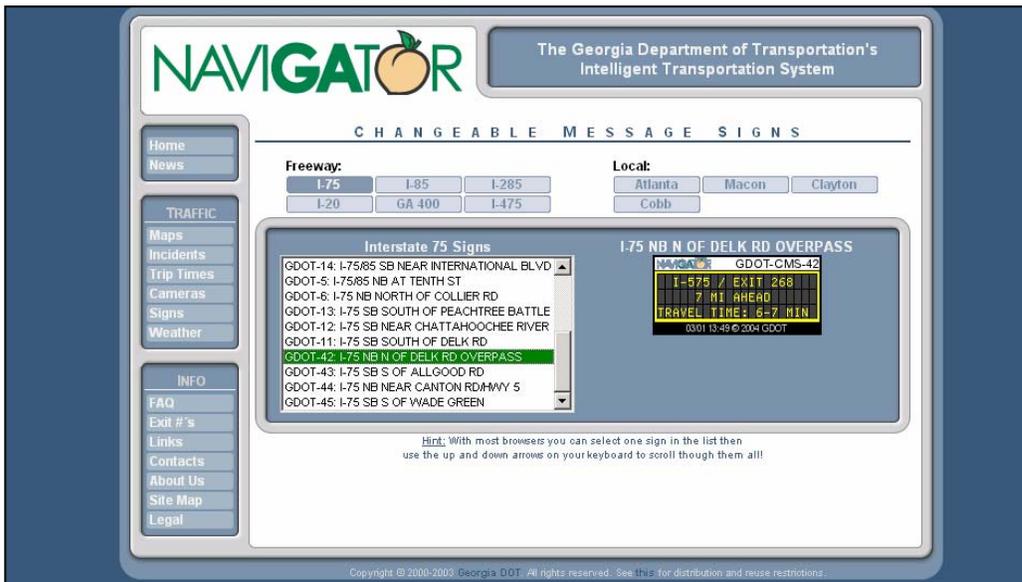


Figure 114. Screen Shot of Georgia Navigator Traffic Website with CMS Information

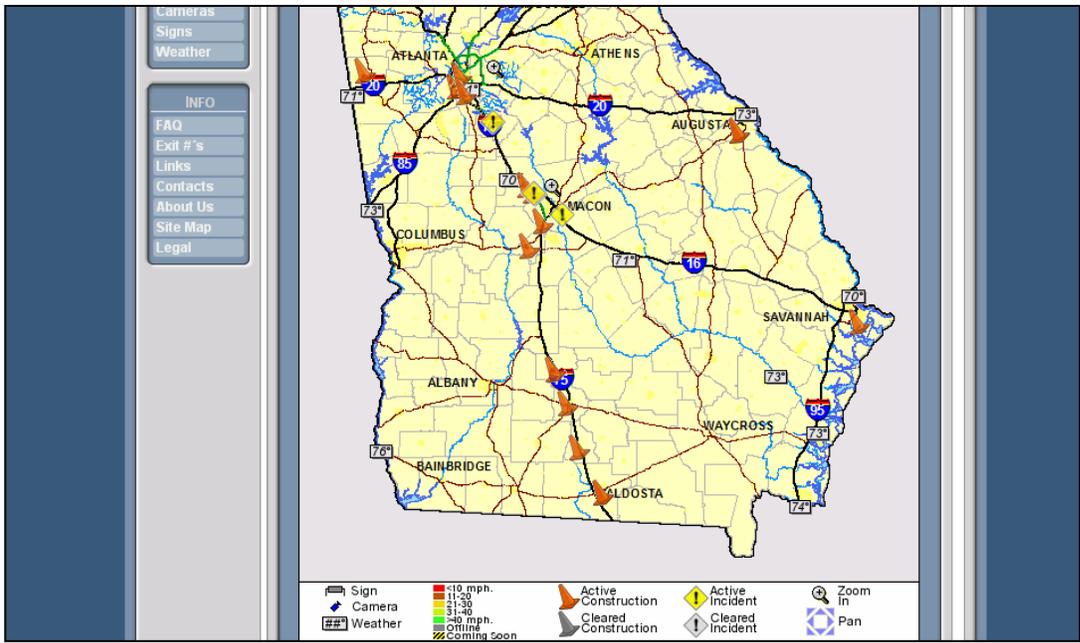


Figure 115. Screen Shot of the Navigator Traffic Website for 24-Hour Planned Construction

13.2.4 Texas Department of Transportation

In a study conducted by Finley et al. [160], the summary of the travel time and speed information provided by TxDOT is given. TxDOT uses different methods to provide information to its consumers as it is shown in Table 36. The most common way of providing information to the consumers is via the Internet. All of the districts in Texas use the Internet to provide travel speed and time information to their consumers.

Table 36. Summary of Travel Time and Speed Information Provided by TxDOT

Methods	Consumers									
	Cities	Counties	Fire/EMS	Police	ISP	Media	CVO	Airports	Transit	Travelers
Direct Line	H	H			H S	H				
Regional Network ^a	D* F*	D*	D* F*	D* F*	F*	F*		F*	F*	
Data Server			S							
IVN				S					S	
Internet	D F H S									
LPTV	S**					S**				
Kiosk							F*			F* H
DMS										D* F H S

D-Dallas District; F-Fort Worth District; H-Houston District; and S-San Antonio District

^a In conjunction with a shared data server

* District is considering the use of the method or planning to provide information via the method in the future

** District is no longer using the method

TransGuide used in San Antonio District, TranStar used in Houston district, and the ITS webpage used in Dallas districts are given as the examples of the TxDOT Intelligent Transportation Systems below.

On the Dallas/Fort Worth ITS webpage (<http://dfwtraffic.dot.state.tx.us/>) [161], real time traffic information on highways is provided by the use of webcams and changeable message signs. In the webpage shown in Figure 116, the users can click on the webcams or message signs and get real time traffic information. In Figure 117, a highway map of the Dallas/Fort Worth area is shown. The speed on the highway, incidents, and closures are shown in this webpage.

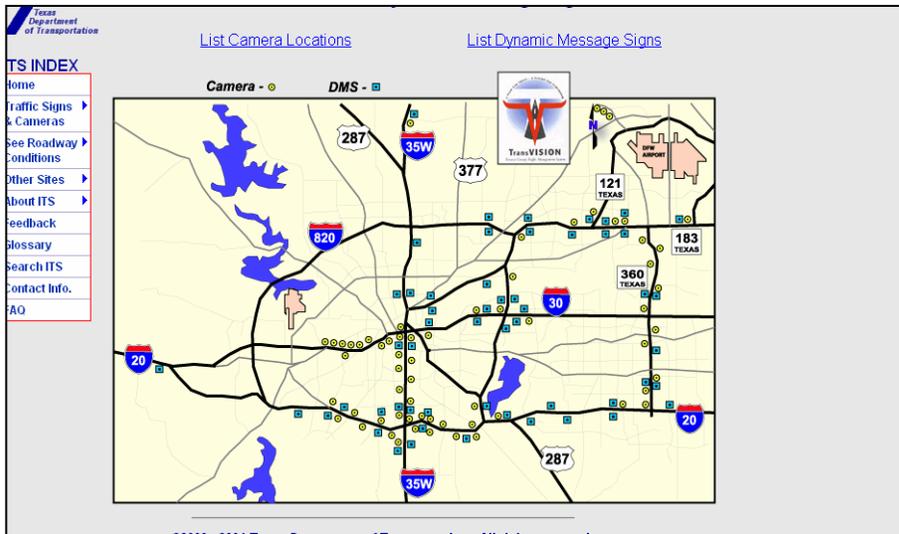


Figure 116. Screen Shot of Dallas/Fort worth Traffic Website Showing Webcams and Message Signs

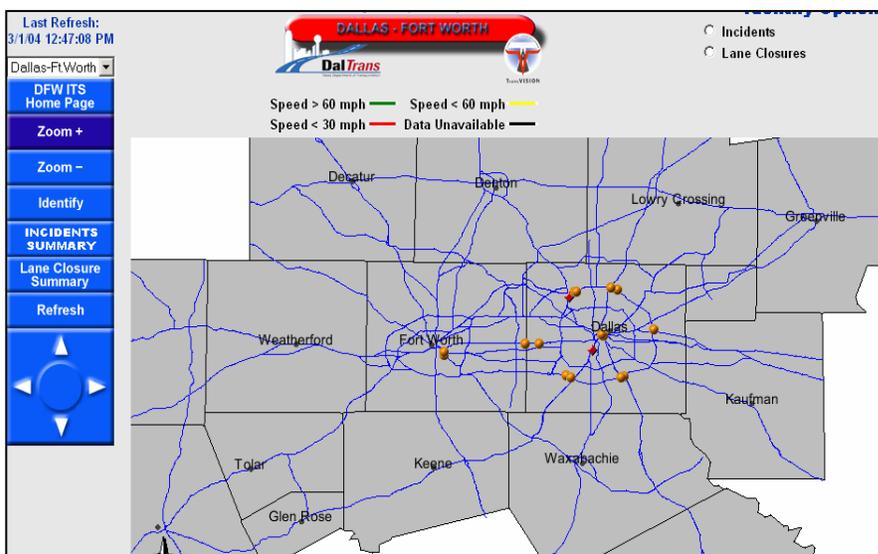


Figure 117. Screen Shot of Dallas/Fort worth Traffic Website Showing Highway Map

TransGuide (<http://www.transguide.dot.state.tx.us/index.php>), an Intelligent Transportation System was designed by the San Antonio District of the Texas Department of Transportation [162]. This "smart highway" project provides information to motorists about traffic conditions, such as accidents, congestion and construction. With the use of cameras, message signs and fiber optics, TransGuide can detect travel times and provide that information to motorists not only with the message signs on the highways, but also with the use of the Internet and a low-power television station. TransGuide rapidly responds to accidents and emergencies. In Figure 118, a screenshot of the real time traffic information provided on the TransGuide website is shown. Message sign information and average speed on the highways are also given on the website [163].

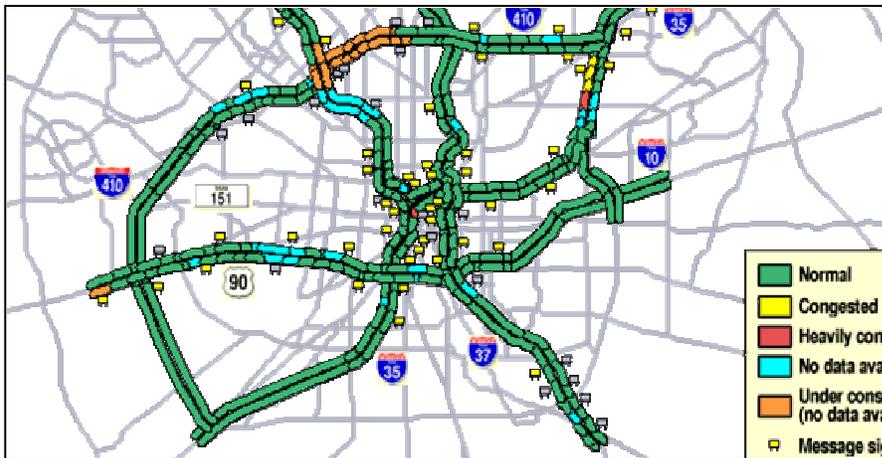


Figure 118. Screen Shot of San Antonio Traffic Website Showing Congestion Status of Major Roads

Houston TranStar (http://www.houstontranstar.org/about_transtar/) is another ITS in use [164]. Houston TranStar is a partnership of agencies that streamlines emergency response. When emergency conditions occur such as hurricanes, floods, industrial explosions or terrorist attacks, the Emergency Operations Center (EOC) housed at Houston TranStar is activated. It is the first application combining transportation and emergency management centers.

The benefits attributed to Houston TranStar’s Transportation Management activities include a net reduction in travel times and fuel consumption and the promotion of a cleaner environment by reducing the amount of exhaust emissions. The emergency management activities have reduced the number of injuries, deaths, and extensive property damage caused by floods and other weather-related and/or man-made events.

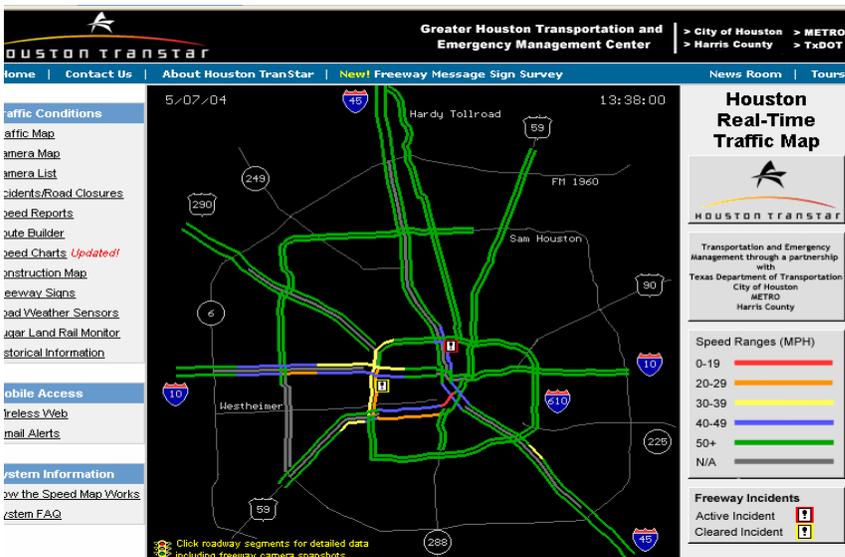


Figure 119. Screen Shot of Houston Traffic Website Showing Average Speed on Roads and Incidents

TranStar users can get the real time traffic information (incident/road closure, speed, construction, and weather) via the Internet. Cameras provide screenshots from the freeways. The system also transfers real time traffic data to the dynamic message sign boards on freeways for drivers on the roads. In Figure 119, screenshot of the TranStar webpage is shown.

13.2.5 Arizona DOT ITS

In Figure 120 a screenshot of the Arizona traffic website is given (<http://www.azfms.com/> [165]). Accidents, activity, delay, road closure, road condition, and travel time information is given on the webpage. Another screenshot from the Arizona traffic website is given in Figure 121 showing the average speed on major highways.

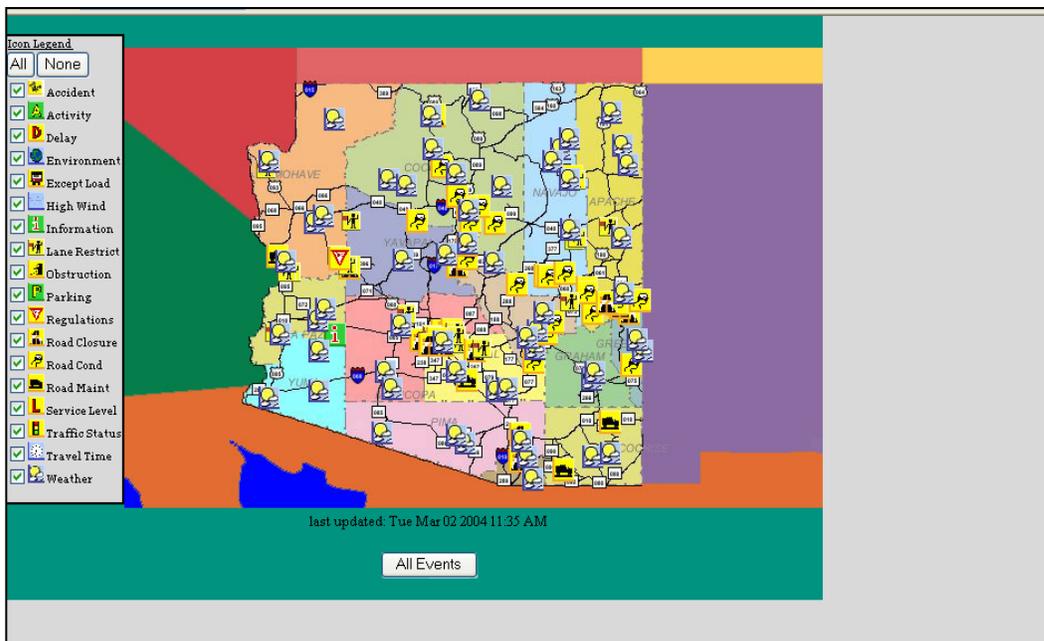


Figure 120. Screen Shot of the Arizona Traffic Website Showing Work Zones Incidents Statewide

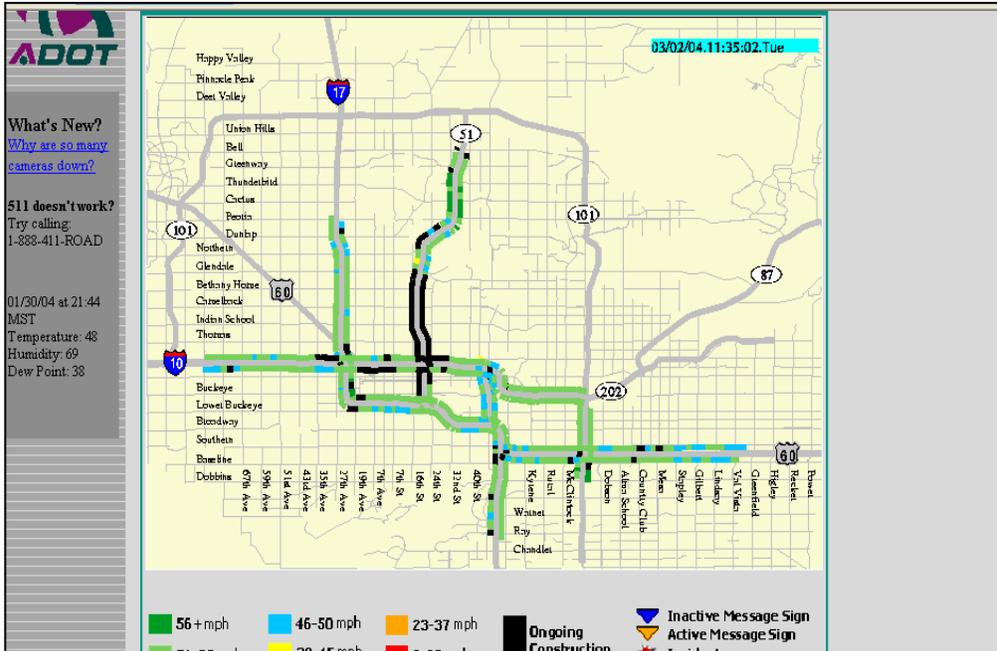


Figure 121. Screen Shot of the Arizona Traffic Website Showing Speed on Major Roads

13.2.6 Washington State DOT

The website maintained by the Washington State Department of Transportation (WSDOT) (<http://www.wsdot.wa.gov/pugetsoundtraffic/cameras/default.html>) provides access to snapshots and video clips from many of the cameras located along the major freeways in the Puget Sound area [166].

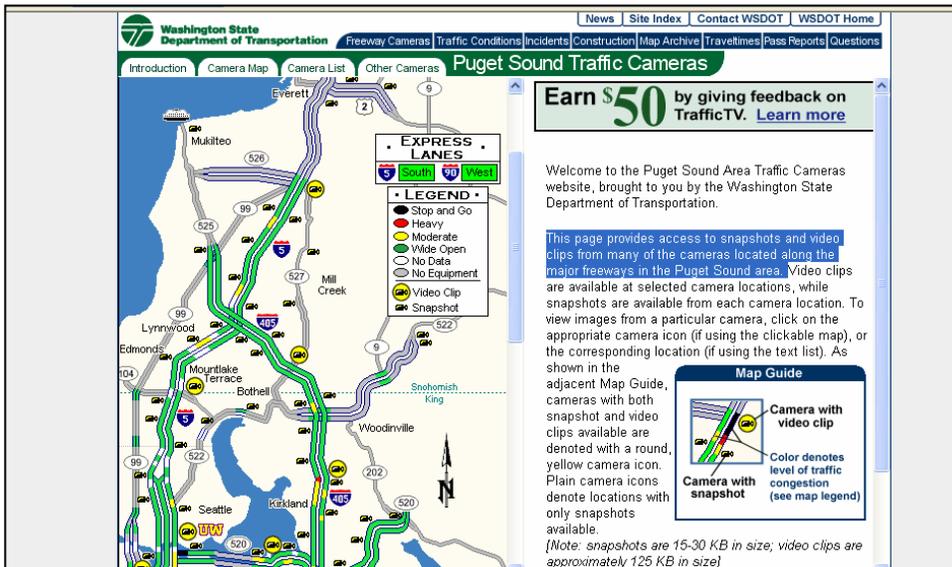


Figure 122. Screen Shot of the Washington State Traffic Website Showing Traffic Conditions in the Puget Sound Area

Visitors are able to see snapshots of the major freeways. In addition, the traffic condition on the freeways is given by the color coded legends. Incident and construction information is also provided in the webpage as shown in Figure 122.

WSDOT also uses Traffic Gauge to provide real-time traffic information to drivers [167]. Traffic gauge is a real-time mobile traffic map of the greater Seattle-Bellevue area. The device pinpoints traffic slowdowns for better drive-time decisions. Continuous updates are provided from WSDOT and it is very much like having the WSDOT traffic map in the vehicle.



Figure 123. The Traffic Gauge used by Washington State DOT

WSDOT gathers traffic data from wire loops under selected roadways, which measure the speed of traffic. This information is sent to WSDOT computers. In partnership with WSDOT, TrafficGauge Inc. accesses this data through custom servers, formats the data, and broadcasts it to TrafficGauge. Updates occur throughout the day, as often as every four minutes. An image of the traffic gauge used by WSDOT is given in Figure 123.

Another channel for distributing driver information is Dedicated Short Range Communications (DSRC) transponders especially for trucks. The DSRC transponders provide safety and traffic advisory information about road conditions, weather hazards, incidents and traffic conditions directly to motorists in vehicles. Timely as opposed to pre-trip information such as with kiosks, web sites can be provided using DSRC. The use of this method is in the experimental stage by the Ministry of Transportation of Ontario [168].

13.3 Telephone Services

13.3.1 511 National Traveler Information Number

The American Association of State Highway and Transportation Officials (AASHTO), in conjunction with many other organizations including the American Public Transportation Association (APTA) and the Intelligent Transportation Society of America (ITS America), with support from the U.S. Department of Transportation, has established a 511 Deployment Coalition. The goal of the 511 Deployment Coalition is "the timely establishment of a national 511 traveler information service that is sustainable and provides value to users". Information collected via ITS will be available to the drivers through one nationwide, three-digit telephone number. The number will be one easy-to-remember number, regardless of the traveler's location, gives travelers' choices - choice of time, mode of transportation, and route – which save lives, time and money. In Table 37, the deployment coordination program draft policies are given.

Table 37. 511 Deployment Coordination Program Draft Policies [169]

Issues	Draft Policy
Institutional Leadership	<ul style="list-style-type: none"> • Public and private sector must work together • Include non-traditional partners in the coalition
Content	<ul style="list-style-type: none"> • Establish a set of minimum service guidelines • Can provide both basic and premium services • Can be tailored to meet local needs • Americans with Disabilities Act (ADA) compliant • Connect to other N11 numbers • Grow and evolve with the advent of new technologies
National Consistency	<ul style="list-style-type: none"> • Need same “look and feel” of basic services • Premium services may vary in appearance • Minimum level of quality • Marketing plan
Consumer Pricing/ Service Cost	<ul style="list-style-type: none"> • Business models will be investigated for appropriateness of their application to 511 • Basic service elements should cost the end user no more than the cost of a local landline or wireless call • Can have additional charges for premium services or additional local service options

The 511 deployment coalition released a 511 National Progress Report in May 2004 [170]. The statewide applications and improvements of 511 are given in the report. Vermont, Oregon, Maine, Washington, Alaska, and New Hampshire started 511 traveler information services in 2003. By switching from their existing traveler numbers to 511 agencies observed their call volumes increased by 300% to 600%, thereby delivering important information to their customers even more effectively. The benefits of the 511 deployment for the agencies are listed as follows:

- Reduction in labor intensive processes
- Reduction in calls to highway patrol offices
- Enhanced interagency coordination
- Positive perception of transportation agencies

In addition the surveys completed with the users of the 511 traveler information system showed that their satisfaction with the system was very high and 87% of the users were likely to use it again. The benefits of the 511 traveler information system for users are:

- Ease of use and convenience
- Real-time, accurate and quality road and traffic conditions
- Avoiding traffic congestion and road construction
- Weather information
- Reducing frustration and relieving stress
- Helping users to make informed travel choices
- Changing travel behavior by including altering routes and departure times
- Saving time and lives
- Receiving information about tourism and other services

In the report, information on the cost of deployment of the 511 traveler information systems is given. The deployment costs fall into two basic phases: development costs and operations and maintenance costs. The costs fall into two categories: labor and equipment. The size of systems and types of enhancements made to existing traveler information systems vary greatly among the current set of 511 deployers. A useful comparative measure is the average development cost, as well as a cost-per-call, which includes all operations and maintenance costs. Among surveyed deployers, the average development cost was \$415,683 – with a high of \$1,028,000 and a low of \$133,000. The average cost-per-call is \$1.08 – with a high of \$2.84 and a low of \$0.12.

13.3.2 Toll-free Number Usage in the States

Arizona DOT provides 3 main types of information on roadway conditions on major state roads, city-specific information in urban areas and, weather information from the National Weather Service. The Kentucky DOT provides daily updates (Monday-Friday) on construction, weather, and major event-related information on interstates and parkways. On the other hand Michigan DOT manages a clearinghouse for real-time freeway information for greater Detroit and operates a toll-free statewide phone system which provides construction information on state highway system. The Minnesota DOT has implemented a statewide toll-free and local Twin Cities number to access winter and summer road and weather conditions. San Francisco Metropolitan Transportation Commission provides a phone-based system with real-time information concerning traffic and road conditions and static information on public transit and ridesharing, as well as bicycle programs and airport transportation services. The Utah DOT provides information on winter road conditions.

13.3.3 Applications in Ohio

The Advanced Regional Traffic Interactive Management & Information System (ARTIMIS) provides incident, congestion, and freeway management information for the Cincinnati-Northern Kentucky Region. The project is funded by the Ohio Department of Transportation (ODOT) and the Kentucky Transportation Cabinet (KYTC) to improve traffic conditions and safety along 88 miles (141.68 km) of the region's highways. ARTIMIS is the first major ITS effort in Ohio and the second in Kentucky. Real time route specific information is provided by ARTIMIS Traveler Information service by dialing 511 from any touch-tone phone.

13.4 Traveler Information Systems in Europe

Traveler information systems, practices, policies, strategies, and technological innovations in Europe were analyzed by the panel sponsored by the Federal Highway Administration and American Association of State Highway and Transportation Officials [171]. The panel visited eight cities identified according to the literature surveys and they evaluated the traveler information systems and services for potential implementation in the United States.

The panel found that providing journey time to the traveler is widely recognized in Europe and considerable data points were provided at several locations for the customer needs and usage.

The researchers found that multiple colors and symbols are used in Europe on variable message signs to improve message transfer and understanding among commuters. The researchers recommended using more symbols on the variable message signs. In Figure 124, an example of a variable message sign usage in Spain is provided.



Figure 124. Dynamic Message Sign Showing Alternate Travel Times

In another study conducted for the Federal Highway Administration [172], researchers from U.S. institutes visited transportation officials in Gothenburg, Sweden; Frankfurt, Cologne, and Bonn, Germany; Paris, France; and London and Birmingham, England.

