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Evaluation of Innovative Traffic Safety Devices at Short-Term Work Zones

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16 Abstract

The objective of this study was to investigate and evaluate the usage and effectiveness of innovative traffic control devices that can be used in short-term work zones. Any device to be used in short-term work zones should command the respect of drivers, be durable, have an easily understood meaning, be low cost, be quick and easy to install and remove, and be reusable.

This study was conducted in three sections: a literature review of previously published research, a nationwide usage survey, and a field test for a selected device, portable plastic rumble strip (PPRS).

PPRSs, which have been tested on a closed course, were found to be a device potentially suitable for use at short-term work zones. This field study was to investigate the effects of the PPRSs and drivers' response to them at three short-term maintenance work zones in Kansas. The results showed that the effect of PPRSs in speed reductions was more significant on cars than on trucks. The PPRSs reduced car speeds by 4.6 to 11.4 miles per hour. They also created 5.0 to 11.7 miles per hour mean speed reduction for trucks, but the reductions were only at two test sites. It was observed that 30 to 80 percent of truck drivers activated their brakes (indicated by brake light illumination) when they approached the PPRSs. In addition, about five percent of car and truck drivers swerved around the PPRSs. This indicates that additional signage or other supplemental traffic devices would be needed when the PPRSs are implemented.

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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

NOTICE

DISCLAIMER

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Executive Summary

The objective of this study was to investigate and evaluate the usage and effectiveness of innovative traffic control devices that can be used in short-term work zones. Any device to be used in short-term work zones should command the respect of drivers, be durable, have an easily understood meaning, be low cost, be quick and easy to install and remove, and be reusable.

This study was conducted in three sections: a literature review of previously published research, a nationwide usage survey, and a field test for a selected device, portable plastic rumble strip (PPRS).

Review and Survey Results of Innovative Traffic Control Devices

The usage and the effectiveness of portable devices/systems that possibly could be used at short-term work zones were investigated. The survey focused on innovative or unique safety devices that any state is using or has used in the past and their states' comments on the devices' perceived effectiveness. A total of 26 states responded to the survey. Existing research, implementation, and available evaluation results as well as the survey results for these devices were also reviewed and summarized by device.

Adhesive Rumble Strips

Previous research on adhesive rumble strips, including orange Advance Traffic Marking Rumble Strips (ATMs) and Rumblers, found that these types of strips could create speed reductions, but the reductions were varied. Some of them were found ineffective, especially for trucks. The survey also found that 36 percent of states commented that these types of rumble strips were ineffective at speed reductions. Although some studies found that they can create a speed reduction of over eight miles per hour. Due to the installation time required and the lack of reusability, these devices tended to be used only in long-term work zones.

Intrusion Alert System

Although an intrusion alarm system ideally will alert workers when any vehicle intrudes into the work zone buffer area, the application and effectiveness of these systems are still limited.

The survey found that 44 percent of states believe that this type of device was ineffective. A recent demonstration of the SonoBlaster system showed that the alarm sound was not loud enough at noisy work zones, and the time required for setting up and taking down the units was excessive. Other issues, such as false alarms and maintenance in addition to installation time were the leading concerns prompting state agencies to avoiding using such devices.

Portable Changeable Message Signs (PCMS)

PCMSs were commonly used in all states and were considered very effective not only in directing drivers' paths but also in decreasing traveling speeds and the percentage of speeding traffic. Their effectiveness in speed reduction was found to be more significant when incorporated with radar drones. Although most states said that they usually only applied their PCMS in long-term work zones, the potential of applying PCMSs at short-term work zones was still considerable.

Portable Speed Monitoring Displays (PSMD)

Previous research and this survey found that PSMDs were very effective in both speed reduction and in decreasing the percentage of speeding traffic. A negative impact was also some states' concern that the devices may encourage aggressive driving. Although most states said that PSMDs were only used in work zones lasting longer than a day, it was still possible to be used in short-term maintenance work zones due to the short installation time.

Radar Drones

Radar drones have been tested in many studies and were found to create varied speed reductions. However, responses from the various state transportation agencies frequently commented that this device was not actually effective. This was believed to be caused by the lack of radar detectors among drivers, thus leaving only a minority of drivers who had radar detectors in order to actually get the message and slow down.

Vehicle-Activated Signs (VAS)

Previous research found VASs were effective in reducing speeds and the percentage of vehicles exceeding the speed limit. Although not many states have applied this device, it holds a great deal of potential to be used in short-term work zones due to the fact that this device is simple to install and maintain.

CB Wizard Alert System

User surveys from a previous study showed a very high percentage of drivers considering messages broadcast through CB Wizard alert systems to be effective. More than 50 percent of responding state transportation agencies considered this device to be effective. However, most agencies noted that this device tends to be predominately used in long-term work zones. The practical application of this device in short-term work zones may be limited due to set up times and drivers' reaction time.

Truck Mounted Attenuators (TMA)

TMAs are currently used in short-term work zones by every state contacted, particularly in moving work zones. Previous studies found TMAs could significantly reduce crash severity. The responses received from all states considered the TMAs to be very effective indeed.

Mobile Barriers

Mobile barriers have been tested or used in at least four states (California, Colorado, New Jersey, and Texas). Test results have found that this device was very effective and would be suitable for use in both short-term and moving work zones. However, based on the survey results, the sizeable capital investment required to procure a mobile barrier system has stifled its usage.

Field Test of Innovative Portable Rumble Strips

Portable plastic rumble strips (PPRSs), which have been tested on a closed course, were found to be a device potentially suitable for use at short-term work zones. This field study was to investigate the effects of the PPRSs and drivers' response to them at three short-term maintenance work zones in Kansas. The results showed that the effect of PPRSs in speed reductions was more significant on cars than on trucks. The PPRSs reduced car speeds by 4.6 to 11.4 miles per hour. They also created 5.0 to 11.7 miles per hour mean speed reduction for trucks, but the reductions were only at two test sites. It was observed that 30 to 80 percent of truck drivers activated their brakes (indicated by brake light illumination) when they approached the PPRSs. In addition, about five percent of car and truck drivers swerved around the PPRSs. This indicates that additional signage or other supplemental traffic devices would be needed when the PPRSs are implemented.

Recommendations

Based on a literature review, nationwide survey, and a field test of a device that was currently available on the market, it was shown that indeed there are useful applications for several innovative traffic safety devices. Thus, these devices should be strongly considered for usage where appropriate in addition to existing typical traffic control devices.

Portable Plastic Rumble Strips

The effectiveness of this product has been confirmed through both closed course and field tests. They are easy to install (compared to adhesive-based strips), easy to remove, and are reusable. The field test results also found that they were effective in alerting drivers resulting in speed reductions for both cars and trucks. **Two sets of four strips at 36 inches spacing are recommended for short-term work zones in addition to existing traffic control devices in the temporary traffic control plan**. However, since about five percent of drivers were observed to swerve around the PRSSs during the field test, additional driver information such as a supplemental advisory sign may be needed to assure the public that these devices are indeed meant to be traversed. Additionally, future research into appropriate signage or other supplemental traffic control is needed to minimize drivers avoiding the PPRS.

Portable Speed Monitoring Signs

The portable speed monitoring display has been found to be a very effective device in speed reduction. The speed monitoring display installed in a portable sign (as shown in Figure 2.4) instead of being installed in a trailer is recommended based on the low cost and effort of the installation. This sign could easily be integrated into the existing temporary traffic control plans for short-term work zones.

Vehicle-Activated Signs

Similar to the portable speed monitor display, the vehicle-activated signs are easy to set up to alert drivers who are over the speed limit. They can also be embedded into standard temporary traffic control plans for short-term work zones.

Intrusion Alert System

The idea of an intrusion alarm systems is positive. However, the effectiveness of this device was not shown. Demonstration results from other states found that this device still has some deficiencies such as the inadequate sound and excessive time required for installation. The application of this device at short-term work zones is not recommended until this product space has matured and obtains approval by the demonstration states.

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Chapter 1: Introduction

1.1 Background

There are many traffic control devices available for use in work zones that are designed to promote safe and efficient traffic flow through the work area. While many of these have been designed to maximize safety to both the workers and drivers, not all of these devices are suitable for all work zone situations. Short-term work zones, those work zones that will be in place for a day or a portion of a day, pose special problems when considering the type of traffic control to provide. The short time frame involved means that there is pressure to avoid spending additional time placing extra traffic control measures. Furthermore, a traffic control strategy that is useful for day-long work zones may be considered inefficient for shorter duration projects, and what works for a half-day project may be considered inefficient for a project where a work convoy is in near-continuous motion.

Short-term work zones, by their nature, are more likely to have workers in close proximity to the travel lanes, and with minimal positive protection. Typical traffic control at short-term work zones often consists of little more than temporary signage, cones or barrels, and a flagger at each end of the work zone. Because of the temporary nature of these work zones, drivers may be more likely to be surprised by the presence of the work zone which may not have been there the previous day. Being able to adequately warn approaching drivers of the work zone's presence is a key requirement of the traffic control plan. Because there are many road work activities where a short-term work zone is the only practical option, there remains a need to improve work zone traffic control to mitigate these issues.

Any device to be used in short-term work zones should command the respect of drivers, be durable, have an easily understood meaning, be low cost, be quick and easy to install and remove, and be reusable.

While it is unlikely that any device could meet all of these criteria, there are several commercially available products on the market that may meet some of these criteria and may provide a useful safety enhancement to Kansas Department of Transportation's (KDOT's) typical temporary traffic control plans.

1.2 Research Objective

The objective of this project was to determine how best to incorporate innovative traffic control devices into KDOT's traffic control plans for short-term, short-duration, and moving/mobile work zones, and provide guidance on how existing typical traffic control plans could be amended to include provisions for the evaluated devices. This research focused on portable and innovative traffic control devices that could be considered beneficial for any type of work zones where the duration is one day or less.

1.3 Research Approach and Methods

The research approach used included three methods: literature review, a nationwide survey, and field testing. The literature review focused on the effectiveness of work zone traffic safety devices and/or systems. Portable and innovative traffic control devices available on the market, and their effectiveness based on previous tests or practical application, were researched and reviewed. A nationwide survey was conducted to document the extent to which innovative traffic control devices have been or are being incorporated into short-term work zone traffic control plans. Traffic engineering and maintenance departments at a sample of state transportation agencies were contacted to complete this task. Based on the survey results, the research team held a meeting with the project manager and selected one innovative device for the field test. The selected innovative traffic control device was tested at several short-term work zones to evaluate its effectiveness on traffic speeds and potential impact on drivers.

Chapter 2: Literature Review

There are various traffic control devices available for use at short-term work zones which can be used to alert the drivers to reduce speed and to protect workers' safety through the use of vibration, sound, or interactive information. Due to the short deployment time period, it is unlikely that any device would meet all of the criteria which are needed for short-term work zones. Several commercial products which were currently available on the market and which met one or more of the aforementioned criteria were reviewed and tested to see if they may be a useful addition to KDOT's typical temporary traffic control plans. General categories of devices investigated in this study included:

- Portable rumble strips and similar on-road devices to alert approaching drivers
- Intrusion alarms to alert workers of errant vehicles
- Portable interactive message signs and other roadside devices to alert approaching drivers
- Radio devices to alert drivers they are approaching a work zone
- Intelligent Transportation System (ITS) integration systems

2.1 Portable Rumble Strips

2.1.1 Feature

Rumble strips are devices which can generate both in-vehicle sound and vibration as a vehicle passes over the strips to hopefully prompt drivers to pay more attention to roadway conditions. They can be formed either by cutting grooves into the pavement or creating raised ridges by adding material on surface of the pavement.

2.1.2 Products and Evaluation

Several types of portable rumble trips have been installed and tested in advance of work zones. Based on the material function and installation process, the portable rumble trips can be briefly categorized into two types, single-use removable temporary rumble strips and reusable temporary rumble strips.

2.1.3 Advanced Traffic Marking Rumble Strips

Advanced Traffic Marking Rumble Strips (ATMs) are a 0.25 inch thick self-adhesive and removable rumble strip, produced by Advanced Traffic Marking Industries (Advance Traffic Markings). The strips are available in 4 inch by 50 foot rolls. In addition to orange, other colors available include bright green, white, black, or custom colors. Rubber-based ATMs can be installed easily with simple equipment such as a weighted roller. An example of ATMs is shown in Figure 2.1.