The researchers identified several applications of information management that can be implemented in the U.S.

- Variable message sign information provided in Europe is controlled by a central system, which provides consistency in the applications.
- The researchers observed that real-time parking information is provided to the travelers in various areas of the city through variable message signs. This information allows drivers to make informed routing decisions as they travel to available parking nearest to their destination.
- In France dedicated FM radio frequency is used instead of the AM frequency to provide traffic information to the travelers.
- A radio data system traffic messaging channel is developed by the Europeans to provide traffic information throughout the continent. It is a radio-based traveler information system that automatically tunes the radio to the appropriate frequency, regardless of current radio operation (commercial station, cassette, or compact disc), to broadcast the information. The system provides coded information from different sources that can be easily translated to the appropriate language for the vehicle's occupants.

13.5 Recommendations to ODOT

In ODOT's information dissemination efforts the information needs of drivers should be taken into consideration. Drivers want to know if there is a problem, what the problem is, the delay, a prescribed remedy or alternate route, and how the alternate delay compares with the highway delay. Also the information should be time-stamped or otherwise documented so users know when the data was collected and their timeliness.

A device like TrafficGauge used by WSDOT could be incorporated to the ODOT information dissemination program. Traffic information updates could be sent to travelers using these devices on a real-time basis.

A statewide 511 traveler information service number could be developed and implemented.

Multiple colors and symbols are used in Europe on variable message signs to improve message transfer and understanding among commuters. ODOT could use more symbols on the variable message signs. In addition, variable message sign information could be controlled by a central system, which will ensure consistency in the applications.

Real-time parking information could be provided to the travelers in various areas of the city through variable message signs. This information allows drivers to make informed routing decisions as they travel to available parking nearest to their destination.

ODOT could use dedicated FM radio frequency instead of the AM frequency to provide traffic information to the travelers.

Radio-based traveler information system that automatically tunes the radio to the appropriate frequency, regardless of current radio operation (commercial station, cassette, or compact disc), to broadcast the traffic information could be implemented.

13.6 Recommended Evaluations

An evaluation study for the use of multiple colors and symbols on variable message signs could be performed. The acceptance and effectiveness of different symbols and colors by Ohio drivers could be evaluated. According to the needs of the drivers in different age groups, the best colors and symbols for use in Ohio could be identified.

A survey could be performed with different driver groups to identify their traveling behavior and information demands. This information can then be used to improve existing information dissemination methods and also in future applications.

A comparative study could be performed to identify the benefits of providing real-time parking information to travelers in various areas of the cities through variable message signs.

More information regarding information dissemination can be found in section 15 and 16 of this report.

14 WORK ZONE SAFETY

14.1 Speed Control

At present, speed control in work zones involves installing reduced speed limit signs, “Fines doubled in work zones”, and “Speeding – Fine Double / Cause Death or Injury – Fine / Jail” signs. Failure of drivers to observe these speed limits is a major safety problem leading to many worker and motorist injuries and deaths.

To control speed in work zones, one can envision three levels of increased attention and enforcement, each requiring more effort. Some of these measures are also discussed elsewhere in this report.

Level one consists of a statistics board, perhaps on a Portable Changeable Message Sign (PCMS) that includes a statement such as “Over 80% of motorists obey the speed limit in work zones”. The statement is phrased positively to encourage motorists to also obey the speed limit. The “Fines doubled in work zones” sign can be replaced with a “Fines tripled in work zones” sign. For the effect of this sign change to be realized, additional enforcement is needed. The additional enforcement may require extra pay for the law enforcement officers performing the duties, and this can be paid for by the contractor with project funds budgeted for this purpose. These funds should ultimately be recovered from the increase in collected fines.

Additionally a second pair of speed limit signs, one on each side of the road, could be placed one-half mile downstream from the first set of speed limit signs. Speed limit signs on both sides of road should be longitudinally spaced more closely throughout the work zone and combined with transverse rumble strips in order to provide to the driver a more frequent visual, auditory, and vibrational signal. These extra signs reinforce and emphasize the reduced speed limit message.

Level two involves additional enforcement. In addition, drivers are provided with active feedback on a speed display that displays the speed limit and next to it, in large lights “Your speed” as measured by radar. Placed near the beginning of a work zone, the sign serves the purpose of providing drivers with fair warning of possible enforcement efforts further down the work zone.

Level three includes around the clock patrol or enforcement by automatic camera with tickets mailed to car registrants. Legislative approval may be needed for the use of automated cameras to enforce speed control, but it has the definite advantages of catching every offender and being implementable in areas where limited space makes conventional enforcement difficult or impossible. It has been observed, however, that the presence of police reduces work zone traffic capacity by about 14% in rural freeway work zones [173]. The effectiveness of additional law enforcement presence in work zones has been thoroughly reviewed [174]. For such an approach to be effective, the following needs to be done:

- Establish predictable funding levels and sources
- Establish agreement between law enforcement agencies and ODOT.

- Additional focused training for enforcement personnel.
- Establish individual points of contact in each agency.
- Keep and maintain detailed records of enhanced enforcement.

The visible presence of law enforcement with radar has been shown to reduce average speed of traffic by 5-10 mph (8.1-16.1 kph), but the reduction is lost within an hour or two of law enforcement leaving the area.

Automated speed enforcement using a camera has been used extensively worldwide [174]. They are less common in the United States, but have been shown to decrease crashes, for instance at Paradise Valley, Arizona where crashes went from 460 in 1986 to 224 in 1992. West Valley, Utah had a decline from 2130 to 1710 crashes over two years. Automated speed enforcement also gets around the problem that when an additional officer is chasing and apprehending a speeder, the vehicle is no longer visible in its station in the work zone. There are two options for automated speed enforcement – one is to send the pictures electronically downstream to law enforcement personnel who stop the vehicles and write tickets at the site, and the other is to mail the tickets to the registered car owner. The former option provides the benefit of immediate feedback and also targets the actual driver of the vehicle, who may not necessarily be the registered owner (for instance a spouse or child of the owner). A Texas Transportation Institute study reviewed in [174] found that officers could correctly identify vehicles downstream 84-88% of the time. The speed threshold of the system sending pictures downstream needs to be set at a level that doesn't overload the system.

It may be helpful in speed control efforts to use variable speed limit signs that also display the driver's speed. The speed limit may be controlled remotely and displayed with a light display, or as a cheaper alternative the speed limit may be displayed with a removable panel. The two signs are shown in Figure 125.

Such a display was tested in the state of Kansas in 1999 [50]. The researchers found that average speed decreased significantly at the sign, from 62.3 mph (100.3 kph) to 59.5 mph (95.8 kph) where the posted speed was 60 mph (97 kph). Speeding declined from 67% of cars before deployment to 36% after, with a greater reduction seen for trucks at night. About 0.5 mi (0.8 km) downstream, the average speed was reduced to 61.4 mph (98.8 kph) and speeding was 60%, higher than at the sign but still significantly lower than before implementation. All reductions were significant at the 95% level.

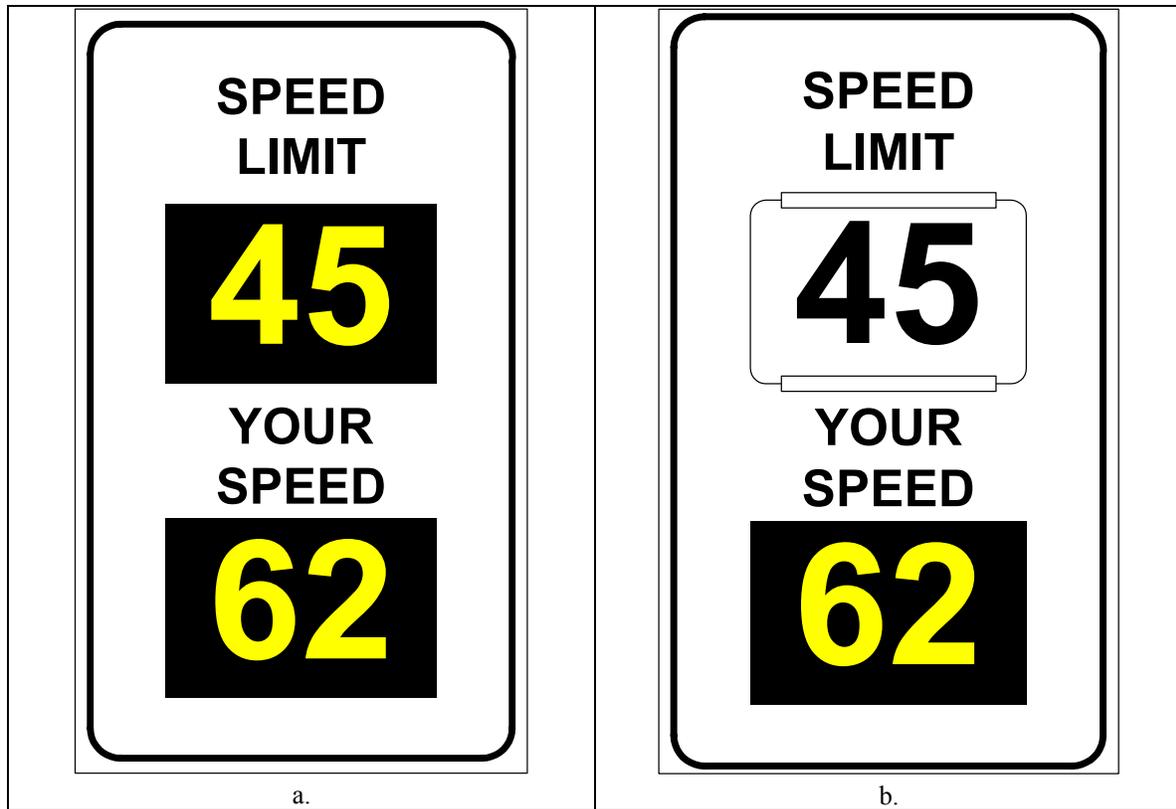


Figure 125. Speed limit signs with driver feedback for use in work zones. a) With speed limit and driver's speed displayed with luminous display. b) With driver's speed on luminous display and speed limit on a removable panel.

A similar product that can be used for speed control in work zones is marketed by VisiSpeed, a company based in Switzerland [175]. The VisiSpeed Information Radar is a device that can be mounted even on a utility pole for permanent use as shown in Figure 126. The device displays the driver speed, updated every 1.5 seconds. Since the device can be mounted permanently it gives the added advantage that drivers are likely to adjust their behavior by reducing speed, than with a temporary trailer mounted speed indication device. The device runs on batteries and the power requirements are also low. The manufacturers claim that the device is useful in traffic calming.

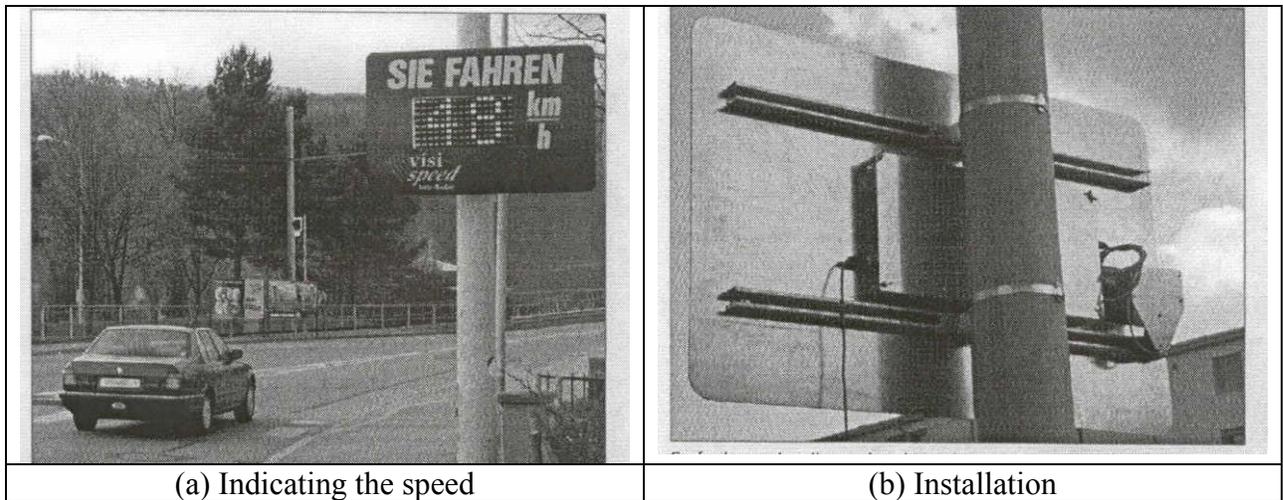


Figure 126: VisiSpeed Information Radar [175]

Another important consideration in speed control in work zones is determining the speed limit when there is no work going on. Drivers tend to maintain a higher speed if they do not see a crew or machine working in the work zone. A speed limit sign equipped with amber flashers at the top and bottom may be used for the speed control in work zone. Flashers will be operated when there is actually construction work going on and the reduced speed limit is effective. In order to use flashers along with the speed limit sign revisions has to be made in the Ohio Revised Code. A sample drawing for the flashing speed limit sign is given in Figure 127. However it should be noted that a Texas evaluation of laws increasing fines in work zones indicated that enforcement personnel were hesitant to mark offences for the higher rate because they weren't sure that there were workers active in the zone [176]. The authors recommend eliminating the "if workers present" provision. It may be possible to make some form of communication available so that law enforcement is aware when there are workers, leading to increased implementation of doubled fines.



Figure 127. Flashing Speed Limit Sign

14.2 Legislation and Enforcement of Speed Zones

It has become common for states to double fines in work zones, in some cases only when workers are in the zone and some cases at all times. The effectiveness of these laws has been studied by the Texas Transportation Institute [176]. As of 1997, when the report was written, 42 of the 50 US states had passed some legislation increasing fines in work zones. 28 states increased fines for speeding only, 9 for all violations, and the remaining 5 for some. 23 states doubled fines, 13 increased fines by a set amount, and the rest adopted other measures. The effectiveness of these laws is limited as drivers often continue to speed unless law enforcement is visibly present. In Pennsylvania there was not a significant change in accident rates until law enforcement vehicles were stationed before work zones. The original fines

doubled law went into effect in 1989 and in 1994 law enforcement vehicles were stationed 0.4-0.8 km (0.2485 – 0.497 mile) in advance of work zones with light bars flashing. A nearly 8-fold drop in accidents can be seen in Figure 128 after a law enforcement presence was mandated, while before that the law had little, if any, effect.

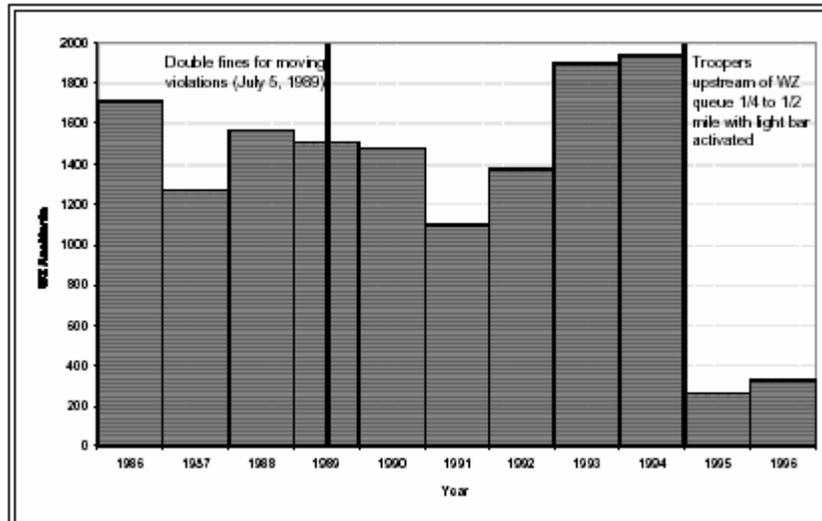


Figure 128. Work zone accidents seen in Pennsylvania after adoption of fines doubled law in 1989 and after stationing law enforcement vehicles before work zones starting in 1994 [176, p. 24].

TTI's own study of Texas work zones confirmed the lack of effect of fines doubled laws. 50% of the work zones studied had no significant speed change, while the rest were evenly split between increases and decreases in speed [176]. TTI suggested the following recommendations to improve enforcement:

- Remove the statutory requirement that workers be present in the work zone at the time of the violation. Officers were hesitant to check this box if they weren't sure that there were workers present at the time of the violation, leading to fewer fines doubled citations.
- The fines should be increased further by a set amount, e.g. Wisconsin specifies a minimum of \$60 for speeding and \$40 for other violations.
- The defensive driving education option should be eliminated or a minimum fine imposed in addition to the defensive driving course. This is needed because with the higher fines, many more drivers opt to take a defensive driving course in lieu of paying the fine, thus reducing the revenue the fine brings in to support enforcement activities.
- The district engineer or appointed representative should be enabled to set temporary work zone speed limits. This should lead to more realistic speed limits being set.

TTI does not have any recommendations in this report to counter the problem of narrow lanes and shoulders making it less safe for officers to pursue and pull over violators.

14.3 Regulatory, Warning, and Guide Signs

Detailed descriptions of the various regulatory and warning signs to be used to inform motorists of legal requirements and specific hazards that may be encountered in the work zone respectively are described in the OMUTCD (Sections 7C and 7D). TEM section 605-4 outlines the standards to be followed in the erection of regulatory signs not included in the OMUTCD – Work Zone Speed Limit sign and Fines Doubled sign. Section 7E of the OMUTCD outlines the various guide signs for use in work zones. Several guide signs that are not included in the OMUTCD are included in the TEM section 605-8.

Several other innovative signs could be included in work zone areas to collect information from the public, to assure motorist happiness and respect for TCDs. A sign with a message akin to ‘Thank You for Your Patience’ may help decrease the disregard drivers may have towards work zone operations. Including a sign with an 800 number for comments will also be very useful in improving activities of the particular work zone in which the sign is installed if not those at other sites. These are two important signs that ODOT ought to consider including in the work zone guidelines to ensure improved cooperation from drivers.

Signs can also be used to give out project information that may help drivers accept the temporary delays. Messages can focus on project content information, such as “Working to improve your safety”, “Working to reduce your commuting time”, or “We are adding a lane”. Project data can also be given such as the construction end date, amount of work done, or length of work zone. This has been done in some work zones, but is probably a good idea in any work zone where the end of the zone cannot be seen from the beginning of the zone. Another possibility is positively formulated driver performance information, such as “Last month over 80% of drivers did not speed”, or The number of accidents in this work zone in the past month.

Some states also use several other signs to improve work zone safety. For example the Pennsylvania DOT uses signs that read as ‘Slow Down My Mom/Daddy Works Here’ [177]. Such signs tug at the heart strings of drivers and make them slow down. A possible improvement may be to use self-interest, as in “Slow Down. It’s for Your Own Safety”. Another group of signs that is used in long-term construction project sites are the web site information signs (Figure 129). Steinke et al. [178] found that improving communication with motorists (both before and during work) is one of the methods used in European countries to improve traffic flow in work zones. Displaying signs that clearly indicate the website where first hand information is available is very useful in educating drivers. This is also an effective means of communicating project information to drivers who use the particular road regularly. Therefore ODOT could consider including innovative signs such these to increase the safety of workers, obtain the cooperation of motorists by creating methods to improve communication, and to promote the Buckeye Traffic website (OTIS) which has construction information. ODOT included a similar sign to increase the work zone safety and provide information to the drivers. ODOT uses a sign that read as ‘Speeding – Fine Double / Cause Death or Injury – Fine / Jail’.



Figure 129: Innovative signs used by the Pennsylvania DOT to improve safety in work zones

Increasing the size of work zone traffic signs is another step that could be taken to ensure that all signs are clearly visible under day and nighttime conditions as well as all weather conditions. Having larger, simpler, and clear signs has been included as one of the top-ten improvements that can help create safer roads by AAA [180]. To improve traffic flow and safety in work zone areas, we recommend that all work zone traffic signs with worded legends be increased by 6" so that they are easily readable. Therefore signs that are 30"x30", 36"x36", and 48"x48" should be increased to 36"x36", 42"x42", and 54"x54" respectively. It is also recommended that word messages be made simpler where possible.

The suggested new signs contribute to assuring motorist happiness and also improve the cooperation from drivers. Since first hand information can be gathered from drivers through a sign with an 800 number, it would also contribute to improve work zone operations. Phone numbers which are simple and easy to remember can be used. The numbers can be expressed as a word message such as Highway Patrol numbers (1-877-7-PATROL) which would mean that the drivers will not necessarily need to write down the phone numbers to make suggestions. Therefore the signs will be beneficial from a human factors perspective as they contribute to worker and motorist safety, and would also improve traffic flow.

14.4 Vehicle Warning Lights

The Texas Transportation Institute (TTI) conducted a study to determine the best configuration and color scheme for DOT vehicle warning lights [181]. The study included a motorist survey which indicated that blue and yellow flashing lights mounted in combination on vehicle roofs were seen as conveying a greater sense of hazard, but this did not translate into an acknowledgement of a need to slow down. Red and yellow warning light combinations did convey a need to slow down, though not to as great a degree as the red/blue/yellow combination presently employed on courtesy patrols in Texas. A field observation study of drivers showed speed reductions at a few but not all sites when a yellow and blue combination was used compared to yellow only lights. However a law enforcement vehicle with lights on did not see a speed reduction compared to a courtesy patrol vehicle with yellow lights, indicating that the reduction seen for yellow/blue combinations may not be due purely to the light combination. There were inconclusive results on whether lane change frequencies or lane distribution percentages were affected by the different color combinations tested. Braking appeared to increase for yellow/blue combinations over yellow, and increased still more for red/yellow/blue combinations. A red/yellow/blue combination on a law

enforcement vehicle resulted in significantly more brake applications than a courtesy patrol vehicle with the same colors.

TTI recommends that the use of blue and yellow warning light combinations on some DOT vehicles is justified, though a combination of yellow plus red rear-facing lights is also justified by the research. The researchers recommend that the addition of blue to a yellow warning light combination should be used when the vehicle is used for activity that requires workers to be out of the vehicle when in a lane of traffic or when the vehicle is used in a moving operation at speeds less than 4 mph (6 km/hr) or at least 30 mph (50 km/hr) lower than the posted speed limit. A further legislative recommendation is that courtesy patrol vehicles be designated as “authorized emergency vehicles” so that they may continue to use the red/blue/yellow light combination. Since these vehicles are often the first at an accident scene on a congested freeway, they need to have maximum conspicuity [181].

14.5 Dancing Diamonds

Several different designs have been considered for using arrow panels to gain driver attention without indicating a closed lane. Several of these are shown in Figure 130 [182]. Turley, Saito, and Sherman studied these different caution displays using a literature review, field tests, and a comprehension-opinion survey [182]. They determined that the best display was the “dancing diamonds” display, which is the second from the top in Figure 125. The dancing diamond alternates between the left and right sides as the display flashes. This display has been used in several western states; for instance Utah has used it since 1972.

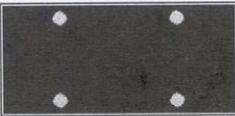
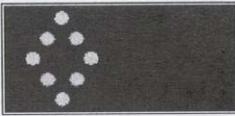
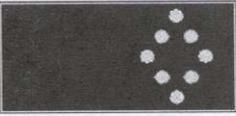
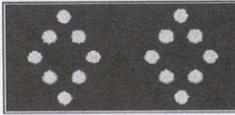
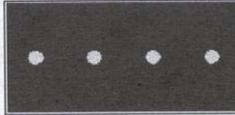
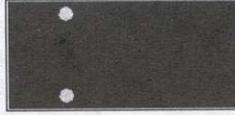
	Flashing Sequence 1	Flashing Sequence 2
Flashing Box or Flashing Four-Corner		
Dancing Diamonds or Alternating Diamonds		
Flashing Diamonds		
Bar or Flashing Line		
Alternating Two- Corner		

Figure 130. Different caution designs implemented on arrow panels. From [182].

For the field test, the researchers went to two work zone locations with an arrow panel and tested various warning configurations, including the flashing box, the dancing diamonds, and a flashing bar. They measured the speed distribution of traffic approaching and entering the work zone, observed lane migration behavior, and looked for unsafe vehicle conflicts as typically revealed by observed hard braking maneuvers. For dancing diamonds, a reduction in speed of 3 km/h (2 mph) was observed between the free-flow traffic and the work zone traffic and this reduction was significant at the $p < 0.01$ level. No such reduction was observed for the flashing box display. However, this effect largely wore off in about a week. The studies of lane migration and vehicle conflicts (brake tapping) were problematic, but suggested no statistically significant difference in braking frequency [182]. In other words, the dancing diamonds appeared to cause no obvious traffic problems.

The authors also conducted a survey of motorists at rest areas [182]. 54% Drivers indicated that the dancing diamonds would best prompt safe driving in work zones, followed closely by the flashing diamonds (43%). In an inverse question, 94% thought the flashing box was the display that was most likely to be ignored. Based on the results of the survey and the field test, the authors recommend that dancing diamonds be allowed in the MUTCD, and suggest further testing before use of the flashing box is barred. The flashing diamonds and flashing bar would need further tests to determine if they are effective.

14.6 Intrusion Alarms

One device that will make work zones safer for workers is an intrusion alarm. An intrusion alarm is a device that typically emits a siren-like loud alarm when a vehicle strikes a traffic cone or other control device and moves into the work zone. This alarm gives a warning that allows workers to take cover. One example of such a device is the SonoBlaster!® by International Road Dynamics [183]. The device is attached to a traffic cone or other traffic control device. The unit is fueled by a CO₂ cartridge that has an indefinite shelf life. When the alarm is set off by being struck or tilted 90° a 125 dB (at 6 ft) whistle blows for approximately 15 seconds. Figure 131 shows a SonoBlaster!® being struck by a car. Having the sound of the alarm at the point of incursion alerts the driver as well as workers [184]. The unit is activated by lifting the levered handle at the top; nesting cones automatically depresses the handle and deactivates the alarm. The device represents an improvement over conventional intrusion alarms because does not require electrical power and also does not require alignment of detection beams which can also be accidentally set off by workers in the area. If the SonoBlaster!®s are set up in a 100 foot (30.48 m) protection zone as shown in Figure 132, there is up to 5 seconds of advance warning, or more if the driver brakes. The alarms can also be used to define heavy equipment operation areas within work zones to help prevent injuries to workers caused with large construction equipment.



Figure 131. IRD's SonoBlaster!® work zone intrusion alarm attached to a traffic cone being struck by a vehicle [183].

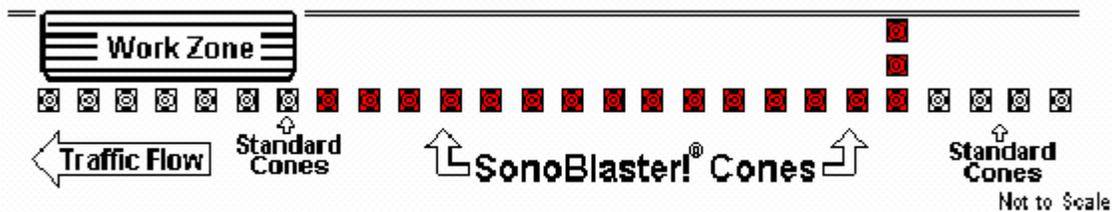


Figure 132. IRD's recommended installation of 16 SonoBlaster!® units to create a 100-yard alarm zone [184].

A standard infrared beam work zone intrusion alarm was successfully tested in Vermont in 1995 [185]. An infrared beam transmitter and receiver were set up in a work zone to create a beam line. When the line is broken, a loud alarm goes off at a receiver in the work zone, giving workers a few seconds to take cover. The alarm could be heard over equipment noise. The Vermont DOT finds the system especially useful in short-term work zones. Despite some effort required in set-up, the department finds that the system is worth the \$3000 cost. Similar systems were tested in New York in 1994 and found to be worthwhile [186]. Set up was considered to be easy, taking 5 minutes or less for the three models tested. The favored model (not specified in the document) also had a drone alarm to trigger the radar detectors on vehicles to prompt drivers to slow down. Ron Eastman, a regional safety and health representative, was quoted as saying that the systems could be particularly useful in long-term work zones and that the alarms could be heard over jackhammers.

Hatzi listed 7 different models of intrusion alarms available [187]. Costs ranged from \$880 to \$4000. The three cheapest models use pneumatic tubes, while the three most expensive use long wavelength electromagnetic beams (radio, microwave, or infrared). One other system uses a sensing wire that is strung around the perimeter of the work zone.

The Texas Transportation Institute studied work zone safety devices [189] and reported on a sign that shows the driver his or her speed as well as the speed limit, as discussed above. The device is depicted in Figure 133. Additionally, the sign has a 130dB siren that is triggered by a very fast vehicle, making the device somewhat like an intrusion alarm.



Figure 133. Speed monitoring sign equipped tested by Texas Transportation Institute with siren activated by extremely high speed vehicles [189].

The Washington State DOT has looked into a number of measures to reduce work zone injuries [188]. Besides intrusion alarms, more visible clothing, and changeable message signs, equipment considered for purchase for work zone safety included truck-mounted attenuators and water-filled barriers. Truck-mounted attenuators are energy-absorbing crash cushions attached to department trucks positioned in front of work zones to block intruding vehicles. Water-filled barriers also absorb energy in a crash.

14.7 Late Merge

Late merge is a traffic engineering technique that has been heavily described and documented to ODOT elsewhere [190, p. 31 and references]. Basically it consists of signs telling drivers to use both lanes to merge up to the merge point and to take turns at the merge point entering the work zone. The Texas Transportation Institute studied late merge and determined when the system would be useful in Texas [191, 192]. Their conclusion is that late merge is useful only when there is congestion upstream of the work zone. Thus they recommend using this strategy only during two circumstances: 1. during short-term work zones where there is congestion expected during the entire time of work and 2. In a longer-term work zone where an ITS system is used to detect congestion and activate CMSs to display messages to drivers implementing the late merge; at other times there would be no late merge.

14.8 CB Alert

TTI also studied a product called CB Alert [191, 192]. CB Alert is an automated system that broadcasts messages on citizens' band radio. The messages are targeted at truckers and can include reminders to slow down or advance notice of lane restrictions. The study's authors found that with CB alert trucks slowed down by about 2 mph on average and that in the work zone tested that had a lane restriction (no trucks in right lane), the percentage of trucks in the correct lane jumped from 55.5% to 77.9%. TTI recommends the use of this device at work zones, particularly in rural areas, when and where there is heavy truck traffic.

The state of Kansas also evaluated CB Alert at a typical lane drop [50]. No significant changes in lane distribution was seen, which the author blames on the low volume at the site. A Safety Warning System (SWS) was also evaluated at a crossover as part of the same study. SWS transmits data that can be received by many later model radar detectors and dedicated receivers. Data were successfully collected at the taper that indicated no significant change in lane distribution and a statistically significant unspecified reduction in speed.

14.9 Law Enforcement Pullout Areas

One problem with enforcing traffic laws in work zones is that there is no convenient way for law enforcement to pull over violators in a long work zone with narrow lanes and very narrow shoulders. A solution to this problem studied by TTI is the enforcement pullout area [191, 192]. A typical design is shown in Figure 134. The design was determined with the assistance of expert panels of law enforcement officers and construction personnel to best suit the needs of all parties. The pullout areas should be placed every three miles within a long work zone to be effective. At longer distances they will not be useful for law enforcement, and at shorter distances they will interfere too much with construction. Placement of pullout areas needs to consider the sight distance needs of drivers both in the pullout area trying to reenter traffic and of mainline traffic. For roads with free-flow operating speeds below 55 mph (88.55 kph), the sight distance needs of the vehicles in the pullouts reentering the traffic stream take precedence; for roads with higher operating speeds, the sight distance requirements of mainline traffic vehicles will take precedence. Advisory signs alerting drivers to the location of a pullout area should be placed at least a decision sight distance in advance of the pullout [192, p. 62]. Law enforcement pullout areas are critical because increasing enforcement appears to work in reducing work zone speeds when increasing fines without increasing enforcement doesn't; see Figure 128 [50].

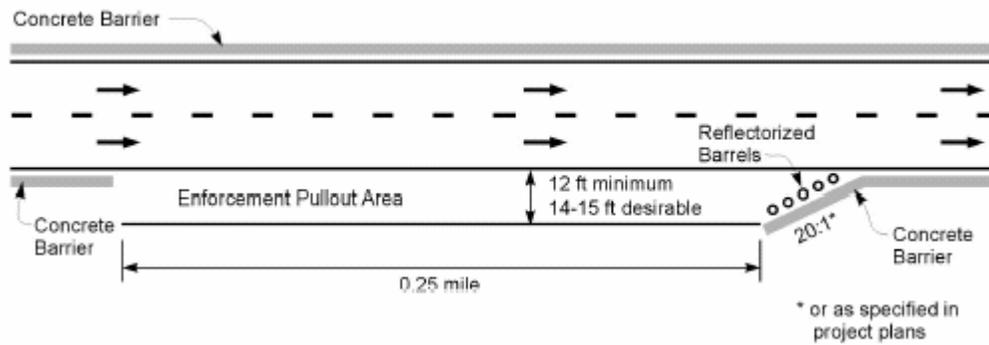


Figure 134. An enforcement pullout area design. One of these should be placed every three miles within a work zone [191].

14.10 Using Portable Traffic Signals to Replace Flaggers

Another TTI study looked at replacing flaggers with portable traffic signals for short-term maintenance operations [193]. The advantage here is that personnel can be freed up from flagging duties to contribute to the maintenance work; thereby speeding up the work, or possibly a position can be eliminated to save labor costs if there are a sufficient number of workers. Such a setup could be used for pavement repair, roadside maintenance, bridge work, or emergency work, for example; any situation where traffic will be reduced to one-lane operation for at least half a day. The concept is simple – instead of a flagger at each end of the work zone, there is a traffic signal. The major design issue is setting the timing for the signal which needs to have a green phase long enough to allow queued up traffic to go through, and an all-red phase sufficiently long to clear all traffic through the work zone, even allowing for the minimum speed through the work zone. On the other hand, total phase time should be kept under 4 minutes so that drivers will not be tempted to assume the signal is malfunctioning and run the red light.

There are several other points made in the report, including that the Texas MUTCD will need to be rewritten to accommodate the use of these signals in short-term work zones. One such provision is the need to be able to place the units without stop bars as placing and soon removing permanent stop bars is expensive and time consuming. An alternative mentioned for future research is developing a temporary stop bar. The portable signals were well recognized by Texas drivers at three maintenance sites where they were implemented, and the only violations of the signals occurred during set up. If there are driveways or intersections within the work zone, special treatment will be needed – most likely a lookout who can indicate which way the direction of travel is. Because there is no flagger to alert workers of errant vehicles, it may be necessary to designate someone as a lookout or use an intrusion alarm system as discussed above. The authors indicate that the all-red phase needs to be set to the maximum time (minimum reasonable speed) for traffic through the work zone. There is no system that uses automatic detection that will work for this purpose, though such a system may be a topic for future research. Some traffic activation is possible for approaching traffic, for instance if traffic is much more prevalent in one direction, that direction may have a default green signal, and traffic going the other way will trigger the end of the green cycle in the other direction; a couple different options are discussed in the report. Another possible

innovation worthy of future research is adding a countdown clock to indicate the time until waiting traffic has a green phase. There are also some sight distance and configuration issues discussed in the report.

Cost savings realized by the portable traffic light system are also discussed [193]. In Texas, maintenance crews are generally stretched thin, so the system cannot eliminate two flagger positions. Instead the authors advocate reassigning ex-flaggers to other aspects of the work to speed up work and realize some time savings. It may be possible to eliminate one flagger position. If so, the \$65,000 cost of the system will be recouped over two years, and then in the third year there will be \$37,000 in savings and an additional \$30,000 per year average after that. If the system is used 10-12 days per month, it will pay itself off in 3 years. To be cost-effective, the system needs to be used at least 8-10 days per month.

14.11 Recommendations to ODOT

Based on the analysis of existing literature and best practices of other states, the following are recommended to improve the safety of work zones

- To have better speed control in work zones, ODOT can provide additional signs to positively encourage motorists to obey speed limits. Flashing speed limit signs and additional reduced speed limits are also beneficial. Also the speed of the vehicles in the work zones could be measured and displayed next to the speed limit in the work zone using PCMS. Controlling speed limits through the use of radar units with automatic enforcement is another alternative to control speeding.
- ODOT could consider including innovative signs to increase the safety of workers, obtain the cooperation of motorists by creating methods to improve communication, and to promote the Buckeye Traffic website (OTIS) which has construction information
- Use the dancing diamonds arrow panel design to indicate the presence of a closed lane in work zones. The flashing diamonds were also found to prompt safe driving in work zones and can be considered for implementation

14.12 Recommended Evaluations

- Strategies for controlling speed in work zones such as messages for speed control, displaying the speed of the vehicles in the traffic with the legal speed, the use of the automatic camera for identifying speeding vehicles must be further evaluated to test their effectiveness. Also evaluations must be carried out to ascertain driver response to tripling the fines in work zones and its impact on controlling speed.
- Further experimentation must be conducted to evaluate the effectiveness of dancing diamonds and the flashing bar, instead of the flashing box, as a means to prompt lane closure in work zones.

15 STATEWIDE DOT SURVEY

An email questionnaire to evaluate the application of human factors on roadway transportation systems was sent out to all the states and territories in the United States. The survey was sent out to personnel at state transportation departments and some research institutions. The respondents were asked comment on whether or not they conducted any research on the topics listed and to list the references for those on which they had conducted research. A copy of the questionnaire is shown in Appendix B and the list of personnel who were contacted is shown in Appendix C.

Twenty three responses were received for the email survey that was conducted. The list of states that responded and the topics on which they have or have not conducted research is summarized in the table provided in Appendix D. Of the state departments that responded, nine indicated that they have conducted research on rumble strips and five states each had studied changeable message signs, work zone delineation, accident mitigation measures, older driver accommodation, and wet/dark delineation at night. Three states each had studied highway lighting, improved curve delineation, and information dissemination to motorists. While two of the states had done research on raised pavement marker spacing, none had studied the use of half-size auxiliary pavement marking. A detailed description of the results obtained through the survey, summarized based on the topics covered, is presented in the following sections.

15.1 Survey Results

15.1.1 *Rumble strips*

Colorado: Centerline rumble strips were been installed in 1996 on 17 miles of a winding, two lane mountain highway for evaluation. The centerline rumble strips used in the study were similar to those used on shoulders: they are made with a 12-inch-wide grinder that makes grooves that are 12- inches long (measured perpendicular to the roadway), and 7 inches across separated by 5- inch flats. They compared traffic records during a 44-month period before and after installation. It was found that head-on accidents decreased from 18 to 14 a 22% reduction; sideswipe from opposite directions decreased from 24 to 18 a 25% reduction. It should be also be noted that the average ADT for the 44 month period before construction was 4628, for the same time span and the same months after construction it was 5463 an increase of 18%. They also report positive comments received from the public about the effectiveness of the rumble strips. Based on the findings of the study the authors recommend that rumble strips be used in areas with a history of accidents involving vehicles traveling in opposite directions on two-lane highways [206].

The state conducted research to evaluate bicycle-friendly rumble strips [207]. The research evaluated three types of rumble strips to determine which type will provide a warning for motorists who drift off the road without making the shoulders unusable for bicycle riders. Based on the research the authors recommend the use of ground rumble strips that are 12'' (0.3048 m) wide with groove depths of $3/8'' \pm 1/8''$ (0.0095 ± 0.0031 m) ground in an interrupted pattern.

Florida: Pilot projects are being conducted and monitored all over the state. However they do not have any documented studies on rumble strips.

Iowa: rumble strips are to be milled in shoulders of the entire interstate system this summer. They also initiated a new paved shoulder policy to pave four foot shoulders and milled rumble strips. According to the response from Troy Jerman (IDOT, Office of Traffic and Safety) – ‘one of our main goals here is to reduce our fatality rate which is currently around 1.4/hundred million vehicle miles (HMVM), In Iowa 52% of the fatalities relate to lane departure and 39% are single-vehicle run off the road crashes. The rumble strips on the interstate shoulders will cover about 700 miles of four-lane shoulders for a relatively low price and in our high volume corridors. It is now our policy to add four foot paved shoulders to our roadways with volumes greater than 3000 ADT and we will mill rumble strips in those also. One of the department’s performance goals in to reduce run off the road accidents by 10% with this new policy and we will be tracking that annually. The last season was our first to monitor and with very limited sampling we have shown a decrease of 17% for last year’. (No other documented results)

Idaho: The state DOT indicated that they have done some research dealing with this topic. However no additional information was available.

Maine: Research has been conducted by University of Maine researchers on the use of rumble strips along shoulders that are designated for bicycle traffic.

Mississippi: They conducted a study to evaluate the constructability of milled rumble stripes on bituminous surfaces, use of different sized rumble stripes and, striping patterns. 6”, 9”, 12”, and the standard 16” (0.1524, 0.2286, 0.3048, and 0.4064 m) rumble strips were installed with the edge stripe located in the rumble strip [20]. They indicate that all rumble strips produced satisfactory audible results while it was observed that the 6” (0.1524 m) and 9” (0.4064 m) rumble stripes seemed to “pull” the vehicle somewhat. They also found that delineation of the edge line was increased due to the near vertical facing of the rumble strip. A customer survey was also conducted to evaluate driver response to conditions before and after installation. Approximately 42% indicated they had difficulty seeing the road when it was raining, 67.8% indicated that the rumble strip pattern helped them see the road better after strip installation, only 32.1% indicated they noticed people driving closer to the center of the road after the installation, and 47.3% indicated that the painted stripes kept them from accidentally driving off the road. When questioned if they would recommend this type of rumble strip be put on all rural highways in Mississippi, 87.8% said yes. The researchers recommend the use of milled rumble strips as an excellent means to provide audible warning and reduce run-off-the-road accidents.

New York: Rumble strips have been installed on all interstates. When they were first introduced on the state highways they found that run-off-the-road accidents were reduced by 70%.

Virginia: research on using rumble strips on interstate highways was initiated in 1993 as a measure to curb the high number of run off the road accidents. Virginia uses milled rumble

strips that are applied to existing pavement (as opposed to rolled strips that are applied during pavement construction). The milled strips were found to be more effective because they produced 12 times the vibration of the rolled type. Currently Virginia has about 1750 miles of continuous shoulder rumble strips. In a study to evaluate the effectiveness of shoulder rumble strips, before and after installation crash data for 790 shoulder miles of roadway were analyzed over a six year period. It was found that milled rumble strips reduced the number of run off the road crashes by more than 51% and related fatalities by 48% [208].

Wyoming: They conducted some studies in collaboration with the Texas Transportation Institute (TTI) and the data are to be used by TTI. However, no documentation is available.

Utah: The response received from Utah indicated that they have conducted research on rumble strips but do not have literature that can be shared.

15.1.2 Changeable Message Signs

Florida: The Florida DOT performed an experimental analysis of a series of changeable message signs functioning as freeway guide signs to assign traffic to Universal Theme Park via one of two eastbound exits based on traffic congestion at the first of the two exits [194]. They conducted a human factors analysis and found that the method used for switching the designated or active theme park exit on the series of changeable message signs led to the presentation of conflicting messages to some motorists. They also evaluated the use of a phased method to switch the designated theme park exit to eliminate the delivery of conflicting messages. Based on the results obtained in the second experiment, they recommend that the system used to assign the active exit based on traffic congestion be added to the MUTCD. A third experiment evaluated the use of a changeable message sign to provide information on cultural events in the Orlando area at a single exit. These signs were not associated with an increase in crashes. The study also recommended that this use for changeable message signs be added to the MUTCD.

Maine: In an effort to improve the safety at intersections, the Maine DOT embarked upon a pilot project to develop a dynamic, traffic-actuated warning system, primarily to warn minor leg traffic of approaching traffic [225]. The objective was to test and evaluate vehicle-actuated warning signs to reduce the incidence of collisions at the selected intersections.

The signs tested warned drivers waiting at the stop signs on the minor approaches when traffic is approaching from either direction. Another warning sign was used on the blind side of the major approach to warn drivers approaching the intersection from south when a vehicle is waiting at the stop sign on the minor approaches. The dynamic warning sign on the major approach had been in place for several years.

Traffic Conflict Technique studies were conducted before and after installation of the new signs, and also survey questionnaires were handed out to the drivers at the minor approaches. They found that the traffic conflicts decreased substantially and critical gap times increased considerably. The critical gaps increased from 5.7 seconds to 8.5 seconds. Based on the results of a survey questionnaire, two out of three respondents favored the sign. However,

25% of respondents expressed concerns, primarily with increased traffic delays, system timing and the potential for drivers to rely too heavily on the warning signs.

Virginia: A two stage study was conducted to evaluate the use of CMSs with radar units to reduce speed in work zone areas. In the first stage it was found that CMSs is more effective in reducing speeds in work zones than the standard Manual on Uniform Traffic Control Devices (MUTCD) signs. In the second phase of the study they concentrated on evaluating the effect of duration of exposure of the CMS with radar on its effectiveness to reduce speeds and influence speed profiles in work zones [209]. The findings indicated that the duration did not have a significant impact on speed characteristics and therefore that the CMS is effective in controlling speeds for long duration projects.

Iowa: Indicated that research has been conducted on this subject. However no additional information is available.

15.1.3 Delineation in Work Zones

Arizona: They conducted studies to evaluate the use of steady-burn warning lights on vertical panels in roadway construction zones [210]. As part of the study they evaluated the policies of other state DOTs on using flashing warning lights on traffic control devices, conducted a review of Arizona DOT's construction zone requirements, a literature search, and interviews with Arizona DOT field construction staff regarding the past performance of the Ultra Panels (Type III sheeting) with and without steady-burn warning lights.

Two of the thirty-four transportation agencies or 5.88% that responded to the survey reported that they had requirements for steady-burn lights similar to Arizona requirements. The Ultra Panel, a type of vertical panel, has been successfully used without warning lights on three highway construction projects in Arizona. They report that ADOT field construction staff associated with highway construction projects strongly supported the use of the Ultra Panel vertical panels without warning lights. Also they did not find any significant deficiencies associated with using the vertical panels without warning lights.

Florida: A new low-profile portable concrete barrier for use in roadside work zone environments has been tested by the Florida DOT. The new barrier design is capable of accommodating both horizontal and vertical roadway curvatures while maintaining low profile and redirecting errant vehicles [196].

Oregon: They conducted research to evaluate the Lighted Guide Tube (LGT) which is a 3M product that was used to delineate a temporary detour curve section in a construction project [211]. They evaluated the LGT over a five month period to observe its effect on vehicle speeds, accidents, and driver perceptions. No conclusive results were found on the effect on vehicle speeds and the presence of the LGT. They also report that no accidents occurred at the site during the LGT's time in service. 86% of the local drivers surveyed indicated the LGT helped them travel through the curve section.

In a separate study conducted to evaluate modified work zone traffic control devices the use of temporary business access signs and blue tubular markers were studied at two different

sites [212]. Telephone surveys were conducted among motorists and businesses. At the first site, 12 out of the 14 businesses studied or 85.7% indicated the signs helped customers locate their driveways. 65% of the motorists surveyed noticed the signs and 83% indicated the signs helped them locate the business access. The findings at the other site provided some evidence that the businesses were not significantly impacted with the signs. Six out of the 12 businesses or 50% indicated the signs helped customers locate their driveways: 62% of the motorists surveyed noticed the tubular markers and signs and 78% felt they were helpful in locating the businesses. Based on the findings of the study, authors recommended the continuous use of the signs and tubular markers in the work zone.

The state also has two ongoing studies on flagger illumination and linear delineation panels.

Utah: A study conducted to evaluate the use of several types of non-directional arrow panel displays in highway work zones is reported [222]. They compared the non-standard “Dancing Diamonds” and “Flashing Diamonds” with the standard “Flashing Box” display. The field research indicated that “Dancing Diamonds” is associated with cautious driving, whereas the “Flashing Box” has no association. Comprehension survey questions showed little difference in comprehension between the three different signs. It was also found that motorists strongly consider either diamond display better than the “Flashing Box” at prompting safe driving near highway work.

Virginia: Reported on research conducted more than 15 years ago to evaluate channelization devices in work zones including type II barricades and chevron panels and, temporary asphalt medians for two-lane highways. Reports are not available.

The state of Iowa indicated that they have conducted research on delineation in work zones but did not have literature to share.

15.1.4 Half-size Auxiliary pavement markings

None of the states that responded to the survey had done research on this subject.

15.1.5 Accident Mitigation Measures

Colorado: A currently on-going study to evaluate sites with promise for safety improvements was indicated in the response to the survey. They do not have any results at the moment. The project is due for completion in late 2005.

Florida: They conducted studies to develop mathematical models to set speed limits using objective measures, rather than following the legislated speed limits which are based on the 85th percentile speed, as a measure to mitigate roadway accidents [197]. The study was done on nonlimited-access arterial roads in urban and rural areas in the state as they are characterized by great variation geometry, roadside development, and traffic movements. The authors conclude that the model developed predicted speed limits more realistically than using the 85th percentile alone.

Oregon: They have conducted several studies to ascertain means of mitigating accidents in their highways. In one study the use of elevated traffic fines, and specifically doubling of applicable traffic fines under certain conditions, as evaluated [213]. The research is based on a telephone survey of 651 adult Oregon drivers, who were asked about their decision to speed in a variety of different situations, to determine whether their judgments differed from one situation to another. The results were used to infer indirectly whether double fine signing was influencing their judgments. The analysis of the survey results showed that when considering safety corridors, people do not report the same elevated perception of crash risk that they report for work zones and school zones. They also do not have the same elevated perception of citation or fine risk. The report concludes that other countermeasure enhancements should also be considered to achieve more effective speed control if double fine signs are used. In another study conducted to investigate whether a relationship exists between motorists' speeds and law enforcement levels they found that enhanced patrols resulted in small but statistically significant reductions in speed at most of the test sites [215].

In a separate study, a knowledge-based decision model that can be used to determine when to use nighttime road construction and maintenance work has been developed [214]. They identified 19 factors affecting decision making in such situation through a literature survey. The information gathered from this and other sources were used to formulate a decision making model. They tested the decision model by applying it to actual Oregon DOT projects and comparing its recommendations on when to conduct the projects with actual decision makers' decisions. The overall testing results were consistent with current decision makers' subjective decisions because of the impact of congestion within the decision model. They assert that the decision model provides a practical and useful tool to help decision makers in real work environments analyze when to use nighttime work

Utah: They have developed and use a Crash Data Delivery System (software) to detect crash locations. The system classifies accident locations and highlights them by cause of accident; wild animal hits, pedestrian accidents, snow & ice related etc.

Virginia: They tested a deer warning reflector that can be used for delineation [226]. It consists of a red, double-sided reflector mounted on posts, similar to those used for roadside delineators along roadways. As vehicles approach and move through the road section, it is supposed that the reflector reflects the beam from vehicular headlights across the highway in a moving pattern of low-intensity red light beams, which in turn is supposed to get deer's attention and deters them from entering the roadway.

Deer warning reflectors were installed at 10 sites in Virginia. Each reflector site had a control site that was typically adjacent to the reflector site. The sites were monitored for 6 to 28 months. There was no evidence to suggest that the deer warning reflectors were consistently effective across most sites based on trend and statistical analyses. An experimental section with deer warning reflectors on one side of the road yielded results similar to those for the standard arrangement with reflectors on both sides of the road and control sections. In order for the benefits of the reflectors to exceed their installation and maintenance costs, the reflectors would have to prevent at least 1.14 deer-vehicle collisions per mile per year.

Several other studies have been conducted by personnel at the Virginia Transportation Research Center (VTRC) which investigated products and practices that could be used to mitigate accidents. Most of them are approximately twenty years old and the reports are not available.

15.1.6 Older Driver Accommodation

Arizona: They conducted a study to examine the current knowledge of state-of-the-art highway design practices aimed at increasing the safety of older drivers, to assess the crash and fatality data for older drivers in Arizona and to survey older adults regarding their perceptions of the state's roadways and possible needs for enhancement [217].

Their findings indicated that older drivers were more likely to have angle and left-turn collisions and to be in collisions involving intersections/junctions, at signaled and un-signaled left-turn intersections, and in daylight hours. The authors indicate that the older drivers surveyed found driving at night to be difficult. They also had difficulty in driving on a freeway and identifying street names. The older drivers felt improvement could be made to lettering for signs and supported increasing the availability of sidewalks.

Survey respondents most frequently rated larger and better-illuminated traffic signs as the most helpful design improvement that could be implemented and most frequently rated special senior driver testing programs as most the most effective screening and assessment option.

Florida: In a study conducted to evaluate cognitive and perceptual factors in aging and driving performance they found that younger drivers had more collisions/crashes than older drivers [198]. They also found that older drivers were less likely to exceed speed limits than younger drivers. It is also indicated that tests such as the Useful Field of View (UFOV), Digit Symbol, Block Design, Trails B, and Contrast Sensitivity tests appear to be able to predict driving performance better when compared to other tests.

Florida has also conducted studies to evaluate various traffic control devices to determine their effectiveness for older drivers [199]. They conducted extensive field tests to evaluate already implemented modifications including overhead and advance street name signs, pavement markings with different widths, offset left turn lanes and raised pavement markers and to test two new types of enhanced traffic control devices; the Clearview font for signs and new pavement marking materials, developed by 3M. Their findings indicate very explicit advantages of using larger lettering as well as wider pavement markings and raised pavement markers. However they indicate that offset left turn lanes did not show specific advantages. Of the new types of devices tested, the Clearview font showed greater legibility distances than other fonts for advance street name signs but not for ground-mounted street name signs. The new lane markings did not show any absolute or relative improvement in visibility.

In a separate comprehensive study, literature relating to senior transportation issues and a summary of results from senior focus groups studies is presented [200]. They also conducted a written survey as part of the study among senior citizens.

Iowa: The response from Iowa DOT indicated that they have placed an emphasis on accommodating the large percentage of older drivers in the state. They continue to have sessions with older drivers to improve their awareness and receive feedback.

New York: The state adopted wider pavement markings, larger lettering and higher grade reflective sheeting a number of years ago. Many changes are the result of field testing by their engineers and small pilot or demonstration projects. No reports are available.

Vermont: They indicated the use of guidelines in FHWA-RD-01-103 Highway Design Handbook for Older Drivers and Pedestrians.

Virginia: They conducted some studies in the early 1990's to determine transportation needs of older drivers. No reports were received.

15.1.7 Traffic Signals

Florida: They conducted research to evaluate the impact of signalization on crashes at newly signalized intersections in Florida by developing statistical crash prediction models [201]. These models can estimate the expected number of crashes at an intersection before and after the installation of traffic signals, in terms of total number of crashes and number of crashes for different crash types, including angle, left-turn, rear-end and other crashes. Using the model the change (increase or decrease) of the estimated crash frequencies before and after signalization can be calculated. From the findings they conclude that signalization has some impacts on traffic safety at intersections [203].