FIGURE 2.1
The installation of orange rumble strips (Fontaine 2010)

Specially designed for concrete and asphalt surfaces, ATMs have a pre-applied adhesive backing that creates a secure bond to the road surface. Test configuration and evaluation results for the ATMs, as documented in the literature are listed in Table 2.1.

A review by Iowa of ATMs concluded that 0.125 inch thick strips did not provide an adequate rumbling sensation (Maze 2000). However, the 0.25 inch thick strips were effective in providing adequate sound and rumbling sensation to passenger cars and pickup trucks. It also found that the 0.25 inch thick strips did not provide sufficient rumbling sensations to commercial trucks.

A test in Kansas by Meyer (2001) evaluated the effectiveness of ATMs and compared them to the commonly used cold mix asphalt rumble strips on a rural two-way 65 miles per hour highway, with a reduced work zone speed limit of 30 miles per hour. He used 0.125 inch thick and 4 inch wide strips, which were self adhesive and were configured in a group of six strips spaced 12 inches apart. Meyer concluded that the use of these ATMs did significantly reduce mean speeds downstream of the strips for both passenger cars and trucks by 2.2 to 2.3 miles per hour. He noted that the high visibility of the ATM had also likely contributed a positive effect in reducing vehicle speeds. He also pointed out that the optimal thickness of the strips and spacing of the strips remained to be studied. However, despite the positive findings, it was also noted that there was a consistent problem with the strips becoming loose and detaching from the roadway. This detachment results in additional work to reattach the strips and represents another detail that merits additional research.

A similar set of ATMs with supplemental adhesive was also tested by Meyer (2004) for their ability to resist vertical loading and repeated installation and removal. He concluded that the supplemental adhesive was easily applied and the strips were more difficult to remove but still could be removed by a single person. Additionally, there were no detrimental effects from loading on their ability to retain their shape. He also recommended that the strips could be reused several times by using additional supplemental adhesive.

TABLE 2.1
Previous orange rumble strips tests configuration and results

Year	State	Test Configuration	Evaluations/Findings
2000	Iowa	Thickness: 0.125 inch; 0.25 inch Width: 4 inch # of Strips: 5–7 Spacing: 2, 4 ft	The 0.125 inch thick strips did not provide an adequate rumbling sensation, but the 0.2 inch thick strips were effective in providing adequate sound and rumbling sensations to both passenger cars and pickup trucks, but did not provide a statistically significant rumbling sensation to commercial trucks.
2000	Kansas	Thickness: 0.125 inch; 0.25 inch Width: 4 inch	The 0.25 inch thick strips were an effective warning device when compared to strips composed solely of raised asphalt bumps.
2000	Missouri	Thickness: 0.125 inch Width: 4 inch # of Strips: 6 Spacing: 2, 5 ft	The tested strips were shown to increase the distribution of speeds while reducing the percentage of traffic traveling within the 10 mph pace. It was also found that the strips encouraged drivers to preemptively leave the closed lane ahead of the taper.
2001	Texas	Thickness: 0.125 inch Width: 4 inch # of Strips: 6 Spacing: 18 inch	The test showed a greater impact was observed on trucks than passenger cars, reducing the average truck speeds by up to 7.2 mph, while reducing passenger car speeds by less than 2 mph. They also found that motorists would occasionally drive around the rumble strips to avoid hitting the strips.
2005	Wisconsin	Thickness: 0.25 inch Width: 4 inch # of Strips: 5–6 Spacing: 2–5 ft	The rumble strips were not shown to be a more effective warning device than cut-in-pavement rumble strips when traversed at 55 mph, and were completely ineffective when traversed at 40 mph.

Another test in Missouri (Sanford et al. 2001) found that there may be both an increase in the standard deviation of speed and a reduction in the percentage of traffic traveling within the 10 miles per hour pace. They also found that the ATMs could be used in an interstate highway construction zone when applied to dry pavement with a 200-pound roller. If one-way traffic was being reduced from two lanes to one lane, the rumble strips could be expected to encourage earlier merging (preemptively abandoned the closed lane ahead of the taper) and to reduce speeds slightly. The primary costs of the ATMs included the material, several hours of labor for installation and removal, and any additional traffic delay or hazard caused by the temporary lane closures required for installation and removal.

Fontaine and Carlson (2001) in Texas also evaluated the effectiveness of ATMs on two-lane rural roads with a 70 mile per hour posted speed limit. The thickness of the rumble strips used were 0.25 inches, the width was 4 inches, and 6 strips spaced at 18 inches on center. They found that the ATMs had a greater impact on trucks than passenger cars, reducing the average truck speeds up to 7.2 miles per hour. Passenger cars experienced mean speed reductions of less than two miles per hour. They also noted that the installation time for these rumble strips was seemingly excessive and recommend their use only in rural maintenance work zones. Although the rumble strips could be simply peeled off the road surface, they noted, if the surface of the road was not clean, or if it was composed of loose pavement, some debris could still be attached to the back of the rumble strip. In these cases, the rumble strips were not reusable. In addition, they also found that motorists would occasionally drive around the rumble strips to avoid hitting them. These vehicles moved into an oncoming traffic lane in order to go around the rumble strips. It is possible that these maneuvers could be hazardous in locations with high volumes or limited visibility.

Another research project in Wisconsin (Horowitz, Notbohm 2005) was conducted to identify the optimal design of the 0.25 inch thick ATMs in work zones. The project involved a focus group and a psychological scaling experiment, where each subject was asked to evaluate a temporary rumble strip relative to a cut-in-pavement rumble strip. In addition, sound and vibration measurements were made from within a vehicle passing over the strips. They concluded the ATMs were as effective as cut-in-pavement rumble strips as a warning device when traversed at 55 miles per hour, however the ATMs were ineffective when traversed at 40 miles per hour. They also commented that three-foot spacing was optimal for the test vehicle, and that the louder sounds observed at this spacing might not carry over to other vehicles, which could be considered a positive result.

2.1.3.1 The Rumbler

The Rumbler is a product of Swarco Industries (2010) and consists of several plastic strips between 4 to 6 inches wide, 4 to 6 feet long, and between 0.15 and 0.25 inches high. The plastic used is a mixture primarily of polymer resins and glass beads and is available in three solid colors. The Rumbler was glued to the pavement along a set of lines such that a vehicle's tires would hit several strips within a short time interval as shown in Figure 2.2. The Rumbler was advertised to produce an 80 decibel (dB) warning audible to vehicular interiors at speeds between 30 and 55 miles per hour.

FIGURE 2.2
The installation of rumbler (Horwitz 2002)

Table 2.2 summarized the previous test configuration and results for several Rumbler installations. Tests of the Rumbler in Wisconsin (Horowitz 2002) indicated that the Rumbler was designed to be more permanent in nature and so was more time-consuming to install than other temporary devices. Additionally, it was concluded that the Rumbler was much quieter than a conventional cut-in-place in-pavement rumble strip. The Rumbler also produced considerably fewer vibrations in the test automobile, and although the Rumbler’s sound was qualitatively different and louder than road noise, it did not elicit a practical behavioral response from drivers.

TABLE 2.2
Previous rumbler test configurations and results

Year	State	Test Configuration	Evaluations/Findings
2002	Wisconsin (Horowitz 2002)	Thickness: 0.125–0.25 in. Width: 4 in. # of Strips: 12 (cover wheel area) Spacing: 7 ft Color: white	The Rumbler was much quieter than conventional cut-in-place in-pavement rumble strips. It was designed to be more permanent and was somewhat more difficult to install.
2002	Kansas (Meyer, Walton 2002)	Thickness: 0.25–0.75 in. Width: 6 in. # of Strips: 12 (cover wheel area) Spacing: 2 ft Color: black	The Rumbler performed comparable to the cut-in-place in-pavement rumble strips with respect to sound and vibration inside the vehicles.
2002	Missouri (Manjunath et al. 2002)	Thickness: 0.25–0.375 in. Width: 6 in. # of Strips: 12 (cover wheel area) Spacing: 2 ft Color: black	Reductions in both mean speed and standard deviation of speed were not consistently present during tests. The Rumbler should not be expected to reduce speed nor speed variability on multilane highway work zones.
2009	Florida (McAvoy et al. 2009)	Thickness: 0.25–0.375 in. Width: 4 in. # of Strips: 6 (cover wheel area) Spacing: not available Color: White	Was more effective when they were placed closer to the work zone. The Rumbler produced a speed reduction of over 8 mph in comparison to those locations without rumble strips.

A test of 0.75 inch thick Rumbler in Kansas (Meyer, Walton 2002) found that the Rumbler performed comparably well to the asphalt rumble strips with respect to both sound and vibration inside vehicles. Slightly higher sound levels were observed at the roadside. It was demonstrated that the Rumbler could be reused without significant loss of performance. The Rumbler also proved to be secure, remaining affixed to the pavement for six weeks with the only failures occurring as a result of improper installation.

The other test in Missouri (Manjunath et al. 2002) concluded that reductions in both mean speed and standard deviation of speed were not consistently present with the Rumbler. They recommended that the rumble strips should be able to be placed in a reasonable amount of time and could remain visible and attached to the pavement for several months. However, the desired reductions in speed and speed variability did not occur. The authors also noted that the

Rumbler should not be expected to reduce speed or speed variability on multilane highway work zones.

A comparative parallel study (McAvoy et al. 2009) revealed that travel speeds were not significantly different at 5,500 feet upstream of the work zone regardless of whether or not the adhesive-based temporary Rumbler was placed. At 600 feet upstream of the work zone, the Rumbler produced a speed reduction of over eight miles per hour in comparison to those locations without rumble strips. This reduction was more effective when they were placed closer to the work zone and when there were several sets of rumble strips placed in succession.

2.1.3.2 Recycled Technology (RTI)

This type of rumble strip was produced by Recycled Technology (2009) and were in 0.75 inch thick, 6 inch wide, and distributed in 5 foot lengths having a 45° bevel on all sides. They were manufactured from recycled tire rubber, and include several suggested installation options, including various adhesives options too.

A closed course test in Wisconsin (Horowitz, Nothbohm 2005) concluded the RTI product was an effective warning device for vehicle speeds between 10 and 40 miles per hour. They also found that the spacing between strips was relatively unimportant. However, the other test in Kansas (Meyer 2001) stated that a single RTI strip alone was not heavy enough to remain in place without adhesives under traffic traveling at highway speeds. The test also noted that the adhesives provided would not be suitable for very short-term applications, either because of the damage likely to be done to the pavement upon removal or because the set time for the adhesive was too long to be practical.

2.1.3.3 Steel Rumble Strips

A prototype steel rumble strip 2 inches wide and 1.25 inches high was tested by Meyer for movement and uplift (2006), and was subsequently reevaluated by Heaslip et al. (2010). Each strip was comprised of 24 steel elements strung together with wire cable, comprising a nominal unit length of four feet. While the system showed promise, it never moved beyond the prototype stage, thus there were insufficient units available for this study.

2.1.3.4 Portable Plastic Rumble Strips

Portable Plastic Rumble Strips (PPRS) were removable and reusable temporary portable rumble strips produced by Plastic Safety Systems Industries (2009). The standard size of PPRS is 11 feet long, 12 inches wide, 13/16 inch thick, and weighing 105 pounds. No fasteners or adhesives were required for installation. This system was designed for quick installation and removal, and was intended for repeated use. In February 2009, PPRS received a second place "Innovation Award" from the American Traffic Safety Services Association.

Schrock et al. (2010) tested the sound and vibration generated by PPRS in various configurations of both number of strips and spacing between strips. They found that the PPRS were more effective in generating in-vehicle vibration and increasing the in-vehicle sound level in cars than in trucks. The configurations with four strips were found to sufficiently generate similar vibration and sound levels as permanent cut-in-place in-pavement strips for both heavy trucks and passenger cars. The movement and vertical displacement test results revealed that the earlier generations of PPRS did not perform as well as the fourth generation especially at 60 miles per hour (Heaslip et al. 2010).

The PPRS have also been demonstrated to many state transportation agencies, including Maine, Ohio, and Minnesota, according to the Plastic Safety Systems Industries website (Plastic Safety Systems Industries). A field test in Missouri (Missouri Department of Transportation 2009) found that the PPRS could reduce speeds by 5 to 10 miles per hour. An increase in driver attentiveness resulting from the audible and vibratory alerts was suggested to offer increased safety to workers in work zones. However, the Missouri field tests on the product were limited and resulted in a conclusion that additional field testing was necessary to ultimately determine the potential for this product.