Another report presents a brief summary of the current literature and technologies used to develop safer and more secure bus stops, with a focus specifically on vulnerable populations such as women, children, senior citizens, and the disabled.

Maine: Research has been conducted by University of Maine researchers to analyze red-light running in Maine in order to evaluate the effectiveness of traffic signals. No report is available.

Utah: They conducted a study to investigate the usefulness of adaptive signal control. Adaptive Traffic Control Systems (ATCSs) are a latest type of signalized intersection control that instantaneously detect vehicular traffic volume, compute optimal signal timings based on this detected volume and simultaneously implement them. The studies have been conducted using the University of Utah-built interface between the micro-simulation models CORSIM and VISSIM and the Split, Cycle and Offset Optimization Technique (SCOOT). The authors conclude with a firm recommendation to deploy adaptive signal control. They show that adaptive control in Salt Lake City will bring immediate delay reduction and improved traffic control for many years to come.

Virginia: Some studies were conducted by the Virginia Transportation Research Center to evaluate strobe lights in the red lens of traffic signals and on developing guidelines for exclusive/permissive left-turn signal phasing. The reports on these studies are not available.

15.1.8 Highway Lighting

Colorado: The state is in the planning stage for a study involving replacement of overhead lights with LED barrier markers. No work has been done yet and no published information is available as of now.

Virginia: VTRC conducted research in 2003 to determine methodologies to screen for fixed highway lighting needs [227]. Their study was focused on developing further the screening methods provided in AASHTO and NCHRP which have not been updated since the late 1970's. A two phase method has been developed where first an exposure assessment is developed and then the outcomes of this are used to build on selected concepts of the NCHRP method. The exposure assessment technique helps to describe the individual and population exposure to crashes. The two-phase method was tested on highways of Virginia and based on the findings the authors recommend that (i) highway agencies should consider designating funds for lighting and visibility enhancement using the developed screening method in resource allocation; (ii) agencies should provide training and continuing education in the developed screening method, and emphasize the unity of principles of risk assessment and management across highway safety issues; (iii) through a testing phase, agencies should consider replacing the AASHTO and NCHRP methods with the developed method; (iv) agencies should perform regional data analysis and screening of unlighted locations on an annual basis; and (v) incorporate the method in holistic lighting master plans [227].

The state of Florida indicated that they have conducted research on highway lighting. However no literature is available.

15.1.9 Curve Delineation

Colorado: The state DOT is currently conducting a study evaluating the use of barrier markers applied to concrete barriers on curving mountain highways. The results are not documented. However CDOT intends to publish the results of the study by the end of June, 2004 on their website, but could not be found on their website.

Iowa DOT indicated that they have conducted research in curve delineation but did not provide any additional information.

15.1.10 Wet/Dark Delineation

Oregon: The state investigated the use of Lighted Guide Tubes, a 3M product, as a delineation device. The experimental results were described previously under the work zone delineation section [211].

Vermont: The state is currently testing 3M Liquid Pavement Markings (LPM). It is a reflective liquid pavement marking containing glass beads. They have been designed for long lines, edge lines, channelizing lines, gore markings, and symbols and legends on pavements which have multiple years of service life remaining. However no literature is available at the moment.

Virginia: A study was conducted to evaluate pavement markings for improved visibility during wet night conditions. There is also a project currently underway to evaluate the visibility needs of drivers during wet night conditions.

The states of Florida and Iowa indicated that they have conducted research relating to wet/dark delineation at night.

15.1.11 Raised Pavement Markers

Colorado: The state has conducted considerable undocumented testing using different types of pavement markers. However they indicate that none were able to withstand snow plow operations.

Virginia: The Virginia Transportation Research Center (VTRC) conducted research in the late 1970's to evaluate raised pavement markers for roadway delineation and also recessed, snowplowable markers for centerline delineation. However they have not conducted any research in recent times on this subject.

In their response to the survey Florida indicated that they follow Florida DOT standards with respect to raised pavement marker spacing. However, they did not indicate if they conducted any research on the subject.

15.1.12 Information Dissemination

Texas: They conducted studies to evaluate various aspects relating to providing advanced and real-time travel/traffic information to tourists [220]. Based on the results of the study they identified systems/technologies that are suitable for the information needs, technical regulations, legal constraints, and compatibility with traveler information system standards established in Texas.

In a separate study the advanced traveler information system in the San Antonio area has been evaluated [221].

New York: The Governor's Traffic Safety Committee website is used to communicate most of the current research and other information to the public.

15.1.13 Other Research in Human Factors

Arkansas: Studies have been conducted to evaluate the effectiveness of Do Not Block Intersection/Drive signs [218]. The findings indicated that at three of the sites studied the signs had no effect on driver behavior. The fourth site which was a high-volume shopping center driveway, a minimal impact was observed.

In a separate study, a literature review and two surveys were conducted to examine the usage of cross traffic signs, circumstances under which they have been installed, the effectiveness, and future actions that could be taken [219].

Florida: The DOT conducted several studies including the evaluation of pedestrian crossing patterns in urban areas [204], the use of triple left turn lanes from an operational, safety and

modeling perspective and to develop guidelines for their use [205], and developing accident tracking methodologies that can be used to reduce transit costs.

Utah: The state has conducted a literature review of pedestrian safety measures practiced in twenty eight other states and an analysis of pedestrian-vehicle crashes in Utah [224]. Recommendations are made based on the findings.

California: In response to the survey from the Mineta Transportation Institute attached to San Jose State University they indicated that they are currently completing research on the impact of using telecommuter rail cars on modal transport.

16 PRODUCT SURVEY AND REFERENCES

The human factors research project activities also included contacting various manufacturers, vendors and consultants of traffic engineering. The people and/or companies contacted were asked to state, which of their products were the results of some special research conducted by the companies with respect to the human factors point of view. The email that was sent out is included in Appendix F.

Of all the companies contacted only some have responded in detail to the email. Some have sent in information which they felt was pertinent to this research either by mail or electronically while some have provided us with information regarding the companies with whom they interact and which play a more significant role in actually designing the products and hence would have more research incorporated.

In order to proceed further with the product survey, an effort to peruse the websites of the companies to find innovative or improved transportation products was undertaken. This report contains the results of this effort along with the information given to by individual companies.

Each of the specific type of product that was mentioned in the email could be placed under one of the 13 categories that were identified for the Human Factors Opportunities project. The products have thus been divided into these categories and their innovativeness has been explained with references being made to the corresponding company website.

No specific products are endorsed or recommended since the introduction of most of these products would require conducting an evaluation before a widespread implementation could be started. The information contained here is thought to be more of an informational nature from which promising new products could be selected for evaluation and if successful for implementation.

16.1 Survey Results

16.1.1 Rumble Strips

Advance Traffic Markings [228] is a company that makes removable, rumble strips. These environmentally safe, lead free, strips come in three colors: bright orange, white and black. The strips are 4" wide and 150 mil thick. These are used essentially, to alert traffic of changes in roadway conditions and to indicate caution. These rumble strips are shown in Figure 135. Application information for these rumble strips is shown in Figure 136. Company contact information is provided in Table 38.

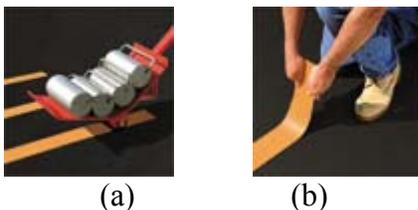


Figure 135: Applying Removable Rumble Strips [228]

Suggested Applications.

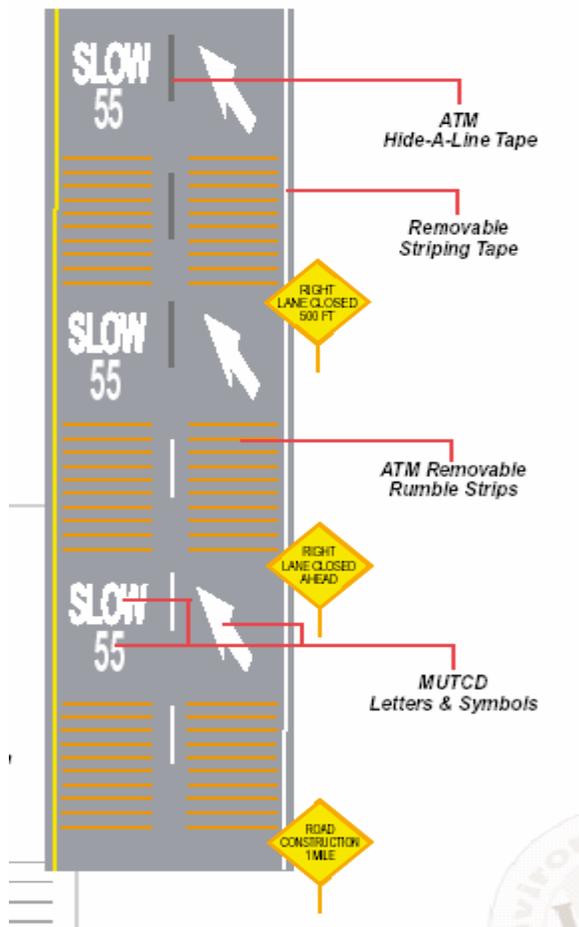


Figure 136: Applications for Removable Rumble Strips [229]

Table 38: Contact Information for Advance Traffic Markings [230]

Name: Michael Hare
Phone: 334-538-6976
Fax: 334-272-2258
Email: mhare@mindspring.com
Headquarters
Phone: 252-536-2574
Fax: 252-536-4940

Stop-Painting is another company that makes removable rumble strips. The rumble strips come in black and a bright green so as to be able to give a visual indication of their presence as well. The rumble strips and an application are shown in Figure 137 and Figure 138.



Black Rumble Strip Green Rumble Strip

Figure 137: Examples of Removable Rumble Strips [231]



Figure 138: Application of Removable Rumble Strips [232]

Traffic and Parking Control Inc (Tapco Inc) is another company that makes plastic, removable rumble strips that are 4" (0.1016 m) wide and come in white, yellow, red, blue and black. These strips are sold on a per foot basis but also come in 10' (3.05 m) pieces. These rumble strips are installed using either epoxy or butyl pads. The rumble strip is shown in Figure 139.



Figure 139: Removable Rumble Strip (TAPCO) (extracted from [233])

The websites featuring these products do not have any evaluation reports that are freely available and therefore the use of these should be decided only after the evaluations have either been studied or conducted under different operating conditions. These evaluations will confirm whether these products can be used under all extreme conditions.

16.1.2 Changeable Message Signs

American Signal Company (AMSIG) makes changeable LED message signs. The model shown in Figure 140 is GP 232-T. This is a fully programmable portable message sign that can be used for general traffic management and work zone traffic control where space is a consideration. The complete capability of this CMS system can be seen using the URL given below. The main point is that the LED can be controlled manually or via a photosensitive circuit that adjusts the LED intensity with respect to the ambient illumination. This ensures that the display is both visible and legible under all lighting conditions. It is originally trailer mounted but it is very small (32" X 72") or (0.8128m X 1.8288m) and light (< 100 lbs) and so can be moved from one vehicle to another easily. Another advantage of this CMS system is that the programming needed for this is the same as that required by the other CMS systems and therefore does not require that the user be trained specially for this sign system. Contact information for the company is provided in Table 39.

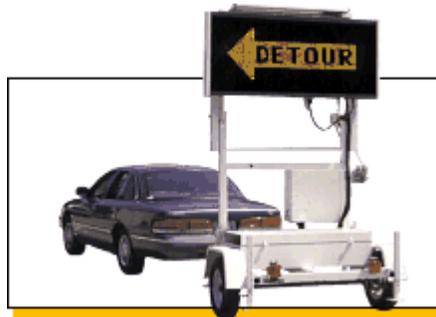


Figure 140: LED Changeable Message Sign [234]

Table 39: Contact Information for Amsig

Headquarters

Phone: 770-448-6650

Fax: 770-448-8970

PWS Ireland Ltd. makes solar powered portable changeable message signs called the PWS 320 shown in Figure 141. It uses LED that requires low energy input and thus can work using solar charged batteries in all climates. The advantage is that each LED is encapsulated separately so this enhances the output of the sign. The operator can create text, symbols and images. Since the sign is solar powered it is environmentally safe as well. The technical specifications available in the corporate website [235].



Figure 141: Solar Powered LED Changeable Message Sign [235]

A variation on the general changeable message sign is this message sign that is made by PWS Ireland. It is a vehicle activated road signs. These LED roads signs are activated only if the drivers do not observe speed limits and they display messages like “Speed Kills” (Figure 142) or “Slow Down”. Other such signs that are available are Overhead Activation Signs, Weather Hazard warning activation and Queue Ahead warning activation signs. PWS Ireland is based in Ireland and contact information is given in Table 40.



Figure 142: Vehicle Activated Speed Sign [236]

Table 40: Contact Information for PWS Ireland

Headquarters

Phone: 44-2830264511

Fax: 44-2830269633

Email: info@pwssigns.com

Ver-Mac Incorporated is another company that makes a wide range of changeable message signs. The first among these are message boards, which are available in different sizes and display configurations i.e. character, line or full matrix. These message boards are used mounted on trailers. There are five different types of message boards available as shown in Figure 143. Each is solar powered, the difference between them being the type of programming necessary, the character display and the application of each. Ver-Mac also custom makes message boards.

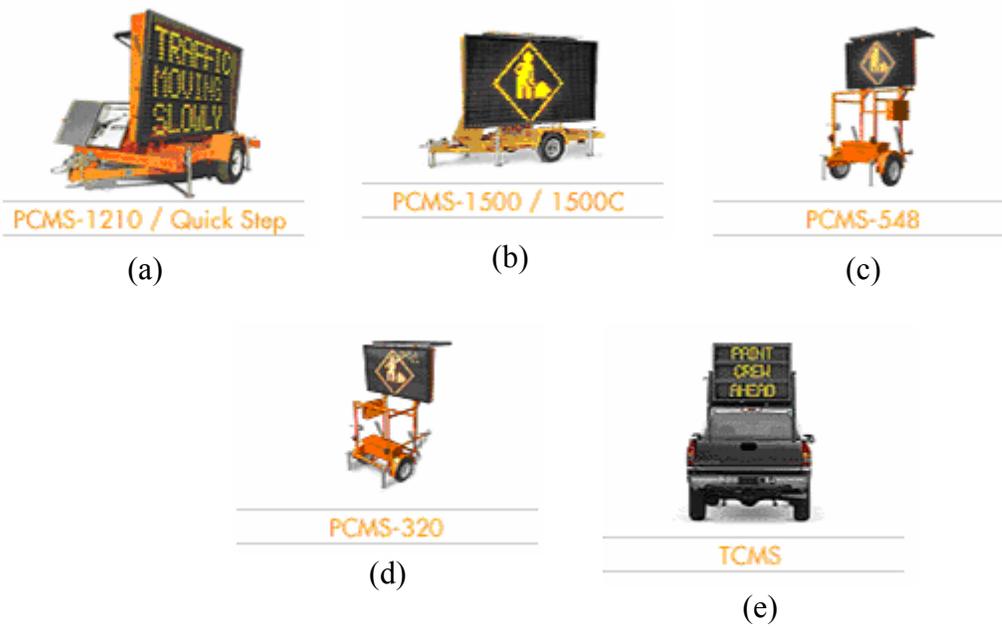


Figure 143: Types of Message Boards [237]

The second type of changeable message sign that Ver-Mac manufactures is the speed trailer, shown in Figure 144. It comprises of a speed monitoring trailer, two or three-digit display, a radar to detect approaching traffic and a data log option. This sign is also solar powered and hence environmentally friendly. The technical specifications regarding size, structure, display, radar and the programming is available in the website [237].



Figure 144: Speed Trailer

The third type of changeable message sign that Ver-Mac makes are solar operated arrow boards shown in Figure 145. These arrow boards are of three types that differ according to installation. These boards have solid-state controllers with standard or customized flash patterns, different sizes and different solar configurations. The complete technical details can be obtained from the website. Ver-Mac is a Canadian company and contact numbers are given in Table 41.



Figure 145: Arrow boards made by Ver-Mac [237]

Table 41: Contact information for Ver-Mac

Headquarters

Phone: 1-888-488-7446

1-418-654-1303

Fax: 1-418-654-0517

Traffic Safety Supply Company is the supplier of the world’s first modular sign called the “BRICK” Modular Message Sign made by ADDCO shown in Figure 146 and Figure 147. It is completely programmable, versatile and durable message owing to its unique environmentally sealed polycarbonate and thermoplastic case. The LEDs are mounted inside this case. This BRICK concept can be used in any kind of sign such as a speed sign, a ramp queue sign, etc. The full range of applications can be seen on the website. The advantage to road users is that each brick display module consists of ADDCO’s unique silk-screening process, which minimizes glare and thus increases visibility in all lighting conditions. Traffic Safety Supply Co. is based in Portland, Oregon and contact numbers are shown in Table 42.

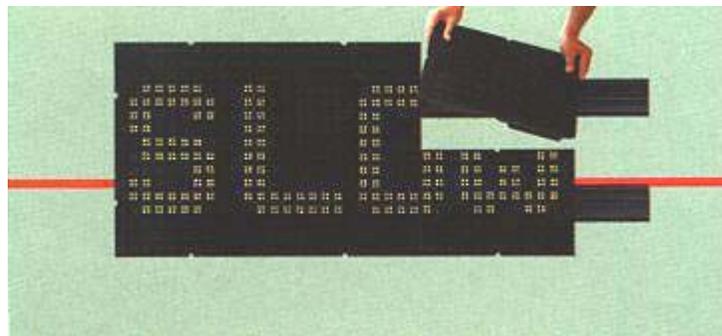


Figure 146: BRICK Modular Design [238]

Simplicity of Design



Speed Limit Sign

Versatility and Flexibility



Ramp Queue Sign

Figure 147: Some Applications of BRICK [238]

Table 42: Contact Information of Traffic Safety Supply Company

Headquarters

Phone: 503-235-8531

Fax: 503-235-5112

Email: Sales@TSSCO.com

(extracted from [238])

ADDCO is based in St. Paul, MN and the contact information is shown in Table 43.

Table 43: Contact Persons at ADDCO [239]

Blake Balzart

Central Region

Phone: 651-558-3519

Fax: 651-558-3600

Email: bpbalzart@addcoinc.com

John C. Mueller

Northern Region

Phone: 218-586-2153

Fax: 218-586-2154

Email: jcmueller@addcoinc.com

Dan Boop

Northeast Region

Phone: 570-523-7072

Fax: 570-523-7083

Email: dcboop@addcoinc.com

Dave Sorenson

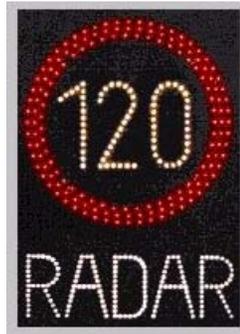
Sales Support Manager

Phone: 651-558-3514

Fax: 651-558-3600

Email: djsorenson@addcoinc.com

Swarco is a company that makes two types of variable message signs: Fiber Optic and LED shown in Figure 148. Their fiber optic VMS has about 15 different signal types and can be combined with flashers and text bars. The signals are bright because the light from the halogen source sent to the pixels are totally reflected as they pass through the glass fiber light conductors.



(a) Fiber Optic VMS



(b) LED VMS

Figure 148: Fiber Optic VMS [240]

The LED VMS also has 15 different signal types that can be combined with flashers and text. The optical system is different however with the display being a dot matrix of LEDs that display in red and white. There is no heating in this as well.

Swarco has another LED VMS system shown in Figure 149, which is different from the one previously explained: it is freely programmable. Since there is not a front screen, there are no reflections and no heating. The manufacturers claim that the luminance is very high (up to $18,000 \text{ cd/m}^2$ (11.61 cd/in^2)) with a high contrast ratio; greater 20 with the sunlight impacting at $40,000 \text{ lx}$ at an angle less than 10 degrees and greater than 25 with the sunlight impacting at $10,000 \text{ lx}$ at an angle less than 5 degrees. There is a high degree of uniformity due to a calibrated LED module being used.



Figure 149: LED VMS from Swarco [240]

Swarco is based in Wattens, Tyrol. In the US the offices are in Denton, TX. The contact numbers and email are in Table 44:

Table 44: Contact information for Swarco

Offices for USA

Phone: 254-562-9879
 Fax: 254-562-7601
 Email: ryan.futurit@swarco.com

Tassimco makes Countdown Pedestrian Signals. Ideal for high traffic, high-risk pedestrian crossings, pedestrians find these signals to be clear and devoid of the mystery that exists in the conventional pedestrian signals. There are three ways in to install these countdown signals.

- ❖ Conversion of 18", 1 section ICC Pedestrian Signals: This is a sealed module that replaces the conventional pedestrian signal and connects directly to the terminal block. The Portland Orange LED "HAND" is combined with a white LED "MAN" and a double digit red LED countdown display shown in Figure 150.



Figure 150: 18" Pedestrian Countdown Signal [241]

- ❖ Conversion of 12", 2 section Pedestrian Signals: This type consists of a pedestrian hybrid signal and a pedestrian countdown module. These sealed modules are installed

in place of a standard two-section system and connect to the terminal block. The hybrid signal consists of the Portland Orange LED “HAND” overlaid on the white LED “MAN”. This replaces the upper section. The pedestrian countdown module comprises of a two-digit LED display and replaces the lower section shown in Figure 151.



Figure 151: 12" Pedestrian Countdown Signal [241]

- ❖ Supplemental signalization for existing pedestrian signals: The pedestrian countdown module can be added to an already existing one or two section pedestrian signal without adding additional wiring. The double digit countdown display has dual rows of LEDs Figure 152.



Figure 152: Addon Pedestrian Countdown Signal to existing signal [241]

Control Specialists is the sales company that features these products made by Tassimco Technologies. They are based in Orlando, Florida and their contact personnel and numbers are given in Table 45:

Table 45: Contact information for Control Specialists

General Information info@controlspecialists.com	Phone: 407-628-1965 Fax: 407-628-1932
Sales sales@controlspecialists.com Eric Deason eric@controlspecialists.com Sales Manager	Allen Reid allen@controlspecialists.com Regional Sales Representative for Data collection, products, and general sales.
Robb Bingham robb@controlspecialists.com Regional Sales Representative for data collection products, and general sales.	Terence Tomlin terence@controlspecialists.com Regional Sales Representative for data collection products, and general sales.

Polara makes a product called the Navigator. It is an accessible pedestrian signal (APS) with a 2” (0.508 m) push button, which activates audible signals during all pedestrian cycles. The speaker is behind the unit. There is a custom message that is relayed when the push button is depressed for an extended period of time. The message gives information about the intersection and the street being crossed. The device is shown in Figure 153.



Figure 153: Pedestrian Push Button Audible Signal [262]

The main features of this system are detailed in the website [262]. The advantage of the system is that it is a customizable to some extent and has a volume range of 60 dB. This pedestrian intersection is a complete advantage to blind people. The entire pedestrian intersection has synchronized sounds and so there is no noise clutter. Polara is based in Fullerton, CA. The contact details are given in Table 46:

Table 46: Contact information for Polara

Headquarters

Phone: (local) 714-521-0900
Toll free: 888-340-4872
Fax: 714-521-5587
Email: sales@polara.com

Distributors for Ohio and Kentucky

Baldwin & Sours
Phone: 614-851-8800
Fax: 614-851-0101

16.1.3 Delineation in Work Zones

Roadtech Manufacturing makes many traffic safety products, the latest of these products being of interest with respect to the human factors aspect. These products are VIS Strobe Lights for Cones, Movable Deluxe Delineator Posts and Surface Mounted Highway Delineators.

VIS Strobe Lights for Cones: This light as a Xenon flash 60-70 times per minute. It has a high reflective visibility. This light can be fixed onto any cone that has a hole on top. Barrier tape can also be attached as shown in Figure 154, with the help of a clip that comes with the light. Different colors are available such as amber, red, green, blue and clear.



Figure 154: VIS Strobe Lights for cones [242]

Movable Deluxe Delineator Posts: Roadtech also makes delineator posts that are 4" X 42" (0.1016 m X 1.0668m), with two 3" reflective bands standard. The delineator posts have a 16" (0.4064m) Wide x 1 1/2" (0.0381m) High, octagon base made from interlocking high-density, polyethylene. There is an optional 3" (0.0762m) round yellow reflective dot on both sides of

post for additional safety as shown in Figure 155. The post is made from durable, 100 percent recycled rubber. This product is NCHRP-350 approved.



Figure 155: Movable Deluxe delineator posts [242]

Surface Mounted Highway Delineators: According to the manufacturer’s literature ‘This product is as much of a boon for road users as it is for the people at the transportation department’. This delineator is made by means of a color impregnated polycarbonate extrusion and consists of a flexible hinge. They are easy to assemble and can be installed on virtually any road surface be it concrete, asphalt, or wood using lag bolts, burl rubber, epoxy and nails. Roadtech has crash tested this product and the results have been summarized in Table 47.

Table 47: Test Results for the Surface Mounted Highway Delineators [242]

# Vehicular Impacts	Speed (mph),(kph)
340	30, 48.28
> 75	55, 88.51
“Numerous”	80, 128.74

These posts are available in standard sizes of 18", 2', 2.5', 3'and 4' (0.4572 m, 0.6096 m, 0.762 m, 0.9144m, and 1.2192 m) and in standard colors of red, white, yellow, orange, green, blue, brown and gray. These posts can be fitted with any federally approved sheeting material as shown in Figure 156. These can also be fitted with signs if so needed.

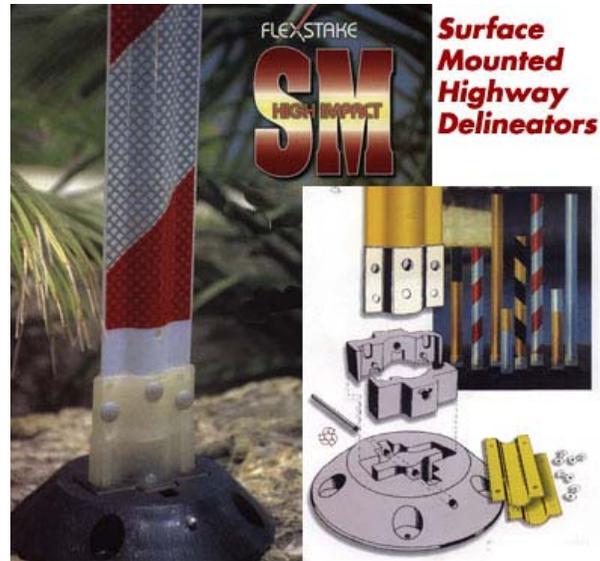


Figure 156: Surface Mounted Highway Delineator Posts [242]

Roadrunner is a portable traffic barrier used to clearly guide the vehicle much before it reaches a sudden change in traffic pattern or a work zone, shown in Figure 157 and Figure 158. The best aspect of this barrier is that its linear characteristics get the attention of drivers far better than cones or barricades. They are also bigger than cones or barricades or barrels and so can be seen by the driver when he/she is farther away. This would help the motorist to decide on a plan of action much earlier. It is made of lightweight UV stabilized maintenance free polyethylene. But these should not be used in situations where concrete barriers are absolutely needed to deflect high-speed traffic as in New Jersey. These barriers are effective under all weather conditions and can be employed with or without ballast (sand or water). Since they form a continuous barrier, they prevent motorists from sneaking around the traffic control device.



Figure 157: Roadrunner [242]

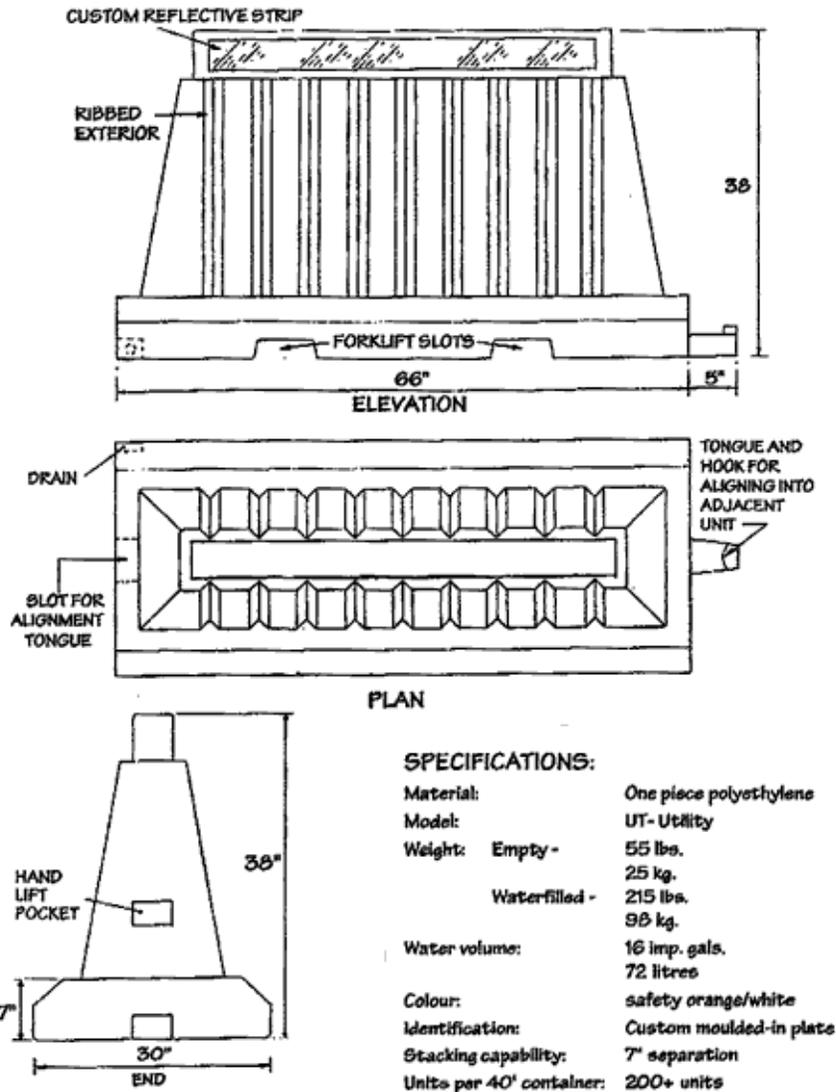


Figure 158: Design for the Roadrunner [242]

Roadtech Manufacturing is based in Oak Park, IL. The contact phone and email are shown in Table 48.

Table 48: Contacts for Roadtech

Headquarters
 Phone: 800-880-3073
 Fax: 773-866-1698
 Email: sales@roadtech.com

SCSupply Company is a supplier of many types of safety equipment; flared delineator posts being only one of these products. These posts are shown in Figure 159 with the corresponding costs. These delineator posts can use rubber bases or surface mount bases.

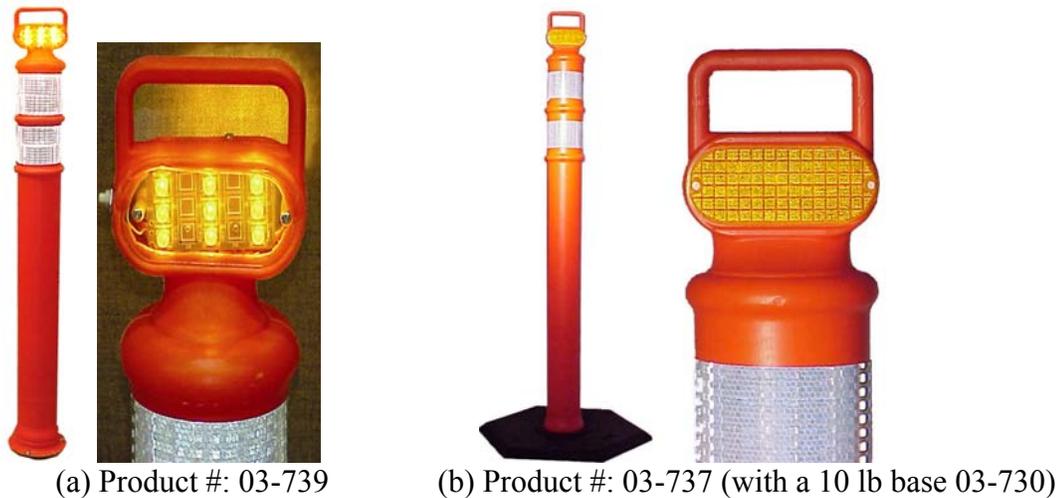


Figure 159: Flared Delineator Posts [243]

Table 49: Product Information for the Products mentioned in Figure 159 [243]

Product #	Description	Weight	Price
03-730	Rubber Delineator Base	10 lbs	\$8.10
03-737	Delineator Post, Flared, 45" w/two 3" HI Intensity collars & Oval Reflector	1.5 lbs	\$15.60
03-739	Delineator Post, Flared, 45" w/two 3" HI Intensity collars & 2 Strobes	1.5 lbs	\$96.44

The contact information for SCSupply Company is in Table 50:

Table 50: Contact for SC Supply Company

Headquarters
 Phone: 800-640-1843
 Fax: 574-287-0252
 Email:
 General Information info@scsupply.com
 Sales jimc@scsupply.com
 Customer Support cs@scsupply.com

RC Flagman is a company that makes Remote Controlled Flaggers, making work zones safe for road users and for traffic personnel. These flaggers are also solar powered making them cost effective and environment friendly. This remote controlled flagger can either be used on its own or in tandem with one or two human flaggers. It uses LED lights that are 12' above the ground for better visibility. The 12" red LED indicates that the motorist should stop, 12"

amber when flashing allows the motorists to go through and there is a 4" amber LED light at the rear that indicates current light status. This flagger is shown in Figure 160.



Figure 160: Remote Controlled Flagger [244]

The following is a link to a 20 second video showing the working of the automatic flagger that is available on the website of RC Flagger (viewed with QuickTime only.)

<http://www.rcflagman.com/howitworks-video.htm>

RC Flagger is a Canadian Company based in Ontario and the contact information is in Table 51.

Table 51: Contact for RC Flagger

Headquarters

Phone (local): 905-735-4750

(Toll free): 877-352-4626

Fax: 905-735-3794

Quebec Distributor

Mr. Douglass Pearsall Jr.

Phone: 514-766-3567

Fax: 514-766-5438

Traffic and Parking Control Incorporated (TAPCO) makes the ReflectoMarker, shown in Figure 161 a capped PVC tube, which has a 4" (0.1016 m) high strip made of reflective blue and white vinyl sheeting at the top. This makes the tube highly visible to motorists and hence alerts them day and night, to driveways, parking lot edges, turnarounds, ditches, drop offs, culverts and other objects. Available in heights of 30" (0.762 m) and 40" (1.016 m) and can be adjusted on a support stake.



Figure 161: ReflectoMarker [245]

TAPCO is based in Elm Grove, WI and the contact information is given in Table 52:

Table 52: Contact for TAPCO

Headquarters	
Phone (local):	262-814-7000
(Toll free):	800-236-0112
Fax: (local)	262-814-7017
(Toll free)	800-444-0331

16.1.4 Half size Pavement Markings

Traffic Safety Supply Company manufactures PREMARK, shown in Figure 162 preformed thermoplastic pavement markings. This is a durable alternative to painting lines. It was found that Premark can last from 4 to 8 times longer than regular traffic paints. Premark also does not have any road to air temperature requirement. Several sizes and legends are available. An application of PREMARK is shown in Figure 163. Using PREMARK is shown in Figure 164.



Figure 162: PREMARK [246]



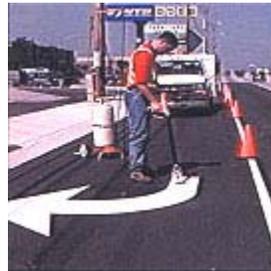
Figure 163: Example of PREMARK Application [246]



Clean the surface and make sure no moisture is present



Position the Premark



Heat Premark with the Flint 2000 ex.



Chisel test to ensure bond.

Figure 164: Pictures showing how Premark is applied to the road [246]

Traffic Safety Supply Company (TSSCO) is based in Portland, OR. The contact emails and phone numbers are given in Table 53:

Table 53: Contact for TSSCO

Headquarters	
Phone (local):	503-235-8531
Fax: (local)	503-235-5112
Email:	CBonin@TSSCO.com
	JDame@TSSCO.com
	CKirstein@TSSCO.com
	TLoun@TSSCO.com
	ProductionManager@TSSCO.com

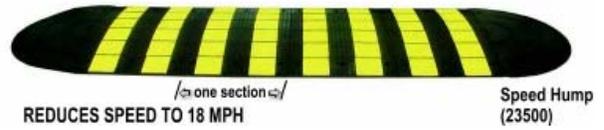
16.1.5 Accident Mitigation

Traffic Logix (A Division of GNR Technologies) makes speed bumps and parking curbs as shown in

Speed Bumps: Safety Rider and the Easy Rider/Glo Rider are the two types of speed bumps that are made. The table below shows pictures and special features of each of these products as taken from the website.



(a)



(b)

Figure 165 : Safety Rider. Consists of modular units that can be added to make as long a speed bump as needed. Embedded with reflective tape to make for high visibility. Made from virgin and recycled rubber. They can be removed, stored and relocated. Slows cars and trucks [247]



(a)

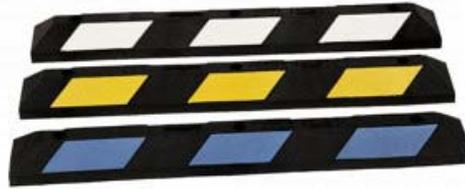


(b)

Figure 166: Easy Rider/Glo Rider. Made completely from recycled tires. Yellow polyurethane glass-beaded paint allows for maximum reflectivity. Can be removed, stored and relocated. Resistant to extreme light and weather conditions. Installs with spikes [247]



(a)



(b)

Figure 167: Park IT. The features of this product are the same as the features of the previous two products [247]



Figure 168: Home Park IT. Highly visible, rubber parking curb for the garage [247]

Control Specialists is the sales company that features these products manufactured by Traffic Logix. The contact information for Control Specialists has been detailed in the Changeable Message Sign Section in Table 45.

Stop-Painting is another company that makes portable speed bumps. The portable speed bumps are of two types. One is the bag version, which is 10 feet (3.048 m) long and comes with a carrying canvas bag for convenient transportation. The hand truck version is 20 feet (6.096 m) long. They need no adhesives and just need to be unrolled on the road where needed to slow down oncoming traffic or to redirect traffic.



Figure 169: Bag Type Portable Speed Bumps [231, 232]

Contact information for Stop-Painting has already been detailed in the Rumble Strips section in Table 44.

Roadtech is a manufacturing traffic consultant company that was mentioned earlier in the section on work zone delineation. Some of their accident prevention products are as follows

Pedestrian Barrier: These barricades completely surround the danger zones i.e. areas where people are working, places where the elevators are not working, etc. as shown in the figures below. These barricades have small openings and therefore there is no danger of children or animals entering the enclosed area. They are lightweight and can be carried easily. They allow for signs to be placed on their periphery to inform people of imminent danger. These barricades come with flat weight accessories that are used to give it bottom weight and thus prevent it from blowing away or moving. Other details of this pedestrian barrier, shown in Figure 170 can be obtained from the website.



(a)



(b)

Figure 170: Pedestrian Barrier [242]

The contact information for Roadtech Manufacturers has been discussed before in the section concerning work zone delineation in Table 48.

16.1.6 Older driver Accommodation

No special products were found that especially focus on the older driver population.

16.1.7 Traffic signal operations for reducing accidents

Ver-Mac Incorporated is a company that has been discussed before in the section concerning changeable message signs. They also make portable, solar powered traffic lights, shown in Figure 171. These traffic lights can be pre-programmed and consists of different user modes, traffic flow settings, vehicle detectors and countdown displays.

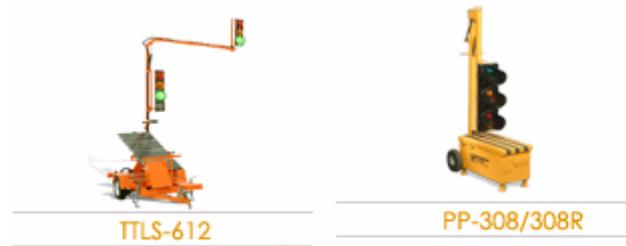


Figure 171: Portable Traffic Signals [237]

The contact information for Ver-Mac has been discussed in the section for changeable message signs in Table 41.

16.1.8 Highway lighting

No specific products were found.

16.1.9 Curve delineation

Traffic Safety Supply Company also makes drivable flexible delineators as shown in the figure. It is called the Carsonite Road Marker (CRM), shown in Figure 172. This delineator can bear many impacts and is said to have a 20-year life. It is ideal for straight-aways and general delineation.

Specifications	
Material:	Fiberglass Composite
Width:	3.75"
Lengths:	62", 66", 72", 78"
Weight:	2.5lbs (62")
Colors:	White, Yellow, Brown, Blue, Red

(a)



(b)

Figure 172: Carsonite Road Marker – CRM [248]

16.1.10 Wet/Dark Delineation

3M makes wet reflective pavement marking tape, which is durable and conformable with specially designed optics for superior reflectivity in both dry and wet conditions. This can be seen in Figure 173. Designed for long line overlay applications on concrete and asphalt surfaces for continuous day/night delineation.



Figure 173: Wet Reflective Pavement Marking Tape [249]

3M also makes liquid pavement marking material that has high initial and long-term reflective capacity and contains a combination of reflective elements and glass beads. Designed for long lines, edge lines, channelizing lines, gore markings, symbols and legends on pavements, which have multiple years of service life remaining before resurfacing. This material takes 3 minutes to dry. It has improved visibility during poor weather conditions [250].

3M is a company in St. Paul, MN. The contact numbers are as follows:
Customer Service: 1-800-553-1380

Swarco is a company that makes traffic safety products and has been making them for 30 years. This section is about the beads made by Swarco for wet reflective marking. These beads are called Megalux-Beads and are said to have consistent and optimal retroreflectivity, shown in Figure 174. They are clear, are 95% round, come in sizes between 600-1500 μ , with a refractive index ≥ 1.5 and a specific gravity of 2.5 (approx). These beads are 3 times brighter than regular beads thus ensuring day and night reflectivity in all weather conditions.

Swarco is ISO 9002 certified. These beads are suited for roads requiring optimum retroreflectivity and durability.



Figure 174: Megalux-Beads [251]

Swarco also makes a product called the Two-component scraper plastic, rain safety marking, shown in Figure 175. It is a layer of cold plastic with large, good quality, reflective glass beads and anti-skid aggregates. This has been used to create durable and skid resistant rain safety markings. This scraper plastic is applied at 3 mm (0.118 in) layer thickness. It is ideal for long term markings where high nighttime visibility is required. The glass beads used in the making of this scraper plastic are the Megalux beads (explained previously) that cause high retro reflection when the roads get wet.

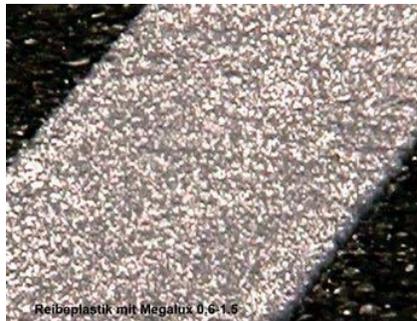


Figure 175: Two-Component scraper plastic, rain safety marking [252]

The third type of road marking material, Swarco makes is the Limboplast D480 structured cold plastic shown in Figure 176. This has very good wet/night visibility and very resistant to mechanical stresses like the ones caused by snow ploughs. Thus it has long-term durability. This material also has a very good price/performance ratio because very little material is used.

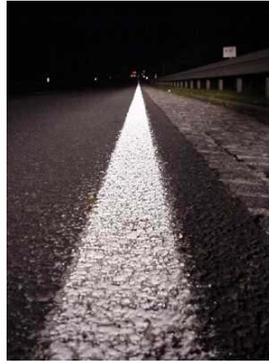


Figure 176: Limboplast D480 [253]

Swarco has been mentioned before in this report in the section discussing changeable message signs and the contact information is in Table 44.

16.1.11 Raised Pavement Markers

RoadVision Technologies makes a snowplowable raised pavement marker called the Highway Beacon, shown in Figure 177. As claimed by the manufacturers this product is ‘a boon to the winter maintenance people’.

This RPM consists of a heat-treated piston with the corresponding reflective lens, which sinks below the surface upon impact from any direction, thus allowing the blade to skip above it harmlessly. After impact, the RPM swings back into place. This RPM has good shock absorption capabilities and is very easy to maintain and hence provides a long lasting and cost effective solution. The construction details can be taken from the website but the assembled RPM as well as the different parts of the RPM can be seen from the figures shown below.

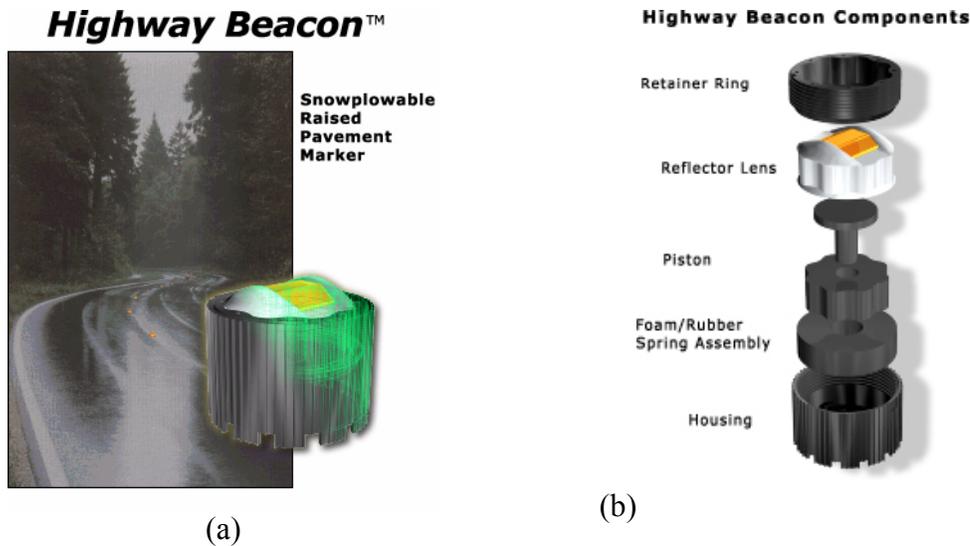


Figure 177: Highway Beacon [254]

The link below also has 4 videos showing the installation of the Snowplowable RPM.
<http://www.highwaybeacon.com/product.htm>

RoadVision Technologies is a company based in Pasadena, CA. The contact numbers are given in Table 54:

Table 54: Contact information for RoadVision Technologies

Headquarters
 Phone (local): 626-564-2750
 Fax: (local) 626-792-1511

Interprovincial Traffic Services, also known as ITS, is a leading supplier of traffic safety products in Canada. They supply a product called LifeLite, shown in Figure 178 manufactured by Avery Dennison, which is a snowplowable raised pavement marker, which provides motorists with high reflectivity in wet or dry conditions (specific intensity = 3.0 cd/ft²) from distances of 1000 feet or more.

The RPM has a low ramp angle and narrow design to allow for better plowability. Small impact area with round corners and a low profile help reduce the damage to the RPM. This product has a narrow anchoring base thus preventing cost of pavement cutting blades and adhesive. The RPM has a new glass-face design that allows vehicles tires to clean the face of the RPM thus improving its visibility.



Figure 178: Snowplowable RPM [255]

Interprovincial Traffic Services is based in British Columbia, Canada. The contact information and email is given in Table 55. Their products are also available through several other companies such as Stimsonite and American Electronic Sign.

Table 55: Contact information for ITS

Headquarters	
Phone:	604-594-3488
Fax:	604-594-9411
Personnel	
Warren Cook – Technical Sales and Service Manager	wcook@its-info.com
Don Goto – Sales and Marketing Coordinator	dgoto@its-info.com
Karen Strozek – Office Manager	karenh@its-info.com

16.1.12 Information Dissemination

Telcontar is a software platform provider for location-based services. This company has developed a product called the Traffic Manager (TM), which integrates real time traffic flow and incident information with existing applications and location based services. Telcontar previously developed a Drill Down Server Platform. The TM used in conjunction with this server platform will enable automatic rerouting of vehicles in case of traffic jams, the visual display of traffic conditions, the integration of real-time traffic with vehicle navigation systems and the creation of new traffic applications for cell phones and PDAs. The features and documentation with respect to the TM are available at the websites mentioned in [256], [257], and [258]. Telcontar is based in San Jose, CA and the contact numbers and emails are given in Table 56:

Table 56: Contact information for Telcontar

Headquarters
Phone (local): 408-294-8400
Fax: (local) 408-294-8464
Email:
Sales: salesteam@telcontar.com
Marketing: marketing@telcontar.com
Public Relations: pr@telcontar.com

ADDCO is a company that specializes in portable traffic management. They have developed a patented process for speed detection and timely information transmission to law enforcement officials. This is called the PASE – Portable, Automated Speed Enforcement, shown in Figure 179. The PASE trailer deploys video detection equipment at one or two lanes of a work zone or road segment. The trailer has radio communications equipment with a wide spread spectrum, which allows the PASE to transmit speed and violation information with actual vehicle images to law enforcement personnel.



Figure 179: PASE System [259]

ADDCO has been discussed previously in this report with respect to the BRICK modular sign design and all the contact information is in Table 43Table 43.

Highway Information Systems (HIS) Incorporated makes smart traffic management systems, which enable motorists to get up to date information on the road conditions ahead by means of radio transmitters. Motorists can tune in to transmitters that have been set up at appropriate locations and get information about traffic up to 3 to 6 miles (4.82 to 9.65 km) ahead of them. This gives them ample time to plan their detours and trips. There are two systems, called HIWAY MAX (Figure 180) and SOLARMAX (Figure 181), which basically work on the same principle. The HIWAYMAX can be installed as a single unit or as part of a network of units but the SOLARMAX is a single unit. But the SOLARMAX is extremely mobile and can be moved from one site to another by just hooking it up to a trailer. Both can also be used in tandem with changeable message signs in order to give motorists the latest information in and beyond the work zone. Both these systems have solid-state designs and the second difference between them is that the latter is solar powered. Both these systems can be accessed remotely

and thus if the change in the situation ahead is sudden it is simply a matter of calling from a cell phone or a touch tone phone to change the message that is to be transmitted.



Figure 180: HIWAY MAX [260], [261]



Figure 181: SOLARMAX [260], [261]

The technical specifications can be obtained from the websites listed below.

- ❖ Technical Specifications on the HIWAYMAX
<http://highwayinfo.com/products/products.php?product=hiway-t>
- ❖ Technical Specifications on the SOLARMAX
<http://highwayinfo.com/products/products.php?product=solar-t>

HIS is a company that is based in Durham, NC and the contact information is given in Table 57.

Table 57: Contact information for HIS

Headquarters

Phone (local): 919-361-2479

Toll free: 800-849-4447

Fax: (local) 919-361-2948

Toll free: 800-849-2947

Email:

Sales: sales@highwayinfo.com

16.1.13 Other Products Reviewed

Transoft Solutions Incorporated is a company that makes software for traffic situations. They have different products that handle different aspects of traffic. The products and brief descriptions of each product are shown below.

ParkCAD 1.0 – A CAD program that allows the user to design parking lots and what if scenarios. The database that is incorporated in the software remembers all the design parameters and thus allows the user to change configurations to get a better idea of the utilization of the area. (extracted from 264)

AutoTURN 4.2 – A CAD based simulation software that allows the users to design intersections, roundabouts, terminals and loading bays.

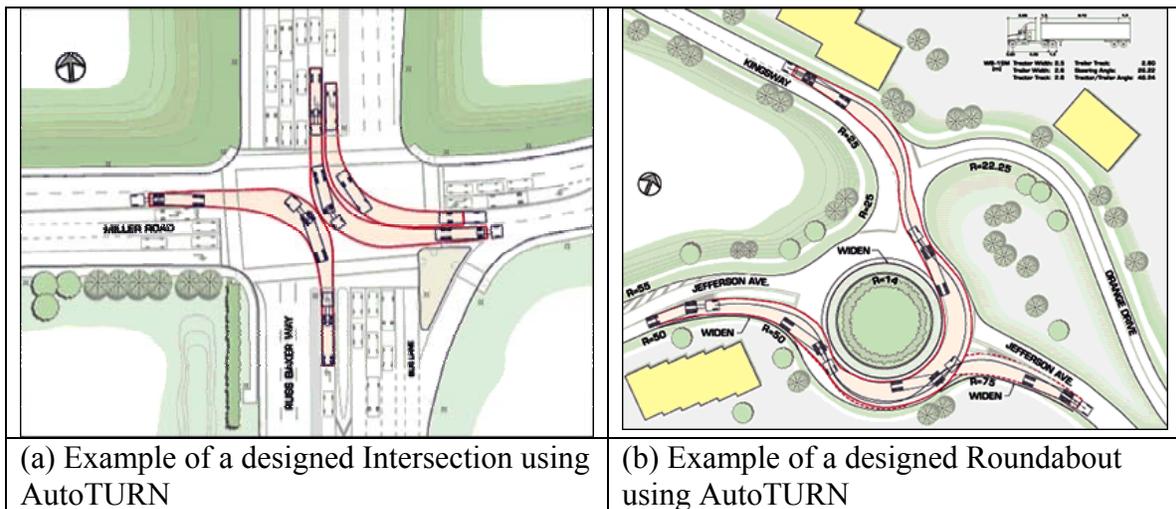


Figure 182: Examples of Intersection and Roundabout Designs in AutoTURN [265]

GuidSIGN 4.2 – A software program that can be used to design highway and roadway signs by selecting options from an already existing library of signs which follow the MUTCD guidelines. It is also possible to interface this program with plotters and cutters in case the user wants to cut and make his/her own signs by converting the signs made to DXF format, which is understood by most cutters/plotters. GuidSIGN can also work with other design software like AutoCAD, Microstation and now can be interfaced with Windows [266].

Transoft Solutions Incorporated is based in Richmond, British Columbia, Canada. The contact information is given in Table 58:

Table 58: Contact information for Transoft Solutions Inc.

Headquarters
Phone (local): 604-244-8387
Fax: (local) 604-244-1770
Toll free: 888-244-8387 (US & Canada)
Email:
Sales: sales@transoftsolutions.com
Support: support@transoftsolutions.com

Seton is a company that makes a wide range of products for the warehousing, transportation, and chemical industry. Traffic safety products are only a part of their product line. The uniqueness of this company is that they have a section of their website that is interactive and allows the user to build their own traffic safety signs. This section would be extremely valuable to traffic safety personnel because of the flexibility involved and the availability of custom made signs when the conventional signs are not sufficient for the purpose for which they are intended. This interactive website can be reached by following the URL that is stated below.