2.2 Intrusion Alarms Devices

2.2.1 Features

Intrusion alarms are a technology which utilized one or more sensors mounted on typical work zone barriers such that when an errant vehicle contacts a sensor, an alarm would be tripped to warn workers that their protective zone had been violated. The concept of such systems was that the alarm mechanism would sufficiently warn workers with enough reaction time to move out of harm's way. The alarm could also possibly alert a distracted or drowsy driver and permit them to steer clear of the work zone and/or brake prior to reaching workers or their equipment.

The original intrusion alarm devices were developed by the Strategic Highway Research Program (SHRP) which incorporated ultrasonic and infrared beam technologies in 1990 (Hatzi 1997). Three types of alarms were available at the time of the SHRP research. Two types utilized microwave and infrared wireless technology in respective models that mounted on work zone barriers and used either microwave signals or beams of infrared light to connect to base units (Figure 2.3). When a vehicle crossed into the work zone and interrupted the signal or beams, a high-pitched alarm was sounded by the base station near the workers. A third type utilized pneumatic tubes placed on the ground such that the tubes were laid around the working area (Figure 2.4). When a vehicle drove into the area and over the tubes, an alarm sounded.

FIGURE 2.3
The installation of microwave intrusion alarm (Hatzi 1997)

FIGURE 2.4
The installation of pneumatic tube intrusion alarm (Hatzi 1997)

More recent products included the SonoBlaster Dual Alert Work Zone Intrusion Alarm (The National Work Zone Safety Information Clearinghouse) and Safety Line Intrusion Alarm System (Kochevar 2002). The SonoBlaster device is shown in Figure 2.5. It is an impact-activated device that warns work crews and errant vehicle drivers simultaneously to help prevent crashes and injuries in work zones. Attached to a standard traffic cone, the SonoBlaster emits a horn alarm when tipped over.

2.2.2 Product and Evaluation

There were no established state policy/guidelines on the use of safety intrusion alarms in work zones at the time of this research. Trout and Ullman (1997) in Texas summarized the application and test results of three types of intrusion alert devices used by several states. For microwave intrusion alarms, they pointed out that many states have had difficulty in using the microwave intrusion alarms and indicated that their setup time was lengthy, the strobe lights were neither bright enough nor were sirens loud enough, and initial alignment of the units was considered to be problematic. The report also noted that false alarms were observed in many states and appeared to be created by rain, dust, and barrier movement.

FIGURE 2.5
The installation of SonoBlaster Intrusion Alarms Devices (The Transpo Group 2010)

For infrared units, several states indicated that the unit was too sensitive, which created numerous false alarms. Due to the difficulty in aligning the beams, the infrared intrusion alarms were used only for stationary operations. Also, it was noted that on hot days when traffic cones became more flexible, thusly not able to support the increased weight of reflectors, an increase in false alarms was observed. For pneumatic tube systems, several states have reported that the system does not provide enough warning time for workers to respond, and that the setup time is excessive. There were also questions about the durability and dependability of the system as the pneumatic tubes were easily punctured by heavy equipment and required air pressure boosters after several hundred feet to ensure that sufficient air pressure was available to activate the system.

According to a 1997 article in *The Bridge* (Hibbs), the states of New York and Washington have done extensive evaluation of these SHRP-developed intrusion alarm devices.

In Washington, all devices, with the exception of the infrared-triggered device, passed tests for warning workers whenever intrusion occurred. They also found most of the alarm systems to be user friendly and easy to set up. However, one consistent observation was that the devices did not produce a loud enough warning for workers to consistently hear the sound over the already-present traffic and construction sounds.

Survey results in New York showed that 88 percent of work crews liked the concept and were interested in purchasing intrusion alarms. During the field evaluation period, errant vehicles set off the intrusion alarms several times, but none of the vehicles entered the work area. The alarms made the crews aware of just how many near-misses occur. The preferred model among New York State Department of Transportation crews used microwave beams to monitor the boundary of the work zone. The device covered a large area and included an optional radar drone, which sent a false signal to drivers' radar detectors, prompting them to slow down. There was some concern that items such as switches, solar panels, lights, etc., may not be rugged enough to withstand the field conditions under which the devices would be used.

On the opposite side of the country in California, the state's Department of Transportation also tested both infrared and microwave based safety intrusion alarms in their work zones. The devices were used informally in field trials and were not perceived to be very effective, and were subject to creating periodic false alarms. However, no official reports were available on the field trials, but oral accounts from work crew members were not at all positive about their use.

The Federal Highway Administration (FHWA) has disseminated SonoBlaster intrusion alarm devices to several states for a demonstration project (FHWA Resource Center 2007). The demonstration project's interim report (Kuta 2009) included the following specific comments about the SonoBlaster system including:

- Cones with [SonoBlaster] units are not easily stored
- Too much time to set up and take down, setting off unit if not careful
- Arming the unit is difficult
- Difficult to verify unit is armed
- It is not loud enough

The suggested usages of the SonoBlaster System were:

- Low speed roads
- Warehouse blind spots
- Gas tanker offloading spaces

Although the intrusion alarms system can ideally alert workers when any vehicle intrudes into their work zone, the problems with these systems are evident and numerous. For instance, most work zones are very noisy due to traffic, wind, and/or heavy construction machinery. The workers and/or flaggers are unlikely to be able to hear an audible warning over the noise. Also at issue was the number of times a system would be unnecessarily activated (referred to as a “false positive”). Such false positives have the potential to cause workers to ignore the system altogether, thus negating the point of having it in the first place. Another shortcoming is that some systems utilize a single detector upstream from the work zone, thus it is possible for vehicles to enter the work zone without activating the detector (a false negative). Furthermore, the heat and audible noise produced by work zone equipment and vehicles passing by have been shown to interfere with infrared and ultrasonic detectors, thus also causing false positives. Moreover, the distance between the detector and the siren necessitated a wireless data link. Modern work zones are flooded with electromagnetic noise within the popular communication frequencies which could interfere with signal communication.

2.3 Portable Message Signs and Driver Interactive Devices

Portable driver interactive devices include portable changeable message signs (PCMS), portable speed monitoring displays (PSMD), vehicle activated signs (VAS), and radar drone systems (RDS). These devices have all been used alone or in various combinations as part of temporary work zones in the surveyed states to warn drivers to reduce their speeds.

2.3.1 Portable Changeable Message Signs

2.3.1.1 Features

PCMSs are moveable traffic control devices that are designed to display a variety of messages, such as words, numbers, or symbols, to inform motorists of unusual driving conditions. The variety of messages the signs could display are limited only by the size of the sign (usually three lines with eight characters per line) and its resolution (for displaying symbols). Thus the signs require precisely designed phrases that are in accordance with the federal regulations ascribed by the *Manual on Uniform Traffic Control Devices*. PCMSs could be mounted on a trailer or on a truck bed so that they could be quickly deployed for meeting the temporary requirements common to many work zones.

Standards that apply to PCMSs were found in the *Manual on Uniform Traffic Control Devices* (MUTCD) (FHWA 2009). The basic guidelines for the use of PCMSs were found in the *Portable Changeable Message Signs Handbook* (FHWA 2003). The handbook presented information on PCMSs and was intended to illustrate the principles of proper PCMS use. Guidelines issued by state transportation agencies were available for Texas, Florida, Minnesota, North Carolina, and Oregon (Ullman et al. 2005).

FIGURE 2.6
The installation of a portable changeable message sign in Texas (Texas Transportation Institute 2004)

2.3.1.2 Evaluation

PCMSs were found to be most commonly utilized to encourage and direct traffic to transition out of one or more closed lanes upstream of a work zone. A 1985 study found that placing such a sign in advance of a work zone could reduce motorist speeds by three to five miles per hour on rural freeways and zero to two miles per hour on urban freeways, and three miles per hour on an undivided multi-lane urban arterial (Richards et al. 1985). Similarly, when supplemental lane closure warning signs and variable message signs were placed before the merge taper, the percentage of vehicles in the closed lane was reduced from 22 to 11 percent at a location 0.1 mile upstream of the taper (Pigman, Agent 1988). However, Richards and Dudek (1986) commented that PCMSs resulted in only modest speed reductions (less than 10 miles per hour) when used alone and would lose their effectiveness when operated continuously for long periods with the same messages.

In Illinois, Benekohal and Shu (1992) observed the effectiveness of placing a single PCMS in advance of several work zones. The speed reductions observed were statistically significant, in general. However, they were not considered to be practically significant for reducing average truck speeds because the average speed reduction was only 1.4 miles per hour due to placing the PCMS. However, the PCMSs reduced speeds in 20 percent of vehicles that were exceeding the speed limit, indicating they can be effective in reducing speeds in the fastest drivers. In Virginia, Garber and Patel (1994) and Garber and Srinivasan (1998) evaluated the effectiveness of having PCMS with radar, which can automatically display real-time warning messages specifically to speeding drivers. Their studies concluded that this type of PCMS activation was a more effective means than traditional work zone traffic control devices in reducing the number of speeding vehicles in work zones. However, Huebschman et al. (2003) argued that PCMSs displaying the number of tickets were actually no more effective than static signage. They examined the effects of the fixed panel signs and PCMS signs in advance of the construction work zones. The results found that the speed reduction was associated with the installation of the fixed panel signs, rather than with the installation of the PCMS displaying the number of tickets to date.

Zech et al. (2008) evaluated the effectiveness of three commonly used PCMS messages for speed reductions in highway work zones. The three types of PCMS messages tested were the following: (i) RIGHT|LANE|CLOSED ~ KEEP|LEFT, (ii) WORK ZONE|MAX SPEED|45 MPH ~ BE|PREPARED|TO STOP, and (iii) LEFT|LANE|CLOSED ~ KEEP|RIGHT. A field study showed that of the three PCMS messages tested, the second PCMS message proved to be the most effective, significantly reducing vehicle speeds by 3.3 to 6.7 miles per hour. They concluded that properly selected PCMS message wording can be effective in reducing speeds of all classes of vehicles in highway work zones.

Firman et al. (2009) in Kansas also assessed the effectiveness of PCMS installation scenarios on speed reduction. The researchers examined the speed changes that occurred on rural highways when PCMSs were present but not active, and present and active compared to when no sign was present at all. The field data showed that when PCMSs were activated they reduced the vehicle speeds significantly compared to when they were not active but still visible; when the PCMSs were switched on, they reduced vehicle speeds by 4.7 miles per hour over a 500 feet long distance on average. The 4.7 miles per hour speed reduction compared the speed before and over the sign, a distance of 500 feet compared to when the sign was present but not active. The speed reduction without PCMS on site was 1.9 miles per hour, so an additional 2.8 (4.7 to 1.9) miles per hour speed reduction was achieved by activating the signage compared with no PCMS present.

When the PCMSs were turned off but still adjacent to the roads, vehicle speeds were reduced 3.3 miles per hour over a distance of 500 feet. When the PCMS was absent from the road, a 1.9 miles per hour speed reduction occurred over a distance of 500 feet. An additional of 2.8 and 1.4 miles per hour of speed reduction was found when the PCMSs were turned on and were turned off, respectively, compared to when no PCMSs were placed.

2.3.2 Radar Portable Speed Monitoring Display

2.3.2.1 Features

The Portable Speed Monitoring Display (PSMD) system was developed in the late 1980s to reduce vehicle speeds within work zones for added safety and traffic control. The system consists of a portable self-contained trailer unit equipped with a radar drone to measure the speeds of oncoming vehicles. It also employed a variable speed display panel which displayed the speed of each oncoming vehicle. The system also could be implemented as a portable sign without an attached trailer unit as shown in Figure 2.7.

FIGURE 2.7
The installation of a portable speed monitoring display sign (Speed Check 2010)

2.3.2.2 Evaluation

A study in South Dakota (McCoy et al. 1995) examined the effectiveness of trailer mounted PSMDs in rural interstate work zones. The study indicated that the PSMDs reduced mean vehicle speeds by 4 miles per hour (i.e., from 60.5 to 56.5 miles per hour). The percentage of passenger cars speeding through the work zone was reduced by 20 to 25 percent. The percentage of speeding trucks was also reduced by approximately 40 percent. In another study in California, Bloch (1995) compared the speed reduction effects of PSMD (both with and without police enforcement) with those of photo-radar systems. The photo-radar employs radar to detect speeding, automatically takes photographs of speeding vehicles, and issues their drivers citations by mail. The study found the PSMD reduced mean speeds by 6.4 miles per hour alongside the devices and 3.2 miles per hour downstream from the devices, respectively. The study concluded that PSMDs without enforcement are cost-effective speed control treatments.