<http://www.seton.com/cgi-bin/ncommerce3/ProductDisplay?prmenbr=676&prfnbr=265162&CTcount=2&CT1=58184&CT1type=C&CT2=188222&CT2type=C&x=16&y=0>

Seton is based in Branford, CT and the contact information is in Table 59.

Table 59: Contact information for Seton

Product Development
Phone: 800-571-2596
Fax: 800-345-7819

SmartTRAC (Technical Regulatory Assistance Center)
Phone: 800-420-7572
Customer Service
Phone: 800-338-5810
Email: Custsvc_SetonUS@seton.com

17 REFERENCES

1. "Boosting Roadway Safety with Rumble Strips", *Focus*, Federal Highway Administration magazine, U.S. Department of Transportation, May 2002. Available online at <http://www.tfhr.gov/focus/may02/rumble.htm>, accessed January 25, 2005.
2. National Highway Safety Administration, Traffic Safety Facts 2002, January 2004, available at <http://www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/TSFAnn/TSF2002Final.pdf>, accessed on January 25, 2005.
3. Federal Highway Administration, "Roadway Shoulder rumble Strips", Technical Advisory T 5040.35, Washington DC, Federal Highway Administration, December 20, 2001.
4. Chen, C.S., "A Study of Effectiveness of Various Shoulder Rumble Strips on Highway Safety," Traffic Engineering Division, Virginia Department of Transportation, Richmond, VA, Nov, 1994
5. Traffic Engineering Department, Ohio Department of Transportation, *Ohio Manual of Uniform Traffic Devices*, 2003 Edition.
6. Office of Traffic Engineering, Ohio Department of Transportation, *Traffic Engineering Manual*, October 23, 2002 Edition includes revisions through January 16, 2004.
7. Federal Highway Administration, *Manual of Uniform Traffic Control Devices*, 2003 Edition, Section 6F.84.
8. California Department of Transportation, *California Traffic Manual*, Section 6-03.2.
9. Alabama Department of Transportation, "Scoring Bituminous Pavement Surface", Special Provision 01-0109, February 16, 2001, available online at <http://www.dot.state.al.us/Bureau/Construction/Spec2001/01-0109.pdf>, accessed January 25, 2005.
10. Arizona Department of Transportation, "480 Continuous Longitudinal Rumble Strips", *ADOT Traffic Engineering Policies, Guidelines, and Procedures*, Section 400 Pavement Markings, March 2002, available online at <http://www.dot.state.az.us/ROADS/traffic/standards/PGP/TM480.pdf>, accessed January 25, 2005.
11. Colorado Department of Transportation, Standard Specifications, Section 614.
12. Colorado Department of Transportation, Standard Plan No: M-614-1, available at http://www.dot.state.co.us/DesignSupport/MStandards/2000_M_Standards/NEW%20or%20REVISED%20M%20STANDARDS/M-614-1%20Rumble%20Strips/614010303.pdf accessed January 25, 2005.
13. Cheng, E.Y-C., Gonzalez, E., and Christensen, M.O., "Application and Evaluation of Rumble Strips on Highways," Traffic and Safety Studies Engineer, Utah Department of Transportation, ITE Compendium of Technical Papers, Salt Lake City, UT, 1994. Available online at <http://safety.fhwa.dot.gov/fourthlevel/pdf/application.pdf>, accessed January 25, 2005.
14. Griffith, Michael S., "Safety Evaluation of Continuous Shoulder Rumble Strips Installed on Freeways", TRB Paper No. 99-0162, January 1999.
15. Hickey, J. J., "Shoulder Rumble Strip Effectiveness: Drift-Off-Road Accident Reductions on the Pennsylvania Turnpike" *Transportation Research Record 1573*, Transportation Research Board, National Research Council, Washington, D.C., 1997, pp. 105-109.

16. Porter, R.J., Donnell, Eric T., and Mahoney, Kevin M., "Evaluation of the Effects of Centerline Rumble Strips on Lateral Vehicle Placement and Speed". Paper 0440, 83rd Annual Meeting of the Transportation Research Board, National Academy of Sciences, Washington DC, 2004.
17. David A. Noyce (noyce@engr.wisc.edu) and Vetri Venthan Elango (vetriventhan.elango@ce.gatech.edu), "Safety Evaluation of Centerline Rumble Strips: A Crash And Driver Behavior Analysis", Paper Number: 04-3932 , Paper presented at the 83rd Annual meeting of the Transportation Research Board, Washington, D.C. January, 2004.
18. Matthew Filcek, Vladimir Oulevski, Jill Morena, Dave Long, and Thomas Maleck, "Development of a Profiled Pavement Marking System", Paper No. 04-2905, Presented at the 83rd Annual Meeting of the Transportation Research Board, 2004, on TRB 2004 Annual Meeting CD-ROM.
19. Taylor, William, Abu-Lebdeh, Ghassan, and Rai, Sachin, "Effects of Continuous Shoulder Rumble Strips and Pavement Marking on Lateral Placement of Vehicles", Paper No. 05-1239, Presented at the 84th Annual Meeting of the Transportation Research Board, 2005, on TRB 2005 Annual Meeting CD-ROM.
20. Dean, Wes and Willis, Jim, "Mississippi's Rumble Stripe Experience", Presentation by the Mississippi Department of Transportation at the 83rd Annual Meeting of the Transportation Research Board, 2004.
21. Smith, Erika and Ivan, John, "Evaluation of Safety Benefits and Potential Crash Migration Due to Shoulder Rumble Strip Installation on Freeways in Connecticut", Paper No. 05-1299, Presented at the 84th Annual Meeting of the Transportation Research Board, 2005, on TRB 2005 Annual Meeting CD-ROM.
22. Thompson, Tyrell, Burris, Mark, and Carlson, Paul, "Speed Changes due to Transverse Rumble Strips on Approaches to High Speed Stop Controlled Intersections", Paper No. 05-0018, Presented at the 84th Annual Meeting of the Transportation Research Board, 2005, on TRB 2005 Annual Meeting CD-ROM.
23. Gupta, Jiwan D., "Development of Criteria for Design, Placement, and Spacing of Rumble Strips", Report No: FHWA/OH-93/022, the University of Toledo, Toledo, OH, October, 1993.
24. Russell, Eugene R., Rys, Margaret J., and Brin, Troy, "Evaluation of Milled Centerline Rumble Strip Patterns", *Journal of the Transportation Research Forum*, Vol. 57, No. 4, Fall 2003, p. 135-147.
25. Kryter, K.D. and Pearsons, K.S., *Journal of the Acoustical Society of America*, 1963, pp.35, 871.
26. Webb, P., *Bioastronautics Data Book*, NASA SP-3006, Washington, DC, 1964.
27. Outcalt, William, *Bicycle Friendly Rumble Strips*, Report No: CDOT-DTD-R-2001-4, Colorado Department of Transportation Research Branch, May 2001.
28. Perrillo, Kerry, "The Effectiveness and Use of Continuous Shoulder rumble Strips", Federal Highway Administration, Albany, New York, August 1998.
29. Per Garder, "Rumble Strips or Not Along Wide Shoulders Designated for Bicycle Traffic", Paper No. 95-0231, 74th Annual Meeting of the Transportation Research Board, Washington DC, January 1995.
30. Stanford and Carlson, *Update on Centerline, Edgeline, and Lane line Rumble Strips in Texas*, Research Project 0-4472, Texas Transportation Institute, College Station Texas.

31. Swarco, Swarco web page, <http://www.swarco.com/north-america/index.htm>, accessed on January 25, 2005.
32. Swarco, “Suggested Layout Details, Temporary Rumble Strips”, http://www.swarco.com/downloads/Rumbler_Suggest_Layout.pdf), accessed on January 25, 2005
33. Thomas Grinding website, <http://www.rumblestripmachines.com/webpage/Tr2000.htm>, accessed on January 25, 2005.
34. Surface Preparation Technologies, Inc., website, http://www.spt.addr.com/sub_level/contracting_services.htm, accessed on January 25, 2005.
35. Federal Highway Administration Wyoming Division Office, “Shoulder Rumble Strips – Effectiveness and Current Practice”, Federal Highway Administration Wyoming Division Office, April 2, 1998, available online at http://safety.fhwa.dot.gov/fourthlevel/rumble/state_wyom.htm, accessed on January 25, 2005.
36. K. Fitzpatrick, et al., *Accident Mitigation Guide for Congested Rural Two-Lane Highways*, NCHRP report 440, 2000, cited in “Head-On Collisions: Appendix 11: Costs for Centerline Rumble Strips”, available online at <http://safety.transportation.org/htmlguides/HOcrashes/app11.htm>, accessed January 25, 2005.
37. Ohio Department of Transportation, *Traffic Engineering Manual* Section 605-9 and *Ohio Manual of Uniform Traffic Control Devices* section 7G-8.1.
38. Federal Highway Administration, *Manual on Uniform Traffic Control Devices*, 2003 edition, Sections 2A07, 2E21, 6F55, <http://mutcd.fhwa.dot.gov/HTM/2003/html-index.htm>, accessed January 25, 2005.
39. Addco web page, http://www.addcoinc.com/t_solar_1.htm, accessed January 25, 2005.
40. Cao, Wang and Hunter, “A Design of Experiment Approach to Study the Display of Variable Message Signs”, Paper presented at the 16th Biennial Symposium on Visibility and Simulation, University of Iowa, Iowa City, June 2-4, 2002, available online at <http://arrow.win.ecn.uiowa.edu/symposium/DraftPapers/VIS2002-26.pdf>, accessed January 25, 2005.
41. Ullman et al, “Legibility Distances of Smaller Letter Light-Emitting Diode (LED) Changeable Message Signs”, Paper No. 05-1856, Presented at the 84th Annual Meeting of the Transportation Research Board, 2005, on TRB 2005 Annual Meeting CD-ROM.
42. Dudek et al, *Improved Dynamic Message Sign Messages and Operations*, report number FHWA/TX-01/1882-2, College Station TX, Texas Transportation Institute, October 2000 <http://tti.tamu.edu/product/catalog/reports/1882-2.pdf>, accessed May 14, 2004.
43. Patrick T. McCoy and Geza Pesti, *Incident Management – Changeable Message Sign Deployment Guidelines*, Report for Nebraska Department of Roads, Contract No. SPR-PL-1(33) P499, Department of Civil Engineering, University of Nebraska-Lincoln, December 1999. Available online at <http://www.matc.unl.edu/research/images/IncidentManagement1.pdf>, accessed August 24, 2004.

44. Melisa D. Finley, Timothy J. Gates, and Conrad L. Dudek, *DMS Message Design and Display Procedures*, Report No. FHWA/TX-02/4023-1, Texas Transportation Institute, College Station TX, November 2001.
45. Paul Davis, Sangita Sunkari, Conrad Dudek, and Kevin Balke, *Requirements Specification for DMS Message Optimization Software Tool (MOST)*, Report No. FHWA/TX-02/4023-2, Texas Transportation Institute, College Station TX, September 2002.
46. Mark D. Woolridge, et al, *Arrow Panel and Portable Changeable Message Sign Requirements*, Project O-4940, College Station, Texas Transportation Institute, February 2002, online summary at <http://tti.tamu.edu/product/catalog/reports/4940-S.pdf>, accessed May 14, 2004.
47. Zwahlen, H.T, Russ, A., and Vatan, S., (2002), *Unlighted Overhead Guide Sign Feasibility Study, Final Report*, Ohio Research Institute for Transportation and the Environment, Ohio University, OH.
48. Federal Highway Administration, "Georgia Finds Better Alternative for Directing Traffic Through Taper Lanes", FHWA web site, <http://www.fhwa.dot.gov/winter/roadsvr/CS061.htm>, accessed January 25, 2005.
49. Dale Stout, et al., *Maintenance Work Zone Safety Devices Development and Evaluation*, Strategic Highway Research Program report SHRP-H-371, National Research Council, Washington DC, November 1993.
50. Meyer, Eric, "Midwest Smart Work Zone Deployment Initiative: Kansas' Results", *Mid-Continent Transportation Symposium Proceedings*, 2000, pp. 57-61.
51. Melisa D. Finley, Gerald L. Ullman, and Conrad L. Dudek, *Work Zone Lane Closure Warning Light System*, Report No. TX-00/3983-1, College Station TX, Texas Transportation Institute, September 1999. Also project summary report 3983-S.
52. Zwahlen, H.T. and Schnell, T., "Driver-Headlamp Dimensions, Driver Characteristics, and Vehicle and Environmental Factors in Retroreflective Target Visibility Calculations", *Transportation Research Record 1692*, TRB, National Research Council, Washington, D.C.1999, pp. 106-118.
53. Zwahlen, Helmut T., Schnell, Thomas, and O'Connell, Sarah, (1999), "Recognition Distances of Different Pavement Arrow Designs During Daytime and Nighttime," paper presented at the 14th Biennial Symposium on Visibility, Transportation Research Board, The National Academy of Sciences, Washington, DC, April 21, 1998. Published in *Transportation Research Record 1692*, November 1999, pp. 119-128.
54. Oregon Department of Transportation Research Group, "Light Tube Leads the Way", Research Notes, RSN 01-02, September 2000. Contact: Andrew Griffith 503-986-3538 or andrew.s.griffith@odot.state.or.us.
55. Gerard L. Ullman and Steven D. Schrock, *Improving Traffic Control Effectiveness in Complex Work Zones*, Report No. FHWA/TX-03/4021-2, Texas Transportation Institute, College Station TX, January 2003.
56. O'Connell, Sarah Christine, "Increasing the Recognition Distance of Arrow Symbol Highway Pavement Signs", Master's thesis, Ohio University, March 1998
57. Schrock, Steven, Hawkins, Gene, and Chrysler, Susan, "Effectiveness of Pavement Marking Lane Direction Arrows for Reducing Wrong-Way Movements on Two-Way Frontage Roads", Paper No. 05-2364, Presented at the 84th Annual Meeting of the Transportation Research Board, 2005, on TRB 2005 Annual Meeting CD-ROM.

58. "Wrong-way Driver Charged in Riders' Deaths", *The Columbus Dispatch*, May 24, 2004, p. C6.
59. Greg Murphy and Dave Holstein of the ODOT Central Office, personal communication to Andrew Russ, March 26, 2004.
60. Office of Traffic Engineering, *Safety Study Guidelines*, Columbus OH, Ohio Department of Transportation, January 2002.
61. Gianantonio Scaramuzza, "Black Spot Analysis and Treatment: A Technical Approach to An Efficient Accident Prevention", presentation to ODOT January 16, 2004.
62. Helmut T. Zwahlen, personal observation in Switzerland, 2004.
63. Eugene M. Wilson, *Roadway Safety Tools For Local Agencies: A Synthesis of Highway Practice*, NCHRP synthesis 321, Washington DC: Transportation Research Board, 2003.
64. William Crawford, "PennDOT's Highway Safety Countermeasure Evaluations" Presentation, 2002, and "Pennsylvania Department of Transportation's "Dot" Tailgating Treatment" ("DOTfinal.doc"), on *PA Safety Highway Safety Management: Low Cost Safety Initiatives* CD. Contact info: email: wcrawford@state.pa.us; phone: 717-787-6853.
65. Pennsylvania Department of Transportation, "Pennsylvania Department of Transportation's "Dot" Tailgating Treatment" ("DOTfinal.doc"), on *PA Safety Highway Safety Management: Low Cost Safety Initiatives* CD.
66. Pennsylvania Department of Transportation, "Pennsylvania "Dot" Tailgating Treatment" ("PennsylvaniaDOT2_EXP.doc"), on *PA Safety Highway Safety Management: Low Cost Safety Initiatives* CD.
67. Pennsylvania Department of Transportation, "Guidelines for installation of Pennsylvania "DOT" Tailgating Treatment" ("Guidelines for installation of DOT_Exp.doc"), on *PA Safety Highway Safety Management: Low Cost Safety Initiatives* CD.
68. Pennsylvania Department of Transportation, "Pennsylvania "DOT" Tailgating Treatment" ("PENNADotDesign_EXP.xls"), on *PA Safety Highway Safety Management: Low Cost Safety Initiatives* CD.
69. Pennsylvania Department of Transportation, "Pennsylvania Guidelines for the Installation of Utility Pole Delineation" ("DelinSpec_Pole.doc"), on *PA Safety Highway Safety Management: Low Cost Safety Initiatives* CD.
70. Thomas E. Breyer, Director of Bureau of Highway Safety and Traffic Engineering, Pennsylvania DOT, "Safety Management" ("BureauDirectors2001.ppt"), on *PA Safety Highway Safety Management: Low Cost Safety Initiatives* CD, 2001. Contact: email: breyertb@dot.state.pa.us, phone: 717-705-1441.
71. Pennsylvania Department of Transportation, "Pole Crash Cluster Decision Tree" ("Pole Decision.doc"), on *PA Safety Highway Safety Management: Low Cost Safety Initiatives* CD.
72. Pennsylvania Department of Transportation, "Guidelines for Pilot Installation of Pennsylvania Intersection Warning Treatment" ("Guidelines for installation Final Plus.doc"), on *PA Safety Highway Safety Management: Low Cost Safety Initiatives* CD.

73. Pennsylvania Department of Transportation, drawings of gap warning installations (“SLOW xxMPH Option Drawing Layoutnew.doc”), on *PA Safety Highway Safety Management: Low Cost Safety Initiatives* CD.
74. James H. Hedlund, et al., *Methods to Reduce Traffic Crashes Involving Deer: What Works and What Does Not*, Arlington VA, Insurance Institute for Highway Safety, October 2003. An online article describing the study is available at The Car Connection web site
<http://www.thecarconnection.com/index.asp?n=156,241&sid=241&article=6629>.
75. Iowa Department of Public Safety, “Don’t Veer for Deer” brochure, October 2003, available online at <http://www.dps.state.ia.us/deercrashes/brochure.htm>, accessed January 26, 2005.
76. Keith Knapp, Xin Yi, and Tanveer Oakasa, “Deer-Vehicle Crash Countermeasures Effectiveness Review”, *Proceedings of the 2003 Mid-Continent Transportation Research Symposium*, Ames IA, Iowa State University, August 2003. Available online at <http://www.ctre.iastate.edu/pubs/midcon2003/KnappDeer.pdf>, accessed January 26, 2005.
77. Wildlife Damage Control sells fencing material primarily for homeowners looking to protect their gardens. For lightweight plastic fencing see <http://www.wildlifedamagecontrol.com/deerfencenonelec.htm>. And for electric fencing see <http://www.wildlifedamagecontrol.com/deerfences.htm>. Both sites accessed January 26, 2005.
78. Deer-Vehicle Crash Information Clearinghouse, “Exclusionary Fencing”, *Deer Vehicle Crash Countermeasures Toolbox*, available online at <http://www.deercrash.com/toolbox/CMTtoolboxFencing.pdf>, accessed January 26, 2005.
79. M.E. Lehnert, L. A. Ronin, and J. A. Bossonette, “Mule Deer-Highway Mortality in Northeastern Utah: Causes, Patterns and New Mitigative Technique,” *Transportation and Wildlife: Reducing Wildlife Mortality and Improving Wildlife Passageways across Transportation Corridors*, Proceedings of the Florida Department of Transportation/Federal Highway Administration Transportation-Related Wildlife Mortality Seminar, Orlando FL, April 30-May 2 1996, as cited Appendix D of Kay Fitzpatrick et al, *Characteristics and Potential Treatments for Crashes on Low-Volume, Rural Two-Lane Highways in Texas*, Report No. FHWA/TX-02/4048-1, Texas Transportation Institute, College Station TX, October 2001.
80. Robert H. Greiner, “A Study of the Effectiveness of Streiter-Lite[®] Wild Animal Highway Warning Reflector Systems, a study commissioned by the Streiter Corporation, June 2002. Available online at http://strieter-lite.com/images/scientific_report.pdf, accessed January 26, 2005.
81. The Streiter Corporation, Streiter-Lite website, <http://strieter-lite.com/costs.php>, accessed January 27, 2005.
82. Burton W. Sanders and Gary Long, “Supplemental Pavement Markings for Improving Safety ad railroad-Highway Grade Crossings”, Paper No. 03-3265, *Transportation Research Record* 1844 (2003), p. 18.
83. European Approaches to Bicycle and Pedestrian Facility Design
http://safety.fhwa.dot.gov/ped_bike/univcourse/swless23.htm
84. <http://www.wsdot.wa.gov/TA/PAandI/CommPart/PDF/UrbanTreatments.pdf>

85. Portland's Blue Bike Lanes: Improving Safety through Enhanced Visibility, <http://www.trans.ci.portland.or.us/bicycles/Bluelane.pdf>
86. http://athensnews.com/issue/article.php3?story_id=19403
87. Lindsay Griffin, "Older driver involvement in injury and crashes in Texas, 1975-1999", AAA Foundation for Traffic Safety, February 2004.
88. Safe Mobility for a Maturing Society: Challenges and Opportunities, U.S. Department of Transportation, Washington, D.C., November, 2003.
89. Traffic Engineering Handbook, Institute of Transportation Engineers, 5th Edition, 1999.
90. Alicandri et al, "Designing Highways with Older Drivers in Mind", FHWA, Public Roads.
91. Burkhardt, J., A. Berger, M. Creedon, and A. McGavock, "Mobility and Independence: Changes and Challenges for Older Drivers", U.S. Department of Health and Human Services; National Highway Transportation Safety Administration, U.S. Department of Transportation; and Ecosometrics, Inc., Bethesda, MD, 1998.
92. Alicandri, Elizabeth, "An Investigation of Older Driver Freeway Needs and Capabilities", U.S. Department of Transportation, Federal Highway Administration, FHWA-RD-95-194.
93. Helmut T. Zwahlen, "The Fundamental Driver Requirement – Preview Time and Preview Distance", presented at the International Conference on Traffic and Transportation Psychology, ICTTP2000, September 4 - 7, 2000, Berne, Switzerland.
94. Dewar et al., "Symbol Signing Design for Older Drivers", FHWA-RD-94-069
95. Safe Mobility for Older Persons, Transportation Research Board Committee ANB60 Newsletter, April, 2004.
96. Pietrucha, M. T., R. S. Hostetter, L. Staplin, and M. Obermeyer. *Pavement Markings and Delineation for Older Drivers*, Vol. I. Final Report, Report FHWA-RD-94-145, Office of Safety and Traffic Operations Research and Development, Federal Highway Administration, U.S. Department of Transportation, McLean, Va., 1996.
97. The Use of Wider Longitudinal Pavement Markings, Gates and Hawkins, TTI, March 2002.
98. Elder Roadway User Program Test Sections and Effectiveness Study, Guerrier and Fu, University of Miami, October 2002.
99. Designing Roadways to Safely Accommodate the Increasingly Mobile Older Driver: A Plan to Allow Older Americans to Maintain their Independence, prepared by the Road Information Program, July 2003.
100. Staplin, L., D. L. Harkey, K. H. Lococo, and M. S. Tarawneh. *Intersection Geometric Design and Operational Guidelines for Older Drivers and Pedestrians*, Vol. 1. Final Report, Report FHWA-RD-96-132. Federal Highway Administration, U.S. Department of Transportation, McLean, Va., 1997.
101. Reilly, W. R., R. C. Pfefer, R. M. Michaels, A. Polus, and J. M. Schoen. *Speed Change Lanes*. JHK and Associates, Arlington, Va., 1989.
102. Staplin, Loren and Hunt, Linda, "Driver Programs", Conference Proceedings 27 Transportation in an Aging Society, Transportation Research Board of the National Academies, 1998, pp. 69-94.
103. Ohio Department of Transportation, "Sign Design Manual; TEM Section 295-2", http://www.dot.state.oh.us/traffic/Publication%20Manuals/Sign%20Design%20Manual/2003SDM/sdm2003_mainindex.htm , accessed on June 22, 2005.

104. Loren Staplin, "Highway Advancements to Improve Safety and Mobility of Older Road Users: Practical Applications", Conference Proceedings 27, *Transportation in an Aging Society: A Decade of Experience*, Technical Papers and Reports from a Conference, November 7-9, 1999, Bethesda, MD, Transportation Research Board 2004, pp. 155-166.
105. Potts et al, "Guidance for Implementation of the AASHTO Strategic Highway Safety Plan: Volume 9: A Guide for Reducing Collisions Involving Older Drivers", National Cooperative Highway Research Program Report 500, Transportation Research Board, Washington, D.C., 2004.
106. Florida Department of Transportation, "Countdown Pedestrian Signal Head Applications", Traffic Engineering Manual Section 3.9, Topic No. 750-000-005, April 2003.
107. Walkinginfo.org web site, <http://www.walkinginfo.org/aps/7-21.cfm>, <http://www.walkinginfo.org/pedsmart/count.htm>, both accessed January 27, 2005.
108. George Francis, "The Stoplight Zone: High Tech Signals", <http://georgefrancisonline.homestead.com/hitech.html>, accessed January 21, 2005.
109. Beverly Ann B. Farragher, *Pedestrian Countdown Indication - Market Research and Evaluation*, Minnesota Department of Transportation Metro Division summary paper, 1999, available online at <http://www.dot.state.mn.us/metro/trafficeng/signals/files/compendium.pdf>, accessed January 21, 2005.
110. Jan L. Botha, Aleksandr A. Zabyshny, and Jennifer E. Day, *Pedestrian Countdown Signals: An Experimental Evaluation*, Volume 1, Final Report to the California Traffic Control Devices Committee, San Jose CA, San Jose State University and the City of San Jose, 2002 http://www.ci.san-jose.ca.us/dot/forms/report_pedcountdown.pdf, accessed January 21, 2005.
111. James Bonneson, Karl Zimmerman, and Marcus Brewer, *Engineering Countermeasures to Reduce Red-Light-Running*, Report FHWA/TX-03/4027-2, College Station TX, Texas Transportation Institute, August 2002 <http://tti.tamu.edu/product/catalog/reports/4027-2.pdf>, accessed May 14, 2004. and summary at James Bonneson, Karl Zimmerman, and Marcus Brewer, *Signalization Countermeasures to Reduce Red-Light-Running*, Project Summary Report 4027-S, College Station TX, Texas Transportation Institute, 2003 <http://tti.tamu.edu/product/catalog/reports/4027-S.pdf>, accessed May 14, 2004.
112. Institute of Transportation Engineers, "Chapter 3: Engineering Counter Measures", in *Making Intersections Safer: A Toolbox of Engineering Countermeasures to Reduce Red-Light Running*, Publication IR-115, Institute of Transportation Engineers, Washington DC, September 2003, <http://safety.fhwa.dot.gov/rlr/rlrreport/chap3.htm>, accessed January 21, 2005. The entire report may be downloaded from <http://safety.fhwa.dot.gov/rlr/rlrreport/RLRbook.pdf>, and the front page of the web version is <http://safety.fhwa.dot.gov/rlr/rlrreport/index.htm>, both accessed January 21, 2005.
113. Sayed, Tarek, De Leur, Paul, and Pump, John, "Safety Impact of Increased Traffic Signals Backboard Conspicuity" Paper No. 05-0016, Presented at the 84th Annual Meeting of the Transportation Research Board, 2005, on TRB 2005 Annual Meeting CD-ROM.

114. Carroll J. Messer and Kwaku Obeng-Boampong, "Evaluation of Red-Light-Running Using an Advanced Warning for End of Green Phase System" Paper No. 05-1973, Presented at the 84th Annual Meeting of the Transportation Research Board, 2005, on TRB 2005 Annual Meeting CD-ROM.
115. Robinson, et al., "Roundabouts: An Informational Guide," *Report No. FHWA-RD-00-067*, Washington, DC: Federal Highway Administration, June 2000, cited in [112].
116. James Bonneson and Montasir Abbas, *Video Detection for Intersection and Interchange Control*, report FHWA/TX-03.4285-1, College Station TX, Texas Transportation Institute, September 2002, <http://tti.tamu.edu/product/catalog/reports/4285-1.pdf>, accessed May 14, 2004.
117. James Bonneson, *Texas Transportation Researcher*, Vol. 39, No 2, 2003.
118. James Bonneson, et al., "New Detection System for Rural Signalized Intersections", Project Summary Report 0-4022-S, College Station TX, Texas Transportation Institute, 2004.
119. Patrick T. McCoy and Geza Pesti, "Dilemma Zone Protection on High-Speed Signalized Intersection Approaches: Advance Detection Versus Advance Warning Flashers and Advance Detection", paper submitted to the 82nd Annual Meeting of the Transportation Research Board, January 2003. Available online at http://www.ltrc.lsu.edu/TRB_82/TRB2003-000285.pdf, accessed January 21, 2005.
120. Patrick T. McCoy and Geza Pesti, "Improving Dilemma-Zone Protection of Advance Detection with Advance-Warning Flashers", Paper No. 03-2328, *Transportation Research Record* 1844 (2003), p. 11.
121. Peter Martin, Vikram Kalyani, and Aleksander Stevanovic, "Evaluation of Advance Warning Signals on High Speed Signalized Intersections", University of Utah Traffic Lab, Department of Civil and Environmental Engineering, Salt Lake City UT, November 2003. Available online at http://www.ndsu.nodak.edu/ndsu/ugpti/MPC_Pubs/pdf/MPC03-155.pdf, accessed January 21, 2005.
122. Elliott Equipment company, "Barlo Safety Traffic Signal Strobe" webpage, http://www.elliottequipment.com/barlo_strobe.htm, accessed January 21, 2005.
123. W.J. Styles, "Evaluation of the Flashing Red Strobe Signal," report FHWA/MD-83/07, Maryland State Highway Administration, June 1982. Cited in [112].
124. B.H. Cottrell, Jr., "Evaluation of the Use of Strobe Lights in the Red Lens of Traffic Signals," *Technical Assistance Report*. Cited in [112].
125. Eagle-1 Manufacturing website <http://www.eagle-1mfg.com/>, accessed January 25, 2005.
126. Kate Painter and David Farrington, "The Financial Benefits of Improved Street Lighting, Based on Crime Reduction", *Lighting Res. Techno.*, 33:1 (2001), p. 3, available online at <http://www.urbislighting.com/img/LRTv33-1.pdf>, accessed January 25, 2005.
127. Patrick Hasson et al, "Field Test for Lighting to Improve Safety at Crosswalks", interim report, proposal number VIS2002-28, 2002 on web at <http://arrow.win.ecn.uiowa.edu/symposium/DraftPapers/VIS2002-28.pdf> (accessed January 25, 2005)
128. Doug Mace and Richard Porter, *Fixed Roadway Lighting to Benefit Older Drivers*, Proposal VIS2002-21 preliminary results, 2002.

129. Correspondence by e-mail from Dick Schwab to Helmut Zwahlen on February 23, 2004.
130. Road Lighting as an Accident Countermeasure, Publication CIE 93, 1992.
131. Zwahlen, H.T., "Optimal Application and Placement of Roadside Reflective Devices for Curves on Two-Lane Rural Highways," July 1993. Prepared for Ohio Department of Transportation in Cooperation with US DOT, FHA, State Job No. 14466(0). Final Report, Report No. FHA/OH-94/011, 95 pages. Appendix A, FHA/OH-94/012, 138 pages. Appendix B, FHA/OH-94/013, 66 pages. Appendix C, FHA/OH-94/014, 140 pages. Appendix D, FHA/OH-94/015, 257 pages. Appendix E, FHA/OH-94/016, 208 pages. Appendix F, FHA/OH-94/017, 68 pages.
132. Zwahlen, Helmut T. and Schnell, Thomas, "Curve Warning Systems and the Delineation of Curves with Curve Delineation Devices," paper presented at the International Conference on Strategic Highway Research Program and Traffic Safety on Two Continents, September 20-22, 1995, Prague, The Czech Republic. Published in Proceedings of the Conference Road Safety in Europe and Strategic Highway Research Program (SHRP), No. 4A, Part 5, 1996, pp. 8-22.
133. Association of Swiss Road and Traffic Engineers, Swiss Standard SN 640822.
134. Zwahlen, H.T. and Schnell, Thomas, "A Knowledge Based, PC Software Package for the Application and Placement of Curve Delineation Devices," Paper No. 940789, presented at 73rd Annual Meeting of the Transportation Research Board, January 9-14, 1994, Washington, DC. Published in Transportation Research Record No. 1495, 1995, pp. 107-116.
135. Texas Transportation Researcher, Volume 40, No.1, 2004, pp. 11. (Project 0-4052, "Guidelines for the Use and Spacing of Delineators and Chevrons" Paul Carlson)
136. Rose, Elisabeth and Carlson, Paul, "Spacing Chevrons on Horizontal Curves" Paper No. 05-2206, presented at 84th Annual Meeting of the Transportation Research Board, 2005, Washington, DC.
137. William Crawford, "Pennsylvania Dept of Transportation's Advanced Curve Warning Treatment", *Low Cost Safety Initiatives* CD, Pennsylvania Department of Transportation, 2002.
138. Colorado Department of Transportation, Roadway Geometry and Pavement Standard Drawings, Rumble Strips, Standard Plan No: M-614-1 (http://www.dot.state.co.us/DesignSupport/MStandards/2000_M_Standards/2000%20Roadway%20Geometry%20and%20Pavement/614010303.pdf) accessed on January 27, 2005.
139. Torbic et al., "Guidance for Implementation of the AASHTO Strategic Highway Safety Plan; Volume 7: A Guide for Reducing Collisions on Horizontal Curves", National Cooperative Highway Research Program Report 500, Transportation Research Board, Washington, DC, 2004.
140. Schnell, T; Aktan, F; Lee, Y-C, "Nighttime Visibility and Retroreflectance of Pavement Markings in Dry, Wet, and Rainy Conditions", Paper No. 03-3857, *Transportation Research Record* No: 1824, Washington, D.C., National Academy Press, 2003, pp 144-155.
141. Tom Schnell, Fuat Aktan, and Yi-Ching Lee, *Wet Weather Visibility of Pavement Markings*, Iowa City IA, Operator Performance Laboratory, April 2004, http://opl.ecn.uiowa.edu/new_2/Research/FHWA WetWx-FinalReport.pdf, accessed May 12, 2004.

142. Schnell and Ohme, "Evaluation of Various Strategies to Increase Pavement Marking Visibility for Older Drivers", Paper Number 02-3365, 81st Annual Meeting of the Transportation Research Board, Washington DC, 2002.
143. Timothy Gates and H. Gene Hawkins, "The Use of Wider Longitudinal Pavement Markings In the United States, Paper No. VIS2002-31, 16th Biennial Symposium on Visibility and Simulation, Iowa City IA, June 2002. Available online at <http://arrow.win.ecn.uiowa.edu/symposium/DraftPapers/VIS2002-31.pdf>, accessed May 22, 2004.
144. Timothy Gates, Susan Chrysler, and H. Gene Hawkins, "Innovative Visibility-Based Measures of Effectiveness for Wider Longitudinal Pavement Markings, Paper No. VIS2002-30, 16th Biennial Symposium on Visibility and Simulation, Iowa City IA, June 2002. Available online at <http://arrow.win.ecn.uiowa.edu/symposium/DraftPapers/VIS2002-30.pdf>, accessed May 22, 2004.
145. Standard Construction Drawings, (2002) Ohio Department of Transportation (MT-101-20).
146. Grant, A.R. and Bloomfield, J.R., "Guidelines for the Use of Raised Pavement Markers", Final Report No: FHWA-RD-97-152, January 1998.
147. Migletz, James, Fish, Joseph, and Graham, Jerry, "Roadway Delineation Practices Handbook", Federal Highway Administration, Report No. FHWA-SA-93-001, August 1994.
148. Raised Pavement Marking Details, Standard Plan H-3, Washington State Department of Transportation, http://www.wsdot.wa.gov/eesc/design/designstandards/english/pdf/h03_eng.pdf accessed on January 28, 2005.
149. Evaluation of Raised and Recessed Pavement Markings, Oregon Department of Transportation, http://www.oregon.gov/ODOT/TD/TP_RES/AbstractsVIII.shtml#Pavement_Markings, accessed on January 28, 2005.
150. Bahar, Geni, "Safety Evaluation of Permanent Raised Pavement Markers", NCHRP Report 518, Transportation Research Board of the National Academies, December 2003.
151. Freedman, M., Staplin, L. K., Gilfillan, D. P., and Byrnes, A. M. (1988). *Noticeability Requirements for Delineation on Non-Illuminated Highways*. Technical Report No. FHWA-RD-88-028. Washington, D.C.: Federal Highway Administration.
152. Louis G. Neudorff, P.E, Jeffrey E. Randall, P.E., Robert Reiss, P.E, Robert Gordon, P.E., "Freeway Management and Operations Handbook", Office of Transportation Management, Federal Highway Administration, FHWA-OP-04-003, September 2003.
153. Weisser, Kurt Ian and Horowitz, Alan, "Perceptions and Expectations of Drivers: A Literature and Best Practices Scan", Final Report 0092-02-12, submitted to the Wisconsin Department of Transportation, May 2002.
154. A Human Factors Approach to the Design of Traffic-Information Web Sites, Nowakowski et al., UMTRI, 2000
155. Neil D. Lerner, Robert E. Llaneras, and Richard W. Huey, *Analysis of Travelers' Preferences for Routing*, FHWA-RD-00-XXX, September 2000

156. Neil Lerner and Robert Llaneras, Driver Information Demand Guidelines: Ensuring that Traffic and Routing Information Conforms to Driver Information Needs, FHWA-RD-00-XXX, FHWA contract DTFH61-95-C-00017, September 2000.
157. <http://www.buckeyetraffic.org/> accessed January 27, 2005.
158. <http://www.fhwa.dot.gov/trafficinfo/> accessed January 27, 2005
159. <http://www.georgia-navigator.com/> accessed January 27, 2005
160. Finley, Melisa, Durkop, Brooke, Wiles, Poonam, Carvell, James, and Ullman, Gerald, "Practices, Technologies, and Usage of Incident Management and Traveler Information and Exchange in Texas", Texas Transportation Institute, December 2001.
161. <http://dfwtraffic.dot.state.tx.us/> accessed January 27, 2005
162. <http://www.transguide.dot.state.tx.us/index.php> accessed January 27, 2005
163. <http://www.transguide.dot.state.tx.us/Traffic/ccmap.php> accessed January 27, 2005
164. http://www.houstontranstar.org/about_transtar/ accessed January 27, 2005
165. <http://www.azfms.com/> accessed May 24, 2004
166. <http://www.wsdot.wa.gov/pugetsoundtraffic/cameras/default.html> accessed May 24, 2004
167. <http://www.trafficgauge.com/index.html> accessed January 27, 2005
168. <http://enterprise.prog.org/completed/0001dsr.htm> accessed January 27, 2005
169. Melisa D. Finley and Gerald L. Ullman, *Feasibility of Implementing the 511 National Traveler Information Number in Texas*, Report TX-02/4951-2, College Station TX, Texas Transportation Institute, October 2001.
170. 511 National Progress Report: May 2004, Transportation Research Board Newsletter.
171. Rupert et al., "Traveler Information Systems in Europe", Federal Highway Administration Report No: FHWA-PL-03-005, April 2003.
172. Tignor et al., "Innovative Traffic Control Technology and Practice in Europe", Federal Highway Administration, August 1999.
173. Shyam Venugopal and Andrzej Tarko, "Investigation of Factors Affecting Capacity at Rural Freeway Work Zones", *TRB 80th Annual Meeting Preprint CD-ROM*, Transportation Research Board, Washington DC, 2001, paper 01-2196, available at <http://wzsafety.tamu.edu/docs/00545.pdf>, accessed on January 27, 2005.
174. Kamyab, Ali, McDonald, Tom, Storm, Brandon, and Anderson-Wilk, Mark, *Effectiveness of Extra Enforcement in Construction and Maintenance Work Zones*, Report No. MwSWZDI Year 4 Technology Evaluation #1, Center for Transportation Research and Education, Iowa State University, Ames IA, May 2003. Available online at <http://www.ctre.iastate.edu/reports/WZ4E.pdf> accessed on January 27, 2005
175. VisiSpeed Information Radar System, www.redacom.ch (accessed on January 29, 2005)
176. Gerard L. Ullman, et al., *Work Zone-Related Traffic Legislation: A Review of National Practices and Effectiveness*, Report No. FHWA/TX-98/1720-1, College Station TX: Texas Transportation Institute, September 1997. Also project summary report 1720-S.
177. *Pennsylvania Manual on Uniform Traffic Control Devices*, Found at the URL address <http://www.pahighways.com/misc/pamutcd.html#construction>

178. Steinke, D. P., Sanderson, L., Byrnes, J.F. Jr., Conrad, J., Forrestel, R., Harrington-Hughes, K., Kobetsky, K.F., Lanford, S., Snyder-Petty, K., Testa, D., and, Wilkerson, J.D., (2000), *Methods and Procedures to Reduce Motorist Delays European Work Zones, Office of International Programs, Federal Highway Administration, U.S. Department of Transportation.*
179. Stidger, R.W., (2001), "Which Strategies Really Work?", *Better Roads*, found at the URL address <http://www.betterroads.com/articles/braug01c.htm>
180. Karp, H., "Safe Car, Safe Driver, Dangerous Roads", *Readers' Digest*, July 2003, pp. 60-70.
181. Gerald Ullman, John Ragsdale, and Nadeem Chaudhary, *Highway Construction, Maintenance, and Service Equipment Warning Lights and Pavement Data Collection System Safety*, Report No. TX-99/3972-1, Texas Transportation Institute, College Station TX, October 1998.
182. Brent M. Turley, Mitsuru Saito, and Samuel E. Sherman, "Dancing Diamonds in Highway Work Zones: Evaluation of Arrow-Panel Caution Displays", *Transportation Research Record 1844*, Paper No. 03-2014, p. 1.
183. International Road Dynamics, Inc., "SonoBlaster!® Dual Alert™ Work Zone Intrusion Alarm", brochure and web site, <http://www.irdinc.com/english/html/prod/SonoBlaster.htm>, accessed July 30, 2004.
184. International Road Dynamics, Inc., "The SonoBlaster!® 'Dual Alert™' Work Zone Intrusion Alarm", slide presentation, http://www.irdinc.com/english/pdf/ppt/SonoBlaster_0306.pdf, accessed August 6, 2004.
185. Federal Highway Administration, "Alarm System Improves Safety in Work Zones", <http://www.fhwa.dot.gov/winter/roadsvr/CS115.htm>, accessed August 6, 2004.
186. Federal Highway Administration, "New York State Finds Intrusion Alarm a Potential Life-Saver", <http://www.fhwa.dot.gov/winter/roadsvr/CS057.htm>, accessed August 6, 2004.
187. Peter Hatzi, "SHRP Work Zone Safety Intrusion Alarms", PowerPoint presentation available at <http://www.library.unt.edu/gpo/ota/tech/safety/te25.html>, accessed August 6, 2004.
188. Washington State Department of Transportation, Eastern Region "Work Zone Safety", <http://www.wsdot.wa.gov/regions/Eastern/WorkZoneSafety.cfm> [sic], accessed August 6, 2004.
189. Texas Transportation Institute, "Study tests devices to improve work zone safety", *Texas Transportation Researcher*, Vol. 37, No. 3 (2001), available online at <http://tti.tamu.edu/researcher/v37n3/devices.stm>, accessed August 9, 2004.
190. Helmut T. Zwahlen, et al, *Draft Evaluation of Work Zone Design Guidelines and Recommendations to ODOT*, Ohio Research Institute for Transportation and the Environment, Ohio University, Athens OH, November 13, 2003.
191. Gerard Ullman, et al., *Improving Work Zone Safety using Traffic Management and Enforcement Tools*, Project summary report 2137-S, Texas Transportation Institute, College Station TX, July 2003.
192. Gerard Ullman, et al., *Traffic Management and Enforcement Tools to Improve Work Zone Safety*, Project report 2137-3, Texas Transportation Institute, College Station

- TX, September 2002. Available online at <http://tti.tamu.edu/product/catalog/reports/2137-3.pdf>, accessed August 13, 2004.
193. Ginger Daniels, Steven Venglar, and Dale Picha, *Feasibility of Portable Traffic Signals to Replace Flaggers in Maintenance Operations*, Report TX-00/3926-1, Texas Transportation Institute, College Station TX, February 2000. Part 2 of this report (TX-00/3926-2) is a set of guidelines for implementing portable traffic signals in short-term work zones.
 194. Houten, Ron Van and Louis, J.E, “Evaluation of Changeable Message Signs (CMS) on I-4 at Exits 30A and 30B To Assign Ramp Traffic and at Princeton St. To Assign for Cultural Events”, Florida Department of Transportation, Final Report No. BC354 RPWO #40, June 29, 2002, pp. 34.
 195. Al-Deek, H., Wang, M., Abdel-Aty, M., Kerr, P., and Ishak, S., “The Impact of Real-Time and Predictive Traffic Information on Travelers’ Behavior in the I-4 Corridor”, Center for Advanced Transportation Systems Simulation, University of Central Florida, Final Report No. BC355RPWO #3, July, 2003, pp. 117.
 196. Consolazio, G., Gurley, K., Ellie, R., Wilkes, J., and Shriner, J., “Temporary Low Profile Barrier for Roadside Safety: Phase II”, University of Florida, Final Report, Structures Report No. 827-3, University of Florida, January 2003.
 197. Lu, J.J., Park, J., Pernia, J., and Dissanayake, S., “Criteria for Setting Speed Limits in Urban and Suburban Areas in Florida”, University of South Florida, Final Report No. Final Report No. BC353RPWO-14, March 2003, pp. 118.
 198. Rinaldicu, E.J., Mouloua, M., and Smither, J., “Cognitive and Perceptual Factors in Aging and Driving Performance”, Final Technical Report No. VPL-03-01, Visual Performance Laboratory, University of Florida, pp. 60.
 199. Guerrier, J.H., Fu, S., “Elder Roadway User Program Test Sections and Effectiveness Study”, University of Miami, October 2001, pp. 204.
 200. Foreman, C.C., Tucker, L.E., Flynn, and West, M, “Senior Transportation Alternative: Why are They Important and What Makes Them Work”, National Center for Transit Research, University of South Florida, Report No. NCTR-473-09, December 2003, pp. 102.
 201. Pernia, J.C., Lu, J.J., Weng, M.X., Xie, X., and, Yu, Z., “Development of Models to Quantify the Impacts of Signalization on Intersection Crashes”, Transportation Program, University South Florida, January 2002, pp. 266.
 202. Courage, K., and Willis, M., “Development of Traffic Operations Software”, University of Florida, May 2003, pp. 47.
 203. Tucker, L.E., “Safer Stops for Vulnerable Customers”, National Center for Transit Research, University of South Florida, Report No. NCTR-473-13, March 2003, pp/ 87.
 204. Chu, X., Guttenplan, M., and Baltes, M.R., “Why People Cross Where They Do: The Role of the Street Environment”, National Center for Transit Research, University of South Florida, Report No. NCTR-473-06, September 2002, pp. 14.
 205. Courage, K., Stephens, B., Gan, A., and Willis, M., “Triple Left Turn Lanes at Signalized Intersections”, University of Florida, December 2002, pp. 175.
 206. Outcalt, W., “Centerline Rumble Strips”, Colorado Department of Transportation, Report No. CDOT-DTD-R-2001-8, August 2001, pp. 15.

207. Outcalt, W., "Bicycle-Friendly Rumble Strips", Colorado Department of Transportation, Report No. CDOT-DTD-R-2001-4, May 2001, pp. 126.
208. <http://www.virginiadot.org/infoservice/news/CO11262001-rumble.asp>
209. Garber, N.J., and Srinivasan, S., "Effectiveness of Changeable Message Signs in Controlling Vehicle Speeds in Work Zones Phase II", Virginia Transportation Research Council, Virginia, Report No. VTRC 98-R10, December 1998, pp. 72.
210. Sabers, D.P., Pluta, J.J., and Mancini, M., "Light Use Study for Vertical Channelization Devices", Report No. AZ03-554, May 2003, pp. 90.
211. Griffith, A., and Brooks, E.I.T., "Lighted Guide Tube Evaluation", Oregon Department of Transportation, Salem, OR, Report No. OR-EF-01-02, August 2000, pp. 76.
212. Griffith, A. and Horton, D., "Evaluation of Modified Work Zone Traffic Control Devices to Control Business Areas", Oregon Department of Transportation, Salem, OR, Report No. FHWA-OR-RD-01-10, January 2001, pp. 77.
213. Barnie, J., Griffith, A., and Hass, K., "Effectiveness of Double Fines as a Speed Control Measure in Safety Corridors", Oregon Department of Transportation, Salem, OR, Report No. FHWA-OR-RD-03-10, December 2002, pp. 71.
214. Douglas, K. and Park, S. B., "Selection Criteria for Using Nighttime Construction and Maintenance Operations", Oregon Department of Transportation, Salem, OR, Report No. FHWA-OR-RD-03-13, May 2003, pp. 70.
215. Hass, K., Barnie, J., and Kirk, A., "The Effect of Law Enforcement Deployment Patterns on Motorists' Speeds", Oregon Department of Transportation, Salem, OR, Report No. FHWA-OR-DF-04-04, December 2003, pp. 56.
216. Zaworski, J., Hunter-Zaworski, K., "Evaluation of Intrusion Detection Technologies for High Speed Rail Grade Crossings, Oregon Department of Transportation, Salem, OR, Report No. FHWA-OR-HSR-04-09, December 2003, pp. 64.
217. Baggett, S.A., "Highway Facilities for an Aging Arizona Population", Quantec, Portland, OR, Report No. FHWA-AZ-03-486, June 2003, pp. 94.
218. Gattis, J.L. and Iqbal, Z., "Effectiveness of Do-Not-Block Intersection Signs", Transportation Research Record 1456, National Research Council, Washington D.C., 1994, pp. 27-33.
219. Gattis, J.L., "Cross Traffic Signing for Stop Signs", Transportation Research Record 1553, National Research Council, Washington D.C., 1996, pp. 1-12.
220. Mahmassani, H.S., Abdelghany, A., and Kraan, M., "Providing Advanced and Real-Time Travel/Traffic Information to Tourists", University of Texas at Austin, TX, Report No. FHWA/TX-99/1744-S, October 1998, pp. 16.
221. Luz, Y.L., Mahmassani, H.S., Kraan, M., and Abdelghany, A., "Providing Advance and Real-Time Information to Tourists: San Antonio Case Study", University of Texas at Austin, TX, Report No. FHWA/TX-02-1744-I, February 2001, pp. 118.
222. Saito, M. and Turley, B., "Dancing Diamonds in Highway Work Zones: An Evaluation of Arrow Panel Caution Displays", Birmingham Young University, Provo, UT, Report No. UT-02.13, June 2002, pp. 90.
223. Martin, P.T., Perrin, J. et al., "Adaptive Signal Control II", University of Utah, Salt Lake City, UT, January 2003, pp. 122.
224. Cottrell, W. D., "Evaluating and Improving Pedestrian Safety in Utah", University of Utah, Salt Lake City, UT, Report No. UT-02.10, February 1, 2002, pp. 45.

225. Peabody, D., Garder, P., Audibert, G., Thompson, W., Redmond, M., and Smith, M.S., "Evaluation of a Vehicle-Actuated Warning System for Stop-Controlled Intersections Having Limited Sight Distance", International Conference on Rural Advanced Technology and Transportation Systems, Burlington, Vermont, August 25-28, 2001.
226. Cottrell Jr., B.H., "Technical Assistance Report: Evaluation of Deer Warning Reflectors in Virginia", Virginia Transportation Research Council, Report No. VTRC 03-TAR6, June 2003, pp. 24.
227. Lambert, J.H., and Turley, T., "Screening Methodology for Needs of Roadway Lighting", Center for Risk Management of Engineering Systems, University of Virginia, VA, Report No. FHWA/VTRC 03-CR14, June 2003, pp. 76
228. <http://www.trafficmarking.com/rumblestrip.html>
229. <http://www.trafficmarking.com/rumblestrip.pdf>
230. <http://www.trafficmarking.com/mh.html>
231. <http://www.stop-painting.com/rumblestrips.html>
232. <http://lib1.store.vip.sc5.yahoo.com/lib/stop-painting/pdfrubblestrips.pdf>
233. http://64.233.167.104/search?q=cache:4v2fr5rlbJ8J:www.tapconet.com/markers_delineators6.html+rubble+strip+products&hl=en
234. http://www.amsig.com/MSGP_232T.htm
235. http://www.intertraffic.com/marketplace/mypage/products_detail.asp?mypageid=132&productid=1320
236. http://www.intertraffic.com/marketplace/mypage/products_detail.asp?mypageid=132&productid=1266
237. <http://www.ver-mac.com/en/products/index.html#>
238. http://www.tssco.com/sign_board.htm
239. http://www.addcoinc.com/c_tcg.htm
240. http://www.swarco.com/english/allg_pro.asp?Obergruppe%20D=TRAFFIC%20MANA&Produktgruppe%20D=Wechselverkehrszeichen
241. <http://www.controlspecialists.com/tassimco.htm>
242. <http://www.roadtech.com/>
243. <http://www.scsupplyco.com/Delineators.htm>
244. <http://www.rcflagman.com/howitworks.htm>
245. http://64.233.167.104/search?q=cache:4v2fr5rlbJ8J:www.tapconet.com/markers_delineators6.html+rubble+strip+products&hl=en
246. http://www.tssco.com/premark_pavement_markings.html
247. <http://www.controlspecialists.com/safe.html>
248. http://www.tssco.com/deline_flex.htm
249. http://products3.3m.com/catalog/us/en001/safety/traffic_control/node_3ZSWTRWR6Db_e/root_GST1T4S9TCgv/vroot_1PGXVVLN9Xge/gvel_D9B7NST8KWgl/theme_us_trafficcontrol_3_0/command_AbcPageHandler/output_html
250. http://products3.3m.com/catalog/us/en001/safety/traffic_control/node_GWZJP5681Mbe/root_GST1T4S9TCgv/vroot_1PGXVVLN9Xge/gvel_D9B7NST8KWgl/theme_us_trafficcontrol_3_0/command_AbcPageHandler/output_html
251. <http://www.swarco.com/english/pr.asp?Obergruppe%20D=TRAFFIC%20MATERIALS&Produktgruppe%20D=Reflexglasperlen&Produkt%20ID=115>
252. <http://www.swarco.com/english/pr.asp?Obergruppe%20D=TRAFFIC%20MATERIALS&Produktgruppe%20D=Markierungsmaterialien&Produkt%20ID=110>

253. <http://www.swarco.com/english/pr.asp?Obergruppe%20D=TRAFFIC%20MATERIALS&Produktgruppe%20D=Markierungsmaterialien&Produkt%20ID=103>
254. <http://www.highwaybeacon.com/product.htm>
255. http://www.its-info.com/pavemark_snow.htm
256. <http://www.telcontar.com/products/tm/features.html>
257. <http://www.telcontar.com/products/tm/docs.html>
258. <http://www.telcontar.com/products/tm/index.html>
259. http://www.addcoinc.com/w_product.htm
260. <http://highwayinfo.com/products/products.php?product=hiway>
261. <http://highwayinfo.com/products/products.php?product=solar>
262. http://www.polar.com/Nav_Features.htm
263. <http://www.seton.com/cgi-bin/ncommerce/ExecMacro/Seton/newprod.d2w/report>
264. http://www.transoftsolutions.com/transoft/products/pk/product_overview.asp
265. http://www.transoftsolutions.com/transoft/products/at42/product_overview.asp#
266. http://www.transoftsolutions.com/transoft/products/g42/product_overview.asp

Appendix A. Driver Information Demand Guidelines Categories

Content, clarity and timeliness are important when providing travel related information to motorists. Therefore some of the factors that need to be considered in information dissemination are: information set, describing incidents and their locations, characterizing and representing traffic conditions, routing and re-routing recommendations, where/when to present information, and accommodate for individual differences [156].