Fontaine and Carlson (2001) evaluated the effectiveness of PSMDs at a short-term work zone on a four-lane divided highway in Texas. The speed display signs used were radar-activated to show the speed of approaching vehicles. The study found that the display created speed reductions of about five miles per hour within the work zone as compared with static traffic control only. Fontaine and Carlson (2001) also evaluated in another study the effectiveness of PSMDs in reducing speeds on two-lane, low volume, high speed, rural maintenance work zones. The results showed PSMDs were generally effective at reducing speeds in the advance warning area. Mean speeds were often reduced in advance of the work zone with speed reductions of up to 10 miles per hour being achieved. The percentage of vehicles exceeding the speed limit was also reduced in the advance warning area.

Pesti and McCoy (2001) evaluated in Nebraska the long-term effectiveness of PSMDs. Three PSMD were deployed for a five-week period along a 2.7 mile roadway section between two work zones on I-80 near Lincoln, Nebraska. The results found that the PSMDs were effective in lowering speeds, increasing the uniformity of speeds, and increasing speed limit compliance over the five-week period. One week after the removal of the PSMDs, there were still statistically significant speed reductions and compliance increases, although they were less than observed during the deployment.

2.3.3 Vehicle-Activated Signs

2.3.3.1 Features

Vehicle-activated signs (VASs), similar to PCMSs, dynamically display messages corresponding to road conditions. Historically, these signs have been used to display speed limits and to provide curve and intersection warnings. As with PCMSs and PSMDs, the primary assumption was that drivers can be influenced to decrease speeds when they are specifically targeted.

FIGURE 2.8
The installation of vehicle activated sign (Mattox III et al. 2007)

2.3.3.2 Evaluation

Benekohal and Linkenheld (1990) examined the speed reduction effects of an audible system at a work zone in Illinois. The system consisted of a radar unit, which activated a horn when approaching vehicles exceeded a speed threshold. Speed data were collected for 118 vehicles and indicated an average speed reduction of 9.7 miles per hour for vehicles that activated the horn. The study indicated that the horn system may produce slight speed reduction effects; however, the noise generated and human factors considerations may limit any application of this device to very special cases.

Mattox III et al. (2007) also evaluated VASs applied in work zones. Data were collected in work zones on two-lane primary and secondary highways in South Carolina, and the effectiveness of the tested speed-activated sign was evaluated on the basis of changes in mean speeds, shifts of the 85^{th} percentile speeds, and percentages of vehicles exceeding the speed limit. Mean speed reductions ranged from 2 to 6 miles per hour with an average reduction of 3.3 miles per hour. This average reduction improved to 4.1 miles per hour at sites where more than 50 percent of the vehicles were speeding before a sign was introduced.

2.3.4 Radar Drone Systems

2.3.4.1 Features

The use of radar drones in work zone is intended to trigger radar detectors, causing drivers to reduce their speed. A radar drone is a device designed to simulate a police officer using a radar gun, but without the police officer present. Thus this is a device designed explicitly to mislead motorists using radar detectors into possibly believing that a police officer was present in the work zone with the intent that under such a supposition they would slow down to the posted speed limit. Such devices could be mounted on construction vehicles, signs, or otherwise placed to blend in to the roadway scene. Assuming that drivers using radar detectors tend to travel faster than the mean, this would reduce not only the mean speed but also the variation in speeds. An example of a brand of radar drones (Cobra XT 1000 Safety Alert Warning System) and the installation in the field is shown in Figure 2.9.

FIGURE 2.9
Cobra XT 1000 safety alert warning system attached to mounting structure in the field (Eckenrode et al. 2007)

2.3.4.2 Evaluation

In Texas, Ullman (1991) conducted an experiment on the effectiveness of using radar drones to reduce speeds in work zones. In this study, the radar drone effectiveness was examined at work zones on suburban and rural divided highways and on suburban interstates. Ullman performed the study in 30 to 45 minute segments throughout the day and compared the data with the next 30 to 45 minute period to provide comparison data throughout the day. Average speed reductions for all eight sites were reported to be between 0.2 and 1.6 miles per hour when the radar drone was active. They further analyzed the data to determine if the fastest motorists were indeed the most likely to be affected by drone radar. The average speed reduction for vehicles traveling greater than 65 miles per hour at 3,000 feet upstream of the work zone was compared with that of all vehicles. The speed reduction for this speeding group of motorists was determined to be 0.2 to 2.6 miles per hour greater than the average speed reduction for all vehicles once inside the work zone.

In Illinois, Benekohal et al. (1992) studied the effectiveness of radar drones in a rural interstate work zones. Three experiments were conducted with radar drones to determine immediate, short-term, and lasting effects while using multiple drone radar units. The first experiment was conducted for less than an hour, with one drone radar operating from a stationary vehicle near the merge area. This experiment was effective in reducing mean speeds by 8 to 10 miles per hour. However, the second experiment, conducted for a few hours using one radar gun, indicated no speed reductions. The study team monitored the CB radio conversations. They discovered that motorists were quickly able to determine that no police were present in the work zone, and that the radar emissions were drone radar. The motorists were even able to determine the location of the drone radar. In the third experiment, two radar drones were used from different locations for three hours. The study indicated that this modification increased the effectiveness of the radar drones, as motorists were unable to determine the location of the radar signals. In this case, speeds were reduced by three to six miles per hour for trucks and by three miles per hour for cars.

In Michigan, Streff et al. (1995) extensively examined the effectiveness of radar drones with and without the presence of a police car on high-speed freeway locations and in freeway construction zones. They found the effect of the drone radar on general vehicle speeds, although statistically significant, was found to be typically less than 1.5 miles per hour and of little practical difference. A speed reduction effect of drone radar on high speed trucks was found. The percentage of trucks exceeding the speed limit by 10 miles per hour in the passing lane decreased between 30 percent and 70 percent. The findings of the study indicate that drone radar with police patrols can serve as a speeding countermeasure at locations where high speed trucks are a problem. They also investigated the usage of radar detectors and found the percentage of vehicles using radar detectors was estimated at about 5 percent of cars and more than 16 percent of trucks.

In Kansas, Meyer (2000) used two radar drone units in a rural interstate work zone where traffic was limited to one lane in each direction for a reconstruction project. Speed data were collected at several locations over about a one-mile segment for a week prior to deployment and a week following deployment. Several speed differences observed between the before and after data were statistically significant, but the differences were inconsistent. In some locations the speeds decreased after deployment, and in other locations they increased. No explanations for the changes could be identified, but their inconsistency suggested that the radar drones were of limited use as speed control devices. The data also suggested that radar drones may have caused a small decrease in the 85th percentile speed near the unit, but that speeds increased farther downstream. He concluded that the use of a radar drone did not seem to be an effective device for reducing speeds in highway work zones.

Recently, Eckenrode et al. (2007) summarized previous study results from 1986 to 2007 and also evaluated the effectiveness of the drone radar devices in South Carolina. They found the drone radar devices reduced the mean speed by two miles per hour; however, vehicles equipped with radar detectors reduced their speeds on average between from five to eight miles per hour. The drone radar also caused 85th percentile speeds to decrease between one and five miles per hour, and reduced the percentage of vehicles exceeding the speed limit.

2.4 Radio Alert System

2.4.1 CB Wizard Alert System

2.4.1.1 Features

The CB Wizard alert system allowed advisory traffic information to be disseminated directly to truck operators over citizen band (CB) radio channels. This system was similar to highway advisory radio systems for traditional motorist information dissemination. The solar-powered, trailer-mounted CB Wizard alert system broadcasted a work-zone alert and information for advance warning about the changing work zone configurations on a CB radio channel. The messages transmitted included information about lane closures, flaggers, and reduced speed limits to hopefully influence drivers to reduce their speed and/or change lanes.

The CB Wizard alert system was designed and patented by Highway Technologies Inc. and was built and marketed by TRAFCON Industries Inc. A picture of the device is shown in Figure 2.10.

FIGURE 2.10
The installation of CB Wizard alert system (Trimarc)

2.4.1.2 Evaluation

A test in Texas found that the CB Wizard alert system was able to effect both truck speeds and lane choices upstream through various types of work zones (Ullman et al. 2002). The CB wizard alert notifying truck operators about the presence of a downstream work zone and a reduced advisory speed limit at the test location resulted in reduced mean truck speeds of about two miles per hour. An alert message encouraging truck operators to use the left lane through another work zone (due to potential soil stability problems under the right lane) yielded significant increases from 55 percent to 78 percent of trucks using the left lane. The study suggested that it can influence both the speed and lane choices of truck operators approaching work zones, but the extent of this influence is heavily dependent upon roadway, work zone site characteristics, and the message broadcast.

A study in Iowa (Kamyab 2000) evaluated the CB Wizard alert system on a rural section of an interstate highway by surveying truck drivers. The Iowa results found that 75 percent of truck drivers surveyed had heard the message, and all of the drivers who reported hearing the message thought this approach was worthwhile with 89 percent of the drivers surveyed believing the message to be effective. Nearly all surveyed (98 percent) stated that they did not consider the message obtrusive or annoying. It was unclear what direct actions were taken by the drivers.

2.4.2 Highway Advisory Radio System (HAR)

2.4.2.1 Features

Highway Advisory Radio (HAR) is a broadcasting system used by transportation agencies to disseminate vital real-time traffic information to motorists. Each transmitter is restricted by the rules and regulations of the Federal Communications Commission (FCC) to an average broadcast radius of three to five miles. Most commonly these transmitters are located at major highway intersections or near major transportation attractions, such that motorists could take alternate routes in case of congestion or emergencies.

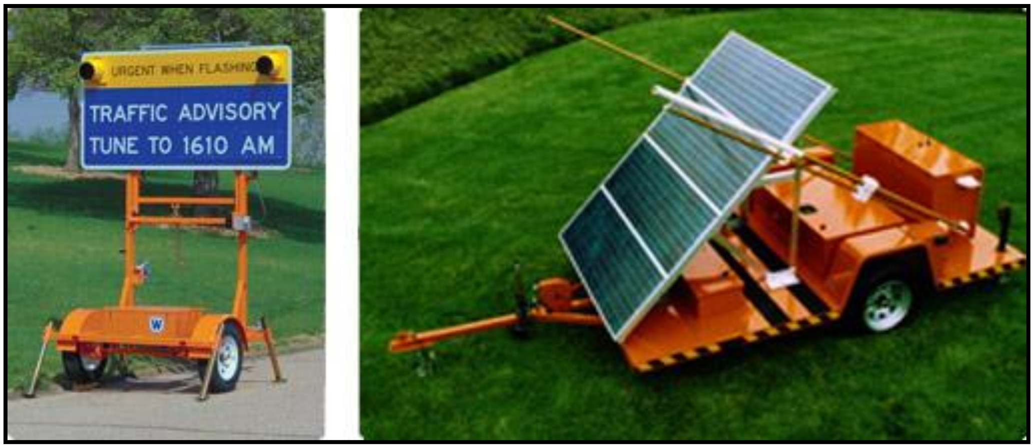

FIGURE 2.11
Highway advisory radio systems (HAR) (Street Smart Rental)

2.4.2.2 Evaluation

An early field study in Texas (Faulkner, Richards 1981) evaluated the use of HAR for traffic management in work zones on a rural interstate highway. The study consisted of lane distributions, volume and vehicle classification counts conducted before and after the installation of the HAR. A questionnaire was administered to motorists observed traveling through the work zone, and the results showed that the HAR had little or no effect on traffic operations in the work zone because of two factors. First, the conventional signage at the work zone was perceived to be excellent and the HAR functioned only as a supplemental source of information. Secondly, the advance signage used to encourage motorists to tune to the HAR broadcasts had legibility and visibility limitations. Almost 40 percent of the motorists who entered the work zone reported that they did not even see the signage. Even though the HAR system did not significantly affect traffic operations in the work zone, the study indicated that HAR could have positive potential for traffic management in work zones in certain conditions, such as for detours. The HAR hardware performed adequately, and generally speaking, motorists were satisfied with the quality of the broadcasts and supportive of this innovative approach to traffic management in work zones.

According to research in Washington (Washington State Department of Transportation 2007), trailer mounted portable HAR units have enjoyed great success over the past few years when integrated into construction projects with high driver interest due to traffic impacts. Timely accurate messages have received positive comments from drivers.