Information Set

- When notifying drivers to the presence of an incident, provide the following elements: (1) incident location, (2) incident type, and (3) delay associated with the incident. For en-route applications, provide a suggested course of action (e.g. keep left).
- Additional incident detail information facilitates diversion. If the situation permits, including one or more of the following items should be considered:
 - Length of backup associated with the incident
 - Number of lanes blocked
 - Time until cleared
 - Suggested alternate routes, with estimated time savings
 - Suggested action
- For recurrent congestion sites, the priority of information to support driver route selections is as follows: (1) location of encountering congestion, (2) speed/congestion descriptor, and (3) origin or length of congestion.
- The relative focus of the information should be tailored to the situation. It is also important to emphasize incident delay, location, and suggested alternate information for pre-trip commutes; provide as much detail as possible with regard to these information elements. In situations where travelers are likely to be operating in unfamiliar areas and/or engaged in discretionary trips (e.g. shopping), emphasize way finding cues over congestion/traffic information.
- For messages restricted to a few information items (e.g. CMS), people prefer to have descriptive information (e.g. incident type, location, delay) rather than route suggestions.
- Orient the user by providing an overall picture of the route, including links between origin and destination, scope of the trip (e.g. distance, estimated time), cardinal direction or key landmarks, and major intervening features.
- Information should be time-stamped or otherwise documented so users know when the data were collected and their timeliness. Data should be updated frequently during peak traffic periods.
- Supplement descriptive (current status) information with predictive information regarding congestion or travel times. A 15-20 minute window is recommended for pre-trip information.

- A consistent, standardized set of terminology for communicating and characterizing traffic as well other information should be used.
- When communicating information to a general audience where aspects of the information are relevant to different user groups (e.g. radio traffic reports), the sequence in which the information is presented can be important. Define the affected area or users first, to capture attention, followed by incident details and recommended routing.
- Travelers should be provided accurate and reliable information while also being conservative. Some delay in providing information is permissible to avoid disseminating erroneous or inaccurate information unless the medium allows providers to indicate whether the traffic information is unconfirmed.

Describing Incidents and their Locations

- An indication of the type of incident that is related to the traffic situation needs to be included. At a minimum, these should distinguish accidents, road work, road closure, and disabled vehicles. Brief (1-3 word) descriptors of the incident should be used. These should be drawn from a standardized set of well-understood categories.
- An attempt must be made to avoid irrelevant fine detail in incident categories. Descriptors should be based upon the responsible dissemination of operationally-relevant information, not sensation or news. The level of detail should not exceed driver operational needs.
- When traffic is comprised of primarily locally familiar drivers, the designation of incident location should include the name of the closest exit or cross street. Where traffic contains substantial numbers of unfamiliar drivers, the designation of incident location should include the closest exit number or route number. If possible, provide both types of information to satisfy the requirements of different users.
- For non-recurrent discrete incidents (e.g. accident, roadwork), the location should refer to the site of the incident. For recurrent congestion, location should specify the area in which the driver will initially encounter congestion, or the segment over which congestion occurs.

Characterizing & Representing Traffic Conditions

- For peak hour situations where there is a history of recurrent congestion, provide a description of current traffic status relative to typical status at that time of day. Use travel time as a descriptor as opposed to speed.
- Supplement information on average travel time (or speed) with some indication of the variability of trip times (or speeds), such as typical range, 90th percentile values, etc.

- Provide travel time/speed estimate between key route segments or links. In general, time based measures are preferable to travel speeds. In either case, provide an indication of traffic status on key route segments or links.
- Provide projected estimates of the time to clear incidents, or the current status. Driver decisions to divert when approaching an accident site are improved by information on the status of the incident. If estimates cannot be provided, indicate the stage of the incident response. Recommended stages of incident status for messages are, (1) backup is increasing; (2) backup is decreasing; and (3) backup is cleared.
- Provide direct views of traffic at strategic locations along the road network so that drivers can assess current traffic or road conditions, as well as the impact of incidents, directly. At a minimum provide the following information to support camera images: (1) time stamp, (2) indication of the camera's location, (3) indication of the camera's direction. Where possible provide dynamic real-time video as opposed to static images. Supplementing static images with vehicle speed data may aid interpretation under some conditions.
- Use current traffic information in combination with historic data to provide near term predictive information that estimates travel conditions along prescribed routes. Displays which plot mean travel times (or speeds) by departure time are recommended (values displayed can also represent percentiles to capture the range of times, or speeds, across time). At a minimum, state whether conditions are currently getting worse or improving.
- Where feasible, integrate information elements so that drivers can readily acquire and process desired information without the need to search multiple information sources. Traffic maps appear well suited to this purpose. Recommended items to be integrated include: location and type of incidents/congestion, extent of delay and pack-up associated with incidents/congestion, link travel times/speeds, video images, text with video displays.
- Do not rely solely on relative trip time comparison between primary/alternative routes to engender trip diversion; drivers desire and use additional information in formulating routing decisions.
- Emphasize quantitative information over qualitative information, particularly when expressing delay associated with incidents.

Routing and Re-routing Recommendations

- When recommending a primary route, use expected trip time as the primary factor for route selection. Trip time variability and predictability are also typically important to drivers and should be included.

- General preference factors to consider in route recommendations include: higher roadway function class, lower path complexity, clearly designated routes (e.g. marked with route numbers); lower traffic density/level of traffic interaction, fewer traffic signals, fewer turns, and lower costs.
- To promote compliance with recommended diversions, incorporate individual driver preferences into the algorithms for triggering recommendations and selecting alternate routes.
- If an alternate route is recommended over a primary route (a driver's typical route or normal best choice route), provide an estimate of the travel time on the alternate route.
- If it is desirable to have a higher percentage of motorists divert to an alternate route, indicate a clear time benefit or provide incident detail. If it is desirable to have a lower percentage of motorists divert to an alternate route, confirm that there are minimal time differences or reduce uncertainty about the delay (through incident status, time, minor severity, number of lanes open, etc.)
- When making route diversion recommendations, provide information regarding path recovery.
- When recommending a route to divert from an incident, suggest diversion routes that by-pass an incident and rejoin the initially-planned primary route rather than alternatives that require an entirely new path.
- If a driver is directed off a freeway route and onto arterial roads, provide as much initial guidance, and subsequent direction or confirmation, as possible.
- Where options for re-routing with similar trip times exist, recommend: freeway rather than non-freeway routes, alternative routes with fewer turns or traffic signals, less navigationally complex routes, or alternative routes where traffic density is immediately lighter.
- Incorporate driver preferences into route selection procedures. The relative weight given to different selection criteria varies by person and trip type, and should match user preferences. In addition to primary and secondary selection criteria listed above, individual preferences may be related to: schedule tolerance and time flexibility, special vehicle restrictions, personal safety concerns, scenery/ambience, and freeway aversion. Provide users with feedback regarding their trip time and compare it with recommended or minimum time routes.

Where/When to Present Information

- Provide traffic information in advance of freeways along feeder routes and freeway interchanges so that traffic status can be communicated sufficiently in advance, allowing drivers time to make decisions about alternate routes.

- Avoid making recommendations to divert from a planned route unless the travel time savings exceeds a threshold defined by the driver “indifference band”. For general application, this threshold is approximately 18% of the remaining travel time, but not less than one minute. Where user-specific criteria can be defined, the recommended diversion thresholds are: low tolerance for late arrival: 5%, if current route jeopardizes on-time arrival, unfamiliar drivers: 20%, where criteria other than time are specified (e.g. scenic, costs): 20-25% and, where the estimated time on the alternate route is highly variable: 20-25%. The above trip-time-based recommendations assume other considerations are equal. In particular, where safety considerations may be involved (e.g. routes might have ice on roads), other factors should be considered as well.

Individual Differences

- Provide a means to allow drivers to customize traffic information based on their preferences and/or trip specific factors.

Appendix B. Email Questionnaire

Dear _____,

We at the Ohio Research Institute for Transportation and the Environment (ORITE) Human Factors and Ergonomics Laboratory at Ohio University are conducting a research project "Human Factors Opportunities to Improve Ohio's Transportation System" for the Ohio Department of Transportation (ODOT). The aim of this project is to identify and recommend to ODOT innovations and practices that positively affect the human factors experience of the driver on Ohio's roads, including improved safety, mobility, and comfort for drivers, bicyclists, and pedestrians.

We may have already contacted some of you in regards to this study and made a general inquiry on human factors research in your department. Thank you for your previous responses. We are now focusing on certain targeted topics.

We are inquiring about the state of the art research that you may have conducted in the following topic areas. For each area, please indicate "Yes" if you have conducted some research on the topic or "No" if you have not. For those topics that you have conducted research on, please list references to any published or in-house research reports, papers, case studies, best practices, and evaluations that your department of transportation is conducting, has recently completed, or knows about. You can include URLs of downloadable documents or bibliographical citations and instructions on how to request a hard copy of the document if it is not online.

1. _____ Yes _____ No * Rumble strip application and configuration (work zone notification, speed control, run off prevention, etc)

References:

2. _____ Yes _____ No * Changeable message sign application (location, messages, angularity of displays, etc)

References:

3. _____ Yes _____ No * Delineation in work zones

References:

4. _____ Yes _____ No * Half-size auxiliary pavement markings (e.g. arrows) used in pairs

References:

5. _____ Yes _____ No * Accident mitigation products, processes, techniques, etc

References:

6. _____ Yes _____ No * Older driver accommodation (signs, delineation, Striping, geometrics, lighting, signals, etc)

References:

7. _____ Yes _____ No * Traffic signal operations for reducing accidents (Red light strobes, loop placement, timing, rumble strips on approaches, count down ped heads, etc)

References:

8. _____ Yes _____ No * Highway lighting (illumination levels, where needed, etc)

References:

9. _____ Yes _____ No * Improved curve delineation

References:

10. _____ Yes _____ No * Wet/dark delineation at night

References:

11. _____ Yes _____ No * Raised pavement marker spacing

References:

12. _____ Yes _____ No * Information dissemination (HAR, kiosk, web sites, paid media, CMS, etc)

References:

13. Is there any other research in human factors in transportation that you have recently conducted that you think we may be interested in that is not covered in the above topics?

References:

Thank you for your assistance!

Appendix C. List of Personnel Contacted

State	State DOT contacts
AL	Steve Walker - walkers@dot.state.al.us
AK	Clint Adler – clint.adler@dot.state.ak.us
AZ	Frank Darmiento – fdarmiento@dot.state.az.us
AR	Karen McDaniels - Karen.McDaniels@ahtd.state.ar.us J. L. Gattis – jgattis@enr.uark.edu
CA	Trixie Johnson – Johnson@mti.sjsu.edu
CO	Gabriela Vidal – Gabriela.vidal@dot.state.co.us Outcalt, William (Skip) - Skip.Outcalt@dot.state.co.us
CT	Angelo Asaro – angelo.asaro@dot.state.ct.us
DE	Teresa Lewandowski – tlewandowski@dot.state.de.us
DC	John Frankenhoff – jfrankenhoff@dc.gov
FL	Sandra Bell – Sandra.bell@dot.state.fl.us Dwight Kingsbury – Dwight.kingsbury@dot.state.fl.us
GA	Phillip Allen – phillip.allen@dot.state.ga.us
HI	Steve Ege – Steve.Ege@hawaii.gov
ID	Lance Johnson - LJohnson@itd.state.id.us
IL	Denis Huckaba – Rahim Benekohal@ uiuc.edu
IN	Bob Cales – rcales@dot.state.in.us
IA	Tom Welch - (515)239-1267 Tom.Welch@dot.state.ia.us Troy Jerman – Troy.Jerman@dot.state.ia.us
KS	Dick McReynolds – (785) 291-3841
KY	Glenn Anderson Library contact Laura Whayne – lwhayne@enr.uky.edu
LA	Rick Holm – (225) 379 -1503 Hadi Shirazi - HadiShirazi@dotd.louisiana.gov
ME	Bruce Ibarguen – Bruce.Ibarguen@state.me.us Dr. Per Garder - Garder@umit.maine.edu
MD	Terri Tabseh - ttabesh@sha.state.md.us , csc@sha.state.md.us
MA	Thomas F. Broderick - Thomas.F.Broderick@state.ma.us Stephen Pepin, Manager of Research – stephen.pepin@state.ma.us
MI	Bruce Munroe - munroeb@michigan.gov
MN	Gary Thompson – (651) 215-0445
MS	Wes Dean – wdean@mdot.state.ms.us
MO	Ernest Perry - perrye1@mail.modot.state.mo.us
MT	Susan Slick - ssillick@state.mt.us
NE	Jodi Gibson - JodiGibson@dor.state.ne.us
NV	Allen Hilton - ahilton@dot.state.nv.us Srinivas Pulugurtha – pss@trc.unlv.edu
NH	Glenn Roberts – groberts@dot.state.nh.us
NJ	Nicholas P. Vitillo – Vitillo@dot.state.nj.us
NM	David Albright
NY	David Clements – dclements@dot.state.ny.us
NC	Brian Mayhew - bmayhew@dot.state.nc.us
ND	Allan Covlin - Acovlin@state.nd.us Kurt Johnson - Kurt.D.Johnson@ndsu.nodak.edu
OH	
OK	Gary Williams - gwilliams@fd9ns01.okladot.state.ok.us
OR	Barnie Jones - Barnie.P.JONES@odot.state.or.us

PA	Andrew Markunas - amarkunas@state.pa.us
PR	Orlando Diaz-Quirindongo - oquirindongo@act.dtop.gov.pr
RI	Frank Corrao - fcorrao@DOT.STATE.RI.US
SC	Terry Rawls - rawlstl@dot.state.sc.us (803) 737-1498
SD	David Huft - dave.huft@state.sd.us (605) 773-3358
TN	Alex Noble - Alex.Noble@state.tn.us , Jerry Everett - jeverett@utk.edu
TX	Rick Collins - rcollins@dot.state.tx.us Rory Meza - ameza@dot.state.tx.us Wade Odell - WODELL@dot.state.tx.us .
UT	Robert Hull - rhull@utah.gov Douglas Anderson dianderson@utah.gov
VT	John H. Perkins - John.Perkins@state.vt.us Bill Ahearn - Bill.Ahearn@state.vt.us
VA	Cottrell, Benjamin H - Ben.Cottrell@VirginiaDOT.org (VTRC)
WA	Keith Anderson - anderke@wsdot.wa.gov
WV	Ray Lewis - rlewis@dot.state.wv.us
WI	Tom Notbohm - thomas.notbohm@dot.state.wi.us (608) 266-0982
WY	Mike Gostovich - Mike.Gostovich@dot.state.wy.us (307) 777 -4491

Appendix D. Summary of States that responded to survey and topics on which research has been conducted

	State	Responses											
		Rumble strips	Changeable Message Signs	Delineation in Work zones	Half-size Auxiliary Pavement Markings	Accident mitigation measures	Older driver accommodation	Traffic signal operations	Highway lighting	Improved curve delineation	Wet/dark delineation at night	Raised Pavement Marker spacing	Information dissemination
1	Alabama												
2	Alaska												
3	Arizona												
4	Arkansas	X	X	X	X	X	X	X	X	X	X	X	X
5	University of Arkansas												
6	California	X	X	X	X	X	X	X	X	X	X	X	X
7	Colorado	√	X	X	X	√	X	X	√	√	X	√	X
8	Connecticut												
9	Delaware	X	X	X	X	X	X	X	X	X	X	X	X
10	District of Columbia												
11	Florida	√	√	√	X	√	√	√	√	X	√	√	X
12	Georgia												
13	Hawaii												
14	Idaho	√	X	X	X	X	X	X	X	X	X	X	X
15	Illinois												
16	Indiana												
17	Iowa	√	√	√	X	X	√	X	X	√	√	X	X
18	Kansas	X	X	X	X	X	X	X	X	X	X	X	X
19	Kentucky												
20	Louisiana	X	X	X	X	X	X	X	X	X	X	X	X
21	Maine	√	√	X	X	X	X	X	X	X	X	X	X

	State	Responses											
		Rumble strips	Changeable Message Signs	Delineation in Work zones	Half-size Auxiliary Pavement Markings	Accident mitigation measures	Older driver accommodation	Traffic signal operations	Highway lighting	Improved curve delineation	Wet/dark delineation at night	Raised Pavement Marker spacing	Information dissemination
22	Maryland												
23	Massachusetts												
24	Michigan												
25	Minnesota												
26	Mississippi	√	X	X	X	X	X	√	X	X	X	X	X
27	Missouri												
28	Montana												
29	Nebraska												
30	Nevada												
31	New Hampshire	X	X	X	X	X	X	X	X	X	X	X	X
32	New Jersey	X	X	X	X	X	X	X	X	X	X	X	X
33	New Mexico												
34	New York	√	X	X	X	X	√	X	X	X	X	X	√
35	North Carolina												
36	North Dakota												
37	Ohio												
38	Oklahoma	X	X	X	X	X	X	X	X	X	X	X	X
39	Oregon	X	√	√	X	√	X	X	X	X	√	X	X
40	Pennsylvania												
41	Puerto Rico												
42	Rhode Island	X	X	X	X	X	X	X	X	X	X	X	X
43	South Carolina												
44	South Dakota												

	State	Rumble strips	Changeable Message Signs	Delineation in Work zones	Half-size Auxiliary Pavement Markings	Accident mitigation measures	Older driver accommodation	Traffic signal operations	Highway lighting	Improved curve delineation	Wet/dark delineation at night	Raised Pavement Marker spacing	Information dissemination
45	Tennessee												
46	Texas	X	X	X	X	X	X	X	X	X	X	X	√
47	Utah	X	X	√	X	√	X	√	X	X	X	X	√
48	Vermont	X	X	X	X	X	√	X	X	X	√	X	X
49	Virginia	√	√	√	X	√	√	√	√	√	√	√	X
50	Washington												
51	West Virginia												
52	West Virginia University	X	X	X	X	X	X	X	X	X	X	X	X
53	Wisconsin												
54	Wyoming	√	X	X	X	X	X	X	X	X	X	X	X

Key:

√	Have conducted research
X	Have not conducted research
	No response to survey

Appendix E. List of Personnel Who Provided Research Information

State	State DOT contacts who responded
AL	
AK	
AZ	Frank Darmiento – fdarmiento@dot.state.az.us Research has been conducted on facilities for the aging population and use of light for vertical channelization devices. See website for reports http://www.dot.state.az.us/ABOUT/atrc/Publications/SPR/SPR_Reports.htm
AR	Karen McDaniels - Karen.McDaniels@ahtd.state.ar.us J. L. Gattis – jgattis@engr.uark.edu Have conducted research on the effectiveness of Do-Not-Block intersection signs and cross traffic signing for stop signs. Both reports published in TRR and are available.
CA	
CO	Gabriela Vidal – Gabriela.vidal@dot.state.co.us Outcalt, William (Skip) - Skip.Outcalt@dot.state.co.us Have conducted/on going research in rumble strips, evaluating sites that promise safety improvement, and barrier markers for use in concrete barriers in curving mountain highways. Considerable testing has been done with raised pavement markers but none have been able to withstand snow plows. Any published reports are available at http://www.dot.state.co.us/publications/researchreports.htm
CT	
DE	
DC	
FL	Sandra Bell – Sandra.bell@dot.state.fl.us Dwight Kingsbury – Dwight.kingsbury@dot.state.fl.us Research has been conducted/on going in relation to rumble strips, CMS, delineation, accident mitigation, older driver accommodation, traffic signal operation for reducing accidents, highway lighting, wet/dark delineation, RPM. Reports and other documentation at http://www.dot.state.fl.us/research-center/ProjectInfo.htm
GA	
HI	
ID	Lance Johnson - LJohnson@itd.state.id.us Some research has been done on rumble strips. Agreed to send report.
IL	
IN	
IA	Tom Welch - (515)239-1267 Tom.Welch@dot.state.ia.us Troy Jerman – Troy.Jerman@dot.state.ia.us Responded indicating that many of the techniques listed (CMS, Delineation in work zones, Older driver accommodation, curve delineation, wet/dark delineation) in the survey were being applied but have not documented anything. Rumble strips to be installed in entire interstate system this summer.
KS	
KY	
LA	

State	State DOT contacts who responded
ME	Bruce Ibarguen – Bruce.Ibarguen@state.me.us Have not done any research in HF Dr. Per Garder - Garder@umit.maine.edu Research has been conducted on use of rumble strips along wide shoulders designated for bicycle traffic, evaluation of vehicle-actuated warning system for stop-controlled intersections having limited sight distances and, traffic signal safety (analyzing red-light running)
MD	
MA	
MI	
MN	
MS	Wes Dean – wdean@mdot.state.ms.us Have conducted research in relation to rumble strips, traffic signal operations. TRB presentation at 2004 conference. Received copy of presentation, video and other material.
MO	Ernest Perry - perrye1@mail.modot.state.mo.us Did not respond to email. Research reports available at http://www.modot.org/services/rdt/byTitle.htm Reports on rumble strips, pavement management systems, safety in expressways
MT	Susan Slick - ssillick@state.mt.us Called and sent email again and indicated that she will respond. But did not receive response. Reports available at the following locations. http://www.mdt.state.mt.us/research/docs/research_proj/crash_test/final_report.pdf http://www.mdt.state.mt.us/research/docs/research_proj/rumble_final_report.pdf http://www.mdt.state.mt.us/research/docs/research_proj/accident_finalreport.pdf
NE	
NV	
NH	
NJ	
NM	
NY	David Clements – dclements@dot.state.ny.us Responded to email. They installed rumble strips in all interstates and found that ROR accidents on the NYS thruway were reduced by 70%. Also indicated that CMS is an integral part of their highway system. Also adopted wider PM, larger lettering, and higher grade reflective sheeting to accommodate for older drivers. Information disseminated through Governor’s Traffic Safety website. All based on small field experiments. No literature available to share with us.
NC	
ND	
OH	
OK	
OR	Barnie Jones - Barnie.P.JONES@odot.state.or.us Research has been conducted in several areas: evaluation of arrow panels, delineation in work zones, flagger illumination, effectiveness of double fines for safety, effect of law enforcement on motorist speed, wet/dark delineation. The literature related to the research are available at http://www.odot.state.or.us/tddresearch/reports.htm
PA	Andrew Markunas – amarkunas@state.pa.us , Bill Crawford – wicrawford@state.pa.us
PR	
RI	
SC	
SD	
TN	

State	State DOT contacts who responded
TX	Rick Collins - rcollins@dot.state.tx.us , Rory Meza – ameza@dot.state.tx.us Wade Odell, Research Engineer - Traffic Operations - WODELL@dot.state.tx.us Indicated that all research reports can be found at, http://library.ctr.utexas.edu/index.htm .
UT	Robert Hull - rhull@utah.gov Douglas Anderson – Research Project Manager dianderson@utah.gov Research has been done on using arrow panels in work zones, adaptive signal control for traffic management, using a crash data delivery system for accident mitigation and improving pedestrian safety. Research reports available at www.dot.state.ut.us/index.php/m=c/tid=297
VT	John H. Perkins - John.Perkins@state.vt.us Bill Ahearn - Bill.Ahearn@state.vt.us Responded to survey. Not much research in HF. 3M LPM in grooves is being tested currently for use as wet/dark delineation at night. Contact Craig Graham (Craig.graham@state.vt.us) for report after completion.
VA	Cottrell, Benjamin H - Ben.Cottrell@VirginiaDOT.org (VTRC) Research has been conducted in continuous shoulder rumble strips, CMS, delineation in work zones, accident mitigation procedures, older driver accommodation, traffic signal operations, highway lighting, curve and wet/dark delineation. For reports see http://www.virginiadot.org/vtrc/main/index_main.htm
WA	
WV	
WI	
WY	Mike Gostovich - Mike.Gostovich@dot.state.wy.us (307) 777 -4491 Some research has been done on rumble strips (together with TTI). They use strobes on midblock, pedestrian signals. No research done.

Appendix F. Product Survey – Email to Manufacturers

29 June 2005

RE: Product literature, evaluations, and/or case studies on products regarding human factors in roadway transportation

Dear _____,

We at the Ohio Research Institute for Transportation and the Environment (ORITE) Human Factors and Ergonomics Laboratory at Ohio University are conducting a research project “Human Factors Opportunities to Improve Ohio’s Transportation System” for the Ohio Department of Transportation (ODOT). The aim of this project is to identify and recommend to ODOT innovations and practices that positively affect the human factors experience of the driver on Ohio’s roads, including improved safety, mobility, and comfort for drivers, bicyclists, and pedestrians.

Some potential areas of investigation include

- Improving legibility of variable message signs
- Larger sign legends and symbols for warning signs to benefit older drivers (as used in some states)
- Older drivers -- larger sign legends and symbols (used in some states), delineation, striping, geometrics, lighting, signals, etc
- Improved curve delineation, pavement marking arrows used in advance of curves (being evaluated in Pennsylvania)
- Post delineators in snow areas
- Half-size but twice as many pavement arrows
- Wrong-way markings including half-size arrows that show the correct driving direction
- Red raised pavement markers
- Red post delineators at intersections and exit/entrance ramps
- Wet weather night retroreflective pavement markings
- Wet/dark delineation
- Video scene cameras for remote traffic management
- Automatic identification technology for speed and weight enforcement
- Reduced roadway lighting at interchanges
- Increased spacing of raised pavement markers on two-lane roads
- Improved construction equipment visibility
- Improved equipment operator instructions
- Innovations in equipment operator training
- Improved diagnostic testing for equipment operators
- Rumble strip application -- work zone notification, speed control, run off prevention, etc.
- Changeable Message Sign application -- location, messages, etc
- Work Zone delineation

- Accident mitigation products, processes, techniques, etc.
- Traffic signal operations for accident reduction -- red light strobes, loop placement, timing, rumble strips on approaches, count down pedestrian heads, etc
- Highway lighting -- illumination levels, location, etc
- RPM Spacing
- Information dissemination -- har, kiosk, wed sites, paid media, CMS, etc.

We are interested in any available case studies, best practices, product literature, safety audits, and published or in-house research reports, papers, and evaluations that your firm is conducting, has recently completed, or knows about regarding improved traffic control devices that take into account human factors considerations.

Thank you,