2.5 Positive Protection Devices

2.5.1 Truck Mounted Attenuators

2.5.1.1 Features

Truck mounted attenuator (TMA) are an attenuator or crash cushion mounted on the rear of a work zone truck that dissipates the energy of a rear-end collision. The purpose is to direct traffic to an open lane in advance of a road work site to provide safe working environment for workers, but able to withstand rear-end collisions with it. Similar to truck-mounted devices, trailer-mounted attenuators also be can be used on a shadow vehicle on a project-specific basis to protect workers and the shadow vehicle driver. The TMAs were standard traffic control devices which were being regularly used in advance of short-term, long term, and moving work zones. Standards and requirements for TMAs are found in the MUTCD (FHWA 2009) and the *Field Guide for the Use and Placement of Shadow Vehicles in Work Zones* (FHWA 2010).

2.5.1.2 Evaluation

A study in Tennessee on the effectiveness of TMAs indicated that they saved about $23,000 per crash and also reduced damage to the maintenance truck (Humphreys, Sullivan 1991). The study showed that the injury rate was higher for maintenance vehicles that were not equipped with TMAs. Also, the cost of crashes where no TMAs were used was considerably higher than those where a TMA was impacted.

A field study in New Zealand (Smith et al. 2006) reported that positioning an advance warning system, such as horizontal arrow signs or skewed arrow panel, 400 meters (1,312 feet) upstream from a TMA outperformed any other practice, resulting in 27 percent fewer drivers changing lanes in the last 300 meters (984 feet). Recognition distances increased at night when the traffic volumes were lower as compared to recognition distances during the day with higher traffic volumes.

Recognizing that there were several popular color variations for TMAs and related signage in use, several studies focused exclusively on this attribute. A study in Iowa (Kamyab, Storm 2001) evaluated fluorescent yellow-green background colored signs on TMAs against orange colored TMA signs in an effort to determine if the fluorescent yellow-green color would provide additional warning to drivers. The researchers found that the yellow-green color improved the contrast between the orange color of the sign and the orange color of the Department of Transportation (DOT) truck. The study also included a survey of drivers conducted at a rest area during on the visibility of TMA signs with and without the fluorescent background. The survey results indicated that more than 50 percent of drivers identified the enhanced orange sign as a sign seen on the back of truck before reaching the work zone. Additionally, traffic volumes on the left and right lanes were collected using a surveillance trailer. An analysis of the collected data revealed that there was a significant decrease in traffic volumes in the lane where the truck was present after using a TMA with a fluorescent yellow-green background compared with a TMA without the yellow-green color. A similar study in Texas (Hawkins et al. 2000) was conducted to test the visibility of orange, fluorescent orange, yellow, white, and red colored signs on TMAs. Driver recognition distances were collected, and from an analysis of the data, fluorescent colors were shown to have higher color perception accuracy and recognition distances during daylight hours but not during the night. Conversely, Atchley in Kansas (2006) suggested that fluorescent traffic signs have no added advantage compared to non-fluorescent signs and provided proof of this claim by conducting an eye-tracking sensitivity measuring experiment.

More recently, a study in Missouri (Bham et al. 2009) used a driving simulator to evaluate the effectiveness of striping pattern and color combination used in the TMA in the mobile work zoning subjects in a driving simulator. Using lane change distance and speed reduction identification distance as the evaluation criteria, the results indicated that a yellow and black inverted ‘V” pattern and a orange and white vertical striped pattern were more effective than a fluorescent yellow-green and black inverted “V” pattern or a red and white checkerboard pattern. They also surveyed practices for TMAs in work zones from 30 states and found it was found that 22 (77 percent) DOTs use VMAs in work zones because it is a transportation agency policy, and only one agency uses VMA because it is a legislative policy. The yellow and black inverted "V" pattern is most commonly used by DOTs and most of the agencies use VMA patterns as they use the colors and designs provided by the VMA suppliers. Most of the agencies (12, 40 percent) use crash data as the measure of effectiveness to evaluate VMAs in work zones.

2.5.2 Mobile Barriers

2.5.2.1 Features

Mobile barriers are integrated, rigid wall, semi-trailer that is used in conjunction with standard semi-tractors to provide improved mobile and safe work environments for personnel at applicable maintenance, construction, and security sites. It serves as an extended, mobile, longitudinal barrier that provides a physical and visual wall between passing traffic and the maintenance and construction personnel. Mobile barrier systems were designed to provide positive protection for exposed workers who normally work behind temporary cones and barrels in space-limited work areas. One of the drawbacks to this system is that it occupies eight feet of lane width, and does not allow large equipment access into the work zone directly from the rear. An adjacent lane or shoulder must be available for vehicles to access the protected work area.

The mobile barriers system was designed to fit the functional requirement for a highly-portable positive protection system established by the Texas Transportation Institute (TTI) for FHWA (Ullman et al. 2007). The functional requirements are listed in Table 2.3.

TABLE 2.3
Functional requirements of a highly-portable positive protection system

Dimension	Minimum Requirement	Desirable Requirement
Spatial	• The system must be capable of allowing workers to access the entire width of a single travel lane. • The system must adequately protect the typical work area lengths required for mobile and short-duration construction and maintenance activities. Limited observations indicate that these activities are currently accomplished within 20 to 50 foot lengths. • The system must be capable of protecting either side (left or right, depending on the lane where work is occurring) of a work area.	• The system should be capable of accommodating varying travel lane widths from 10 to 12 ft in order to minimize the encroachment of the system into adjacent travel lanes. • The system should be capable of being configured so as to protect both sides of the work area when activities occur in the middle lane of multi-lane roadways.
Accessibility	• While deployed, the system must allow rolling equipment such as thermoplastic and bitumen heaters and hand equipment to be brought into the work area. • Once deployed, the system must continue to allow workers to access truck-mounted equipment and materials (i.e., air compressor hoses, pothole patching material, etc.) normally used in mobile maintenance operations.	None
Mobility	• Once deployed, the system must have the ability to protect a work area that progresses continuously or intermittently along the roadway at speeds less than 3 mph.	• The system should be deployable into a travel lane in less than 30 minutes. • The system should be capable of being picked up and ready for transport to another location for deployment within 30 minutes.
Transportability	• When configured in its "transport" mode, the system must operate within the design template of a WB-50 (semi-tractor trailer) design vehicle with regards to horizontal and vertical clearances, turning path radii, vehicle hang-up potential, etc.	None
Traffic Control and Illumination	• The system, when deployed, must comply with the *MUTCD* with regards to delineation and warning light requirements for on-roadway work equipment. • The deployed system must have rear-end crash protection.	• The system should be flexible enough to accommodate special flashing warning light and delineation requirements for work equipment as defined by each state's motor vehicle code, Department of Transportation special vehicle warning light and delineation policies, or similar local requirements. • The system should be capable of accommodating artificial lighting that may be needed in the work area at levels defined by AASHTO guidelines (Gibbons et al. 2008; Bryden, Mace 2002; Ellis et al. 2003).

2.5.2.2 Products and Evaluation

Two types of mobile barrier systems are available on the market. The first one is the Balsi Beam (shown in Figure 2.12) developed by the California Department of Transportation in 2001 and tested since 2004. It consists of a tractor trailer combination, with the trailer converting into a 30 foot long work space between the rear axles of the tractor and the trailer with a collapsible and reversible steel beam barrier. The Balsi Beam was designed for activities that were localized, such as bridge deck repairs, bridge rail repairs, and bridge joint maintenance.

FIGURE 2.12
Balsi Beam mobile barrier system (California Department of Transportation)

The Balsi Beam was reported by workers to be a valuable safety asset, as it provided a high level of confidence to workers in protecting them from potential intruding vehicles while working within a few feet of moving traffic. One of the drawbacks to this system was that it did not allow large equipment access into the work zone directly from the rear. An adjacent lane or shoulder was required for work equipment to access the protected work area. This was only a problem on two-lane conventional highways or freeways with very narrow shoulders.

The other mobile barrier system was the Mobile Barrier Trailer (MBT-1, as shown in Figure 2.13) by IWAPI Inc. which was developed in 2007 (Mobile Barriers LLC 2009). The MBT-1 system could provide 42 to over 100 feet of protected work space.

FIGURE 2.13
Mobile Barrier Trailer (MBT-1) System (Mobile Barriers LLC 2009)

A study in Colorado (Hallowell et al. 2009) investigated the potential effectiveness of the application of the MBT-1 in work zones. The study focused particular attention on the benefits and limitations of lighting schemes associated with the MBT-1. The authors concluded that there were some significant advantages to the MBT-1's lighting schemes, programmable message board, crash-tested barrier, and mobility. Because the signage and lighting are integrated onto the MTB-1, they are always in optimal location relative to the work activity.

A field test in New Jersey (Kamga, Washington 2009) concluded that the MBT-1's functional requirements were state-of-the art for positive protection against lateral intrusions into a work zone. It far exceeded expectations to protect workers from bodily injuries caused by errant vehicles and also protected drivers from possible injuries with its ability to absorb crash energy by crushing upon impact and its integrated TMAs. The report also mentioned that the truck's mobility, both to the site and on the site, was another attractive feature when considering the implementation of this equipment on a given road construction project, likely due to the shorter setup time compared to more traditional traffic control devices. It should also be noted that use of the MBT-1 required pre-planning as it had to be manually converted between left and right side work zone operations. Finally, the study noted that the best application of the device was on straight roadway sections without ramps in the work zone.

2.6 Intelligent Transportation System Integrations

2.6.1 Adaptive Queue Warning Systems

2.6.1.1 Features

The adaptive queue warning system is intended to provide distributed speed-advisory signaling which automatically adapts to the current traffic flow situation in the work zone. The core element of such a system was a smart barrel—an ordinary appearing traffic control barrel containing an inexpensive speed sensor and equipped with a simple display and the necessary equipment for communication to a central controller. As shown in Figure 2.14, the system is primarily based on the notion of a smart barrel, a device similar in appearance to today's work zone traffic-control barrel but containing a short-range traffic speed sensor, a simple but adjustable signaling device and short-range communication equipment for interfacing with a supervisory computers (Sullivan et al. 2005). Such smart barrels could be distributed in large numbers and at relatively short intervals throughout the work zone—as ordinary traffic-control barrels are distributed. The distributed traffic-speed data would be received and processed by the supervisory computers to provide rapid, real-time adaptation of the distributed signals as appropriate for the existing speed differential throughout the work zone.

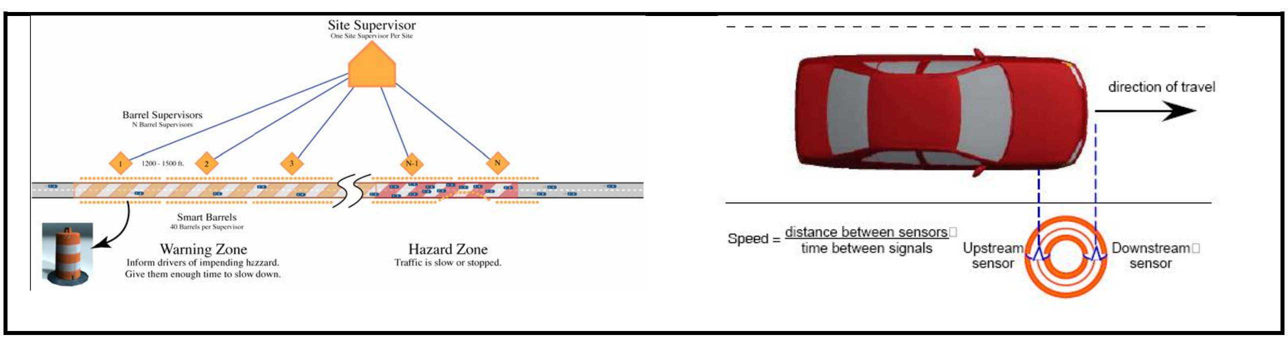

FIGURE 2.14
Adaptive queue warning systems

2.6.1.2 Evaluation

Sullivan et al. (2005) developed a work zone safety ITS concept around the smart barrel idea. Their study focused on initial investigations of two critical elements of such a system: (1) an inexpensive, but sufficiently capable speed sensor and (2) a simple but effective signage system. Three prototype speed sensors were developed and evaluated in a limited field study. They used active infrared, passive infrared, and magnetic sensor technologies, respectively. The active infrared system was found to be the most accurate but consumed the most power, an important factor for a device that would be battery powered in the field. The passive infrared system was nearly as accurate and required the least power of the three prototypes.

Simple signage schemes using a series of pole-mounted warning lights were also prototyped and presented to drivers in a pilot experiment using a driving simulator, as illustrated in Figure 2.15. Both subjective opinions about the utility of the system and objective measures of driving performance were collected. Results suggested that drivers found the adaptive queue warning systems more helpful than static road signs.

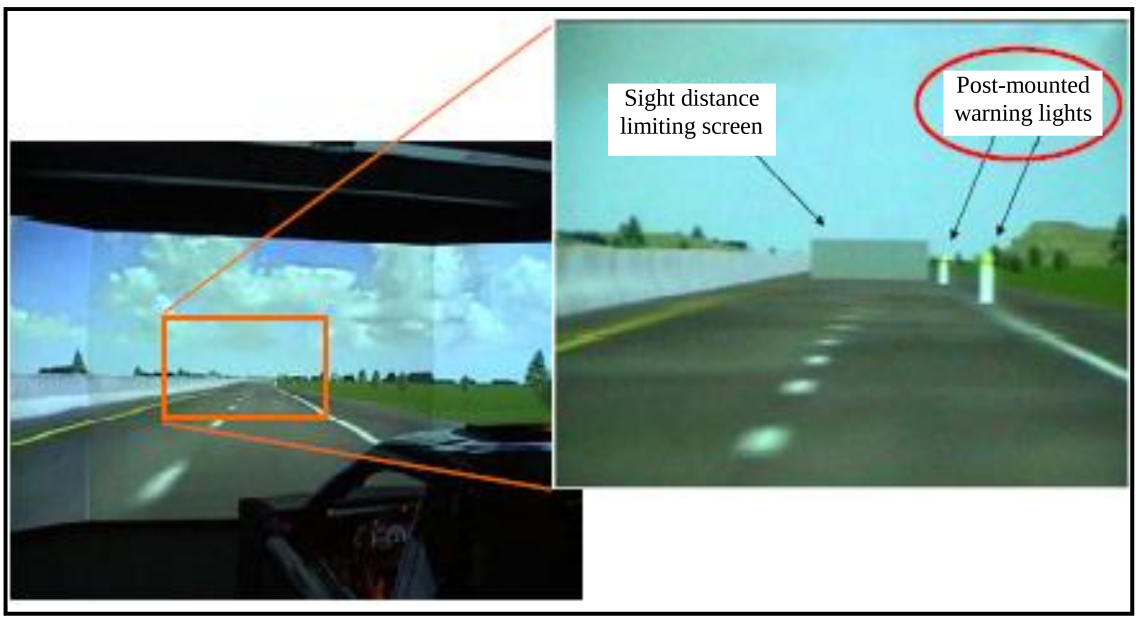

FIGURE 2.15
Driving simulator test of post-mounted warning lights (Sullivan et al. 2005)

Pesti et al. (2007) evaluated the effect of two other queue warning systems in work zones in Texas. One system was deployed on I-610 and another system on US-59 in Houston, Texas. The queue warning system used video detection to determine vehicle speeds in all freeway lanes. The video detection system included video cameras mounted on sign bridges and an Autoscope unit with image processing software that was able to detect each vehicle and determine its speed in all freeway lanes. The advance warning signs included a static message board displaying the queue warning message and two flashing beacons that were activated during congested traffic conditions. They found both queue warning systems reduced the number of vehicle conflicts, such as sudden breaking and forced lane changes to avoid rear-end crashes, by five to seven percent at the study site on I-610 in Houston. The reduction at the other study site on US-59 was less significant. The speed variance was significantly reduced at both sites after the queue warning systems were deployed. Researchers expected more uniform speed distributions in the vehicle stream to reduce the potential for rear-end crashes and thus result in safer traffic operations. They concluded that this technology had the potential to provide effective queue warnings for drivers approaching slow or stopped queues on multi-lane congested freeway segments. However, they recommended that the systems could still be improved by adding managed lane and/or advisory speed messages.

2.6.2 Portable Intelligent Traffic Management Systems

A portable intelligent traffic management system is an integrated system, which consisted of several PCMSs, vehicle detection systems (such as detectors, cameras and other surveillance equipment), a computer-based control center, and other related communication systems. Based on detected traffic data, the system automatically determined messages to be displayed on the PCMSs and could also disseminate the information through highway advisory radio and the internet. An example of an integrated PCMS and HAR systems in a work zone is shown in Figure 2.16.

FIGURE 2.16
Integrated PCMS and HAR systems in a work zone (FHWA 2010)

Fang (2008) reviewed the application of various portable intelligent traffic management systems and other incident and speed management technologies for use in work zones. The study also identified several innovative technologies that had the potential to improve highway traffic operations. Interviews were conducted with representatives from transportation agencies in various states and private industry regarding their experiences with and knowledge of work zone and incident management deployment initiatives and innovative technologies. Guidelines were developed in that study for the effective application of automated portable traffic management systems in work zones and incident areas.

Chapter 3: Nationwide Usage Survey

The purpose of the survey was to investigate potential innovative traffic safety devices which have been or were being used by other states (besides Kansas) and to document their utility.

3.1 Survey Design

A survey was designed and sent to all state transportation agencies to obtain information about traffic control technologies and strategies used by other state transportation agencies to reduce speeds and enhance driver and worker safety at short-term (temporary) work zones on their primary highway systems. The survey focused on innovative or unique safety devices any state was using or had used in the past along with comments on their perceived effectiveness. This survey included four principal questions.

- **Question 1:** Does your state have an established policy or strategy on reducing speed or using positive protection devices in temporary work zones where the working duration is one day or less?
- **Question 2:** What systems does your agency use to alert approaching driver or alert workers of errant vehicles in temporary work zones?
- **Question 3:** Has your organization conducted field trials or closed-course research for these or other devices?
- **Question 4:** Describe the most effective devices or process used by your organization to reduce or manage work zone speeds at short-term work zone.

The survey was emailed to each state's head traffic engineer (or equivalent) and was answered by him/her or a staff member responsible for work zone traffic safety. Telephone follow-ups were conducted as needed. The survey was conducted from April 1 to May 15, 2009.

3.2 Survey Results Summary

A total of 26 states responded to the survey. The responses from states were discussed and summarized by question and for each traffic safety device. Detailed responses are listed in Appendix A.

3.2.1 Question 1: Policy and Strategy

Does your state have an established policy or strategy for reducing speed or using positive protection devices in temporary work zones where the working duration is one day or less?

In general, every responding state had a policy or strategy for the implementation of traffic control devices in work zones. It can be seen in most states' traffic control policies and operation manuals depending on different types of work zones. However, only five states (Delaware, Georgia, Iowa, Massachusetts, New York, and Washington) responded that they have a specific policy or temporary traffic control plan regarding speed reduction in temporary work zones. The remaining responding states stated that they have not adopted a specific policy for short-term work zones, however three states (North Carolina, Ohio, Texas) stated that they have adopted in traffic control plans or otherwise, requirements for the use of truck-mounted attenuators for short-term work zones.

3.2.2 Question 2: Innovative Traffic Control Device Usage and Effectiveness

What systems does your agency use to alert approaching drivers or alert workers of errant vehicles in temporary work zones?

- **Portable Rumble Strips**

Three specific types of portable rumble strips which were commonly used or are current tested were listed for the survey. They were adhesive rumble strip, including Advanced Traffic Markings (ATMs) and Rumblers, and Portable Plastic Rumble Strips (PPRSs). Table 3.1 summarizes the usage and effectiveness comments based on states which are using or have used temporary rumble strips in work zones.

TABLE 3.1
The usage and effectiveness comments for temporary rumble strips

State	Usage		Types of rumble strips	Effective	Comments/Notes
	Currently using	Have used but not now			
AZ	✓		Not sure	**	Used on limited basis to reduce speed of traffic in advance of work zones
FL	✓		Temporary Raised Rumble Strips (FL developed)	**	Are Currently testing. Feedback have not received
GA	✓		Formed in Place Strips	**	For long term projects only.
MI	✓		ATMs	**	On an as needed basis determined by the designer. Recommended on freeway approaches to lane closures.
MN		✓	Various (but PPRSs)	No	Mn/DOT had tested various temporary rumble strips in the past and found nothing that worked successfully. They anticipate trying PPRSs on a trial basis.
MO		✓	Rumbler (PPRS in test)	No	The Rumblers in speed reduction was minor. MODOT brought PPRSs for testing. Results were positive, but not numerous data is available.
NC		✓	Heated In Place	Yes	Were effective in providing an audible as well as a visible warning.
NJ		✓	Usable (not sure what type)	No	Tried it a number of years ago. The performance was not good with truck traffic, as they were picked off the road.
TX	✓		1.Premark in-lane Rumble Bars (Flint Trading) 2. Rumbler	**	For long term projects only.
VA		✓	1. ATMs 2. Part of a SHRP (not sure)	Yes/No	1. to improve motorist awareness and reaction but not for speed control 2. Truck caused some to bunch up. Motorist slowed or stopped to see what they ran over, or swerved around the strips.
WA		✓	Various (not list)	No	Tested many types and found various issues that detract for effective use.
WV	✓		Termoplastic Marking	**	**

**: information was not provided

Among the responses, six states (Arizona, Florida, Maryland, Michigan, Missouri, and West Virginia) were, at the time of the survey, currently using portable rumble strips in work zones, while two states (Georgia and Texas) had used some other kind of temporary rumble strips in long-term work zones but not in short-term work zones. Five states (Minnesota, New Jersey, North Carolina, Virginia, and Washington) had used them in the past but did not use them currently. Among these 12 states, two states pointed out that the rumble strips were ineffective or caused negative issues. Three states noted that the rumble strips were effective in providing audible and visible warnings to increase motorist awareness, but were ineffective in achieving any speed reduction. Four states (Delaware, Iowa, Mississippi, and Oklahoma) have not used temporary rumble strips in maintenance work zones but were interested in using them. Minnesota and Missouri anticipated trying PPRs in field tests. New York said they tended not to use the rumble strips as their maintenance people were concerned with the extra work involved and exposure to traffic while installing/removing them.

- **Intrusion Alarms**

Intrusion alarm systems created by the Strategic Highway Research Program (SHRP), and a new system, SonoBlaster, were listed in the survey. Four states (Indiana, Maryland, Ohio, and Texas) were using or participated in testing the SonoBlaster intrusion alarm systems. There was no opinion yet on its effectiveness. Nebraska had possession of the SonoBlaster systems provided by the FHWA but had not used them yet. Five states (Connecticut, New Jersey, Virginia, Washington, and West Virginia) had used several of the intrusion alarm systems provided by the SHRP, but were not presently using them. When asked for a reason as to why they were no longer in use, they responded that the devices (SHRP) were ineffective.

Connecticut had tried Microwave Beam technology approximately ten years ago, and concluded that it worked acceptably but was not something the state would fund for their maintenance work zones. New Jersey also tested Microwave Beam in the past but found it not to be effective. Virginia had used both Microwave Beam and Pneumatic Tube of intrusion alarm systems, and found neither of them was effective. False alarms, caused by work vehicles breaking the optical beam, made workers less attentive to future alarms ("crying wolf syndrome"). However, when shadow vehicles were used in advance of work zone operations, these devices provided little additional benefit to work crews.

Washington has tested many of these devices (but didn't specify which ones) in past years and found them to be ineffective or problematic. Even if the devices were working, they still did not provide sufficient coverage area or enough reaction time for workers. Two states

(Florida and Iowa) said that they had no plan to use these devices due to concerns about false alarms, maintenance, and the lack of guidance on when or how to use them.

- **Radio Devices to Alert Drivers**
  - **CB Wizard Alert Systems**

Nine states (Indiana, Missouri, Nebraska, North Carolina, Ohio, Oklahoma, Texas, Virginia, Washington) were currently using, testing, or had used CB Wizard alert systems in work zones on case-by-case basis. All of these states used this device almost exclusively in long-term work zones and rarely in short-term work zones. Seven of these states commented that these systems were very effective particularly for, and limited to, commercial trucks.

  - **Portable Highway Advisory Radio**

Ten states have experience in using Highway Advisory Radio (HAR) stations to relay lane restricting work zone information to motorists. This device was most often used for alternate route information during incidents, or was limited almost exclusively to long-term projects. Only two states (Ohio and Texas) noted usages in short-term work zones. Ohio pointed out that some of their districts felt that this device could be useful in some short-term maintenance work zones. Regarding the effectiveness, only three states (Ohio, Virginia, and Washington) considered this device to be effective if the provided message was up to date. Washington commented that simply providing general project information did not seem to be effective and Ohio found that the signals were typically weak and the messages were not able to be kept up-to-date and thus were usually displaying out-of-date information to drivers. The lack of text-to-speech technology and lack of a grounded signal were reported as contributing factors to the shortcomings. Two states (Massachusetts and Mississippi) have not yet used this device but indicated they were possibly interested in using it.

  - **Portable Changeable Message Signs (PCMS)**

Changeable message signs have been commonly and widely used in all states and were found to be very effective. Typically, PCMSs are used on multilane highways to advise motorists of lane closures, traffic shifts and/or detours ahead. However, PCMSs were principally used only in long-term work zones and rarely used in short-term work zones. Some states pointed out that this device was very effective if not overused or left in one location for too long. One state (New York) also equipped their PCMSs with radar speed displays or had truck mounted units, which were used for short-term, short-duration, and/or mobile work zones.

- **Portable Speed Monitoring Displays (PSMD)**

Nineteen states have experience in using PSMDs. However, they have not been deployed routinely for short-term work zones. In longer-term applications, they usually were used in rural and/or high speed areas. Eight states considered these devices to be effective, especially when used in conjunction with police presence. A negative effect of drivers speeding up was also found in some states. For example, Delaware found that occasionally motorists would attempt to test the limits of these devices to see how high of a speed they could register. Virginia pointed out that these devices may unintentionally encourage speeding by young and aggressive drivers.

- **Radar Drones**

Eight states reported experience in using radar drones, however their experience was infrequent. They have use radar drones occasionally. Four of these eight states had discontinued using radar drones due to their perceived ineffectiveness. Only one state (Indiana) mentioned that radar drones were an effective method for getting the attention of motorists who have radar detectors in their vehicles, and were frequently deployed concurrently with PCMSs. The major issue was the drones can only reached people with radar detectors (New York). One other issue was that the drones can only be installed where there is a low percentage of daily commuter traffic. Otherwise drivers notice the (false) alarm and subsequently disregard it (North Carolina).

- **Vehicle Activated Signs**

Only two states had experience in using vehicle activated signs in work zones. Minnesota had intelligent work zone (IWZ) systems, which included vehicle activated signs. They promoted the usage of IWZ systems in they work zones, but the high cost of some systems prevented their usage in short-term work zones. Michigan was developing such a system at the time of this report.

- **Truck Mounted Attenuators (TMA)**

TMAs were commonly used in every state and were found to be very effective in protecting workers and other equipment. Generally speaking, TMAs were required in work zones on high speed, high volume, or limited access roadways and were also required for all mobile work zones. Table 3.3 lists states which have requirement and policy of the use of TMAs. Twenty-one states mentioned their strategies or policies for the use of TMAs in work zones. Some states used trailer mounted attenuators as an option. New York required TMAs where buffer space requirements cannot be met and on freeways. Ohio currently does not have a statewide policy regulating the use of TMAs, but some of their larger districts require them for mobile operations on freeways. Others allow them as long as the TMAs are installed and used per the manufacturer's specifications.

TABLE 3.2
The usage and effectiveness comments for temporary rumble strips

	States
1. TMAs are required on all mobile operations	MI, MN, NE, NJ, OH, OK,
2. TMAs are required on lane closure or limited access roadways	DE, GA, MA, VA
3. TMAs are required on multi-lane highway where minimum post speed is 45, 55 mph or higher	DE, MA, MD, VA
4. Trailer mounted attenuators as an option	IN, MA, MO, NY,
5. States have polices requiring the use of TMAs	CT, DE, FL, GA, IN, KY, MA, MD, MI, MN, MO, MS, NC, NE, NJ, NY, OK, TX, VA, WA, WV

- **Mobile Barriers**

None of responding states had used any variety of this device. Four states mentioned that they may consider using it if the cost comes down.

- **Other Innovative Traffic Control Device/System**
    - **Automatic Flagger Assistant Devices (AFAD**)

In the question about other innovative traffic devices or systems which were applied, three states (Georgia, Texas, and Washington) mentioned that they were either using or testing AFADs in some projects. Georgia noted they still required having certified flaggers on site in case any of the AFADs malfunctioned. Washington has used this device for high-speed, two-lane highways and found it is effective for removing the flagger from hazardous locations.

- **Portable Intelligent Traffic Management Systems**

Four states (Georgia, Minnesota, North Carolina, and Texas) have introduced intelligent work zones or similar systems for work zone traffic management. Georgia has used portable intelligent transportation systems (i.e. “smart work zones”) on some select long-term projects but not on short-term projects. Minnesota also has used portable intelligent transportation systems and listed options in a state policy document, the Minnesota Intelligent Work Zone Toolbox (Minnesota Department of Transportation). North Carolina has also used smart work zone technologies to provide travel time, alternate route, and weather related information to motorists in advance of work zones. Texas maintained a traffic management center to provide messages to urban motorists using dynamic message signs or lane control signals to assist short-term work. Indiana was experimenting with an in-house design for providing travel time and delay information to motorists in advance of work zones.

- **Traffic Flares**

Virginia has used traffic flares to slow motorists down during nighttime operations, however, their effectiveness has not yet been determined.

3.2.3 Question 3: New Innovative Test and Evaluation Results

Has your organization conducted field trials or closed-course research for these or other devices?

This question was trying to investigate any possible innovative traffic control devices that were being or had been tested by the surveyed states. Only five states responded with their experiences or related research:

- Florida evaluated the safety and operational effectiveness of a dynamic lane merge system.
- Maryland had a work zone safety "tool box" which provided guidance for the use of some traffic control devices in work zones.
- Minnesota has evaluated several PCMS devices for legibility, along with testing Clear View fonts and highly reflective prismatic sign sheeting for use in work zones.
- North Carolina has evaluated a smart work zone system and the effects of PCMS on speed reduction.
- Texas has conducted several research projects including the following.
    - *Use of Innovative Traffic Control Devices to Improve Safety at Short-Term Rural Work Zones* (TTI 0-1879-S) (Fontaine et al. 2001)
    - *Improved Work Zone Portable Changeable Message Sign Usage* (TTI 0-4748-S) (Ullman et al. 2005)
    - *Portable Concrete Barrier Simplifies Maintenance Operations* (TTI 0-4692-S) (Bligh et al. 2005)
    - *An Assessment of Various Pavement Marking Applications and Rumble Strip Designs* (TTI 0-4728-S) (Finley et al. 2005)

3.2.4 Question 4: The Most Effective Traffic Control Devices for Short-Term Work Zones

Describe the most effective devices or process used by your organization to reduce or manage work zone speeds at short-term work zone.

Thirteen states commented that on site, uniformed law enforcement officers were the most effective tool for reducing speeds in work zones. However, law enforcement presence was only used in long-term work zones. Short-term maintenance projects that applied for law enforcement were routinely declined due to funding limitations. New Jersey noted that TMAs were one of the most effective safety measures for short-term projects, while their neighboring state, New York, pointed out that radar equipped PCMSs were their most effective tool for protecting workers while reducing vehicular speeds, particularly for short-term work zones. Minnesota indicated that they would be starting a new “informal” partnership program with the state patrol for “extra enforcement” within short-term maintenance work zones.

3.3 Findings

Table 3.3 summarizes the usage and effectiveness comments for traffic control and safety devices from the 26 responding states. The effective/ineffective percentages reported in the table were calculated only for those states which were currently using or had used or tested the devices in the past. Responses that did not indicate if a device was effective or ineffective were considered to have “no opinion.”

TABLE 3.3
The usage of short-term work zone traffic safety devices of surveyed states (26 states)

Device	States Using or Testing	Have Used (Tested) in the Past	Considered Effectiveness		Plans to use or are Interested
			Effective	Ineffective	
Portable Rumble Strips	7	4		4 (36%)	4
Intrusion Alarms	3	6		4 (44%)	3
CB Wizard Alert System	7	1	4 (50%)		3
Highway Advisory Radio	6	3	1 (11%)	3 (33%)	1
Portable Changeable Message Signs	26	0	26 (100%)		
Speed Monitoring Displays	18	1	8 (42%)	1 (5%)	
Radar Drones	4	5	1 (11%)	2 (22%)	1
Vehicle Activated Signs	2	0			
Truck Mounted Attenuators	23	0	23 (100%)		1
Mobile Barriers	0	0			4
Automatic Flagger Assisted Devices	2	0			

It was observed that every state using both PCMSs and TMAs considered that these devices were effective. About 36 percent of states considered the adhesive rumble strips ineffective. Although this type of rumble strip could generate sufficient vibration and noise for drivers, its effect on speed reduction was considered to be limited. About 44 percent of states commented that intrusion alarms were ineffective.

Chapter 4: Field Evaluation of Portable Plastic Rumble Strips

In addition to the innovative devices which had been used or tested in other states and in previous studies, the research team also attempted to look for and test innovative devices which had not yet been tested, or had an undetermined effectiveness for short-term work zones. An innovative portable product, portable plastic rumble strips (PPRS), which had been previously tested on a closed course (Schrock 2010), was found to be a potential device which could be suitable for use in short-term work zones. The PPRS were found to be easily installed and removed compared to other temporary rumble strips and did not require adhesives or other fasteners to remain in place. They also were capable of generating similar vibrations and sounds as permanent rumble strips. However, the effectiveness of the PPRSs on speed reductions in actual work zones had not yet been examined.

The objectives of this study were to evaluate the effectiveness of the PPRS at short-term work zones and to investigate drivers' responses to the PPRS. Field data were collected at three short-term maintenance work zones with flagger control on rural roads in Kansas. Travel speeds were measured at several locations in advance of the work zones when the PPRS were or were not implemented. For comparison purposes, speed data under normal traffic conditions (without any maintenance activities or other temporary traffic control) were also obtained.

4.1 Field Test Sites Selection

The research team collaborated with a maintenance crew from the Kansas Department of Transportation (KDOT). Three sites near Oskaloosa, Kansas, (Figure 4.1) were selected for the field data collection. All three sites were short-term maintenance work zones where the traffic control was performed by flaggers. Each work zone was set up with one lane closed in the morning and all traffic control removed around noon, depending on the maintenance activity being performed.

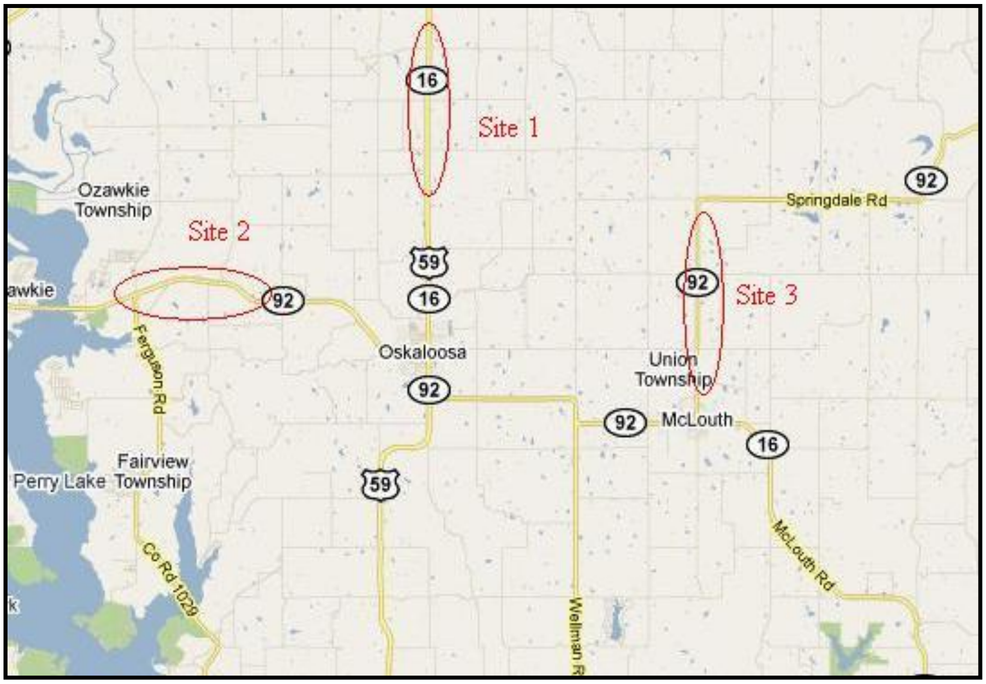

FIGURE 4.1
Data collection sites

4.1.1 Site 1 at US-59 (Oskaloosa)

The maintenance area was located at approximately six miles north of Oskaloosa, Kansas. US-59 in the work zone area was a two-lane highway with a posted speed limit of 65 miles per hour. The maintenance task performed in this work zone was crack sealing on July 20, 2010, starting at 8:00 a.m. and finishing around 2:15 p.m. The work zone was approximately 0.8 miles in length. The PPRS and data collection equipment were set up north of the work zone to collect southbound traffic data. At this location there was a slight downhill grade from 4000 feet to 2000 feet in advance of the flagger. Due to this, the KDOT crew extended the advance warning area approximately 500 feet beyond the minimum distances set forth in their standard plan sheets.

4.1.2 Site 2 at K-92 (Oskaloosa)

The work zone at this site was located approximately six miles west of Oskaloosa, Kansas, on state route K-92, which is a two-lane highway with a posted speed limit of 65 miles per hour. The maintenance activity being performed was a guardrail replacement on July 22, 2010, starting at 8:00 a.m. and finishing around 11:00 a.m. The work zone was approximately

0.2 miles long. The PPRSs and data collection equipment were set up east of the work zone to collect westbound traffic data.

4.1.3 Site 3 at K-92 (McLouth)

The third work zone studied was located near McLouth, Kansas, on state route K-92. At this location the route is a two-lane highway. The work zone was located just within the McLouth city limits, which had a posted speed limit of 30 miles per hour; however, the entire southbound advance warning area (north of the work zone) extended outside of the city limits and had a posted speed limit identical to the rest of K-92 (55 miles per hour). The maintenance activity performed in the work zone was a drainage pipe replacement on July 23, 2010, starting at 8:30 a.m. and finishing around 1:00 p.m. The work zone was approximately 0.2 miles in length, and the PPRS along with the data collection equipment were set up north of the work zone to collect southbound traffic data.

4.2 Test Layout and Scenarios

4.2.1 Traffic Control and Data Collection Layout

The data collection configuration was dependent on the traffic control plans used for the work zones. Figure 4.2 illustrates the traffic control plan, the locations of the PPRSs and the data collection equipment in advance of the maintenance work zone. The traffic control plan was based on the traffic control for a flagger-controlled stationary lane closure on a two-lane highway, as detailed in the Kansas Highway Sign Manual (Kansas Department of Transportation 2009).

For this research, four scenarios were evaluated:

- **Scenario A:** No work zone traffic control was present
- **Scenario B:** The standard work zone traffic control was present (no PPRSs)
- **Scenario C:** The standard work zone traffic control was present, and two sets of PPRSs were also deployed (at locations #2 and #3 as shown in Figure 4.2)

- **Scenario D:** The standard work zone traffic control was present, and three sets of PPRSs were also deployed (at locations #1, #2, and #3 as shown in Figure 4.2)

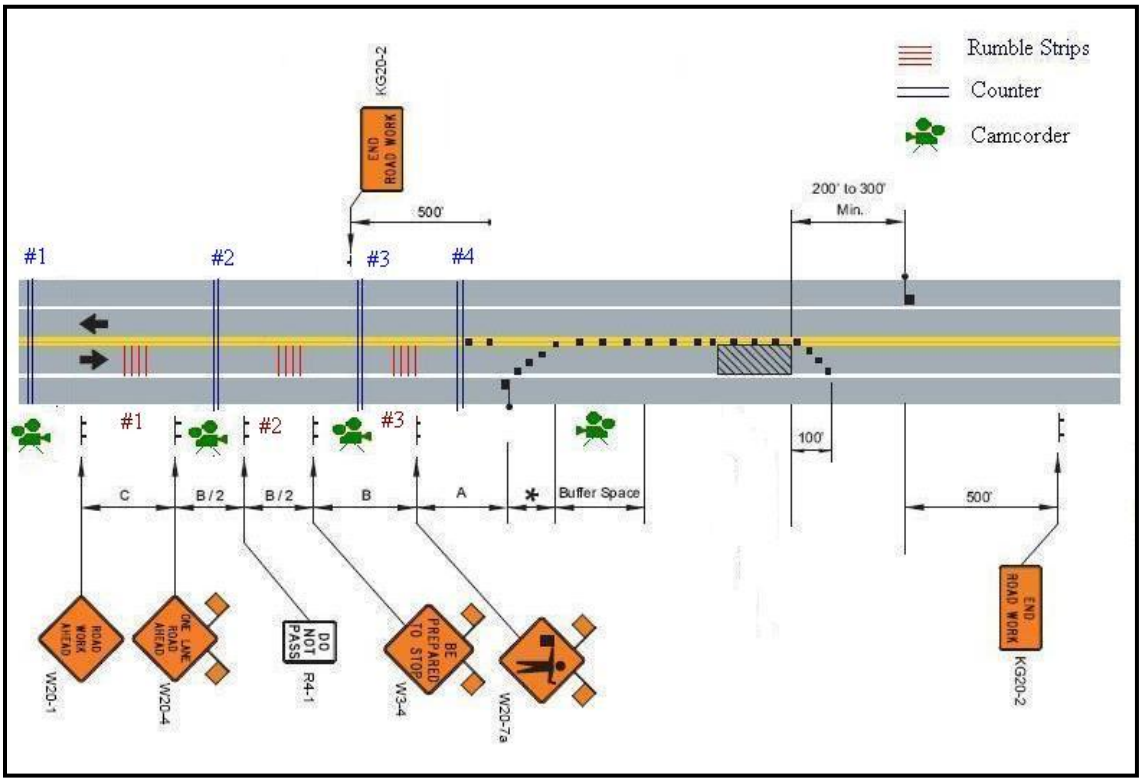

FIGURE 4.2
Traffic control and data collection layout at a short-term maintenance work zone

Each set of PPRSs was placed perpendicular to the direction of travel, and each of the four strips in the set was spaced 36 inches on center. The spacing configuration is based on the result of closed coursed test of PPRSs conducted by research team. If three sets were used for the test, the first set of strips was located halfway between the “ROAD WORK AHEAD” and the “ONE LANE ROAD AHEAD” signs. The second set of PPRSs was placed in advance of with the “BE PREPARED TO STOP” sign. If two sets of PPRSs were used for the test, the first set of strips was installed in advance of with the “DO NOT PASS” sign. The final set (second or third set depending on the scenario) of PPRSs was placed close to the symbolic “FLAGGER AHEAD” sign for both test scenarios, as shown in Figure 4.2, at each test site.

FIGURE 4.3
Installation of PPRSs at Site 1

FIGURE 4.4
The layout of PPRSs at Site 2

FIGURE 4.5
The layout of PPRSs at Site 3

The first tube counter was installed 300 feet in advance of the "ROAD WORK AHEAD" sign. The second counter was placed between the "ONE LANE ROAD AHEAD" sign and the "DO NOT PASS" sign. The third counters were placed halfway between two sets of strips. The fourth counter was placed halfway between the "Flagger" sign and the flagger. Three video cameras were placed in advance of the PPRS to capture instances of adverse driver reactions, such as swerving around the PPRS or hard braking. One video camera was installed behind the flagger aiming at the coming traffic to observe the queue condition due to the traffic control. The video camcorders were also used to remove the workers' and investigators' vehicles from the subsequent speed data analysis so as to not have biased data.

The locations of traffic control and data collection equipment relative to the flagger are shown in Table 4.1. At Site 1, the upstream approach of the work zone had a slight downhill grade. Due to this site-specific condition, the advanced warning area was longer than other sites.

4.2.2 Test Scenarios and Data Collection Time

The maintenance actions were divided into three time periods for testing at Site 1 and two time periods at Site 2 and Site 3. An additional scenario (D) was added at Site 1 as this work zone was in place longer. Scenario D was not tested at Sites 2 or 3 due to a lack of sufficient of time at these shorter-duration work zones. The traffic control scenarios and travel speed data collection time periods at each site are listed below:

4.2.2.1 Site 1: US-59 Southbound (Oskaloosa)

- **Scenario A:** Normal traffic from 2:35 p.m. to 3:25 p.m. (50 minutes of data)
- **Scenario B:** Flagger control only 1:20 p.m. to 2:15 p.m. (55 minutes of data)
- **Scenario C:** Two sets of PPRSs with a flagger from 12:10 p.m. to 1:15 p.m. (65 minutes of data)
- **Scenario D:** Three sets of PPRSs with a flagger from 9:50 a.m. to 12:00 p.m. (included a 45 minute crew and flagger break resulting in 85 minutes of data)

4.2.2.2 Site 2: K-92 Westbound (Oskaloosa)

- **Scenario A:** Normal Traffic from 11:45 a.m. to 12:45 p.m. (60 minutes of data)
- **Scenario B:** Flagger control only from 10:10 a.m. to 11:00 a.m. (50 minutes of data)
- **Scenario C:** Two sets of PPRSs with a flagger from 8:50 p.m. to 10:05 a.m. (75 minutes of data)

4.2.2.3 Site 3: K-92 Westbound (McLouth)

- **Scenario A:** Normal traffic from 1:20 a.m. to 2:30 p.m. (70 minutes of data)

- **Scenario B:** Flagger control only from 12:00 p.m. to 1:10 p.m. (70 minutes of data)
- **Scenario C:** Two sets of PPRSs with a flagger from 8:55 p.m. to 9:45 a.m. (50 minutes of data)

Note that at all three sites, due to concerns for researcher safety, the data collection equipment could be installed only when the other traffic control signs were in place, thus data collection for Scenario A started approximately one hour after the maintenance activity was concluded and all other traffic control devices were removed.

TABLE 4.1
Locations of signs and data collection equipment relative to the flagger

	Distance from Flagger Location		
Location	Site 1	Site 2	Site 3
Counter 1	3,827	3,297	2,821
“Road Work Ahead” Sign	3,527	2,996	2,644
Rumble Strip Set 1	2,909	N/A	N/A
“One Lane Road Ahead” Sign	2,733	2,537	2,295
Counter 2	2,557	N/A	2,295
“Do Not Pass” Sign	2,557	2,189	1,939
Rumble Strip Set 2	2,292	2,205*	1,663
“Be Prepared to Stop” Sign	2,292	1,813	1,663
Counter 3	2,028	1,813	1,146
Rumble Strip Set 3	1,763	1,246	1,146
“Flagger Ahead” Symbolic Sign	1,763	1,092	899
Counter 4	1,234	1,021	300
Beginning of Centerline Cones	588	1,82	0
Flagger Location	0	0	0

* Rumble strips were set in advance of the “DO NOT PASS” sign.

4.3 Results and Analysis

4.3.1 Speed Reduction

In order to realize the effect of the PPRSs on individual drivers, only free flowing vehicles with a headway of at least four seconds were used for the data analysis. Vehicles coming from side roads or driveways, and vehicles related to maintenance and this research study were excluded from the data analysis.

Five motorcyclists were observed at the three study sites during the data collection time period, and were not included in the analysis due to an insufficient sample size. Speeds recorded under normal traffic condition (Scenario A), and under traffic conditions with the regular traffic control signage and flaggers (Scenario B) were compared to the speeds obtained when the PPRSs were in place. Fisher's Least Significant Difference test was conducted for mean speed comparisons, and a grouping at the 0.05 level of significance was used for every counter at each site.

4.3.1.1 Site 1

Table 4.2 summarizes the average speed of cars and trucks from each counter at Site 1 and the speed reduction observed in advance of the work zone for each scenario tested. The differences presented in bold represent the differences of the mean speeds that were statistically significant. A>>B indicates that the mean speed in Scenario A was significantly larger than that in scenario B. A = B represent that the mean speeds in scenario A and B were not significantly different.

Figures 4.6 and 4.7 show the mean speed distribution at each counter location under various traffic control scenarios. Traffic proceeded from counter location 1 toward counter location 4 and approached the flagger and maintenance zone. Due to varying speed limits and geometric alignments of road sections in advance of the maintenance areas, the mean speeds were not consistent at the first site even under Scenario A conditions (no work zone present).

At Site 1, the mean speeds of trucks were not statistically different among the flagger-control only (Scenario B) and the installations of PPRSs at all counter locations. Compared to

Scenario B for cars, the mean speed reductions were significant when the vehicle passed over the PPRSs, except for the first set when only two sets of rumble strips were in place.

TABLE 4.2
Average speed and speed reductions due to various traffic control methods (Site 1)

Vehicle Type	Counter	Scenario	Normal Traffic (A)	Regular Flagger Control (B)	2 Strip Sets +Flagger (C)	3 Strip Sets +Flagger (D)	Mean Speed Reduction and LSD test Result (A)-(B)	(A)-(C)	(A)-(D)	(B)-(C)	(B)-(D)	(C)-(D)
Cars	Sample Size (N)		20	21	22	25						
	#1	Mean	55.3	58.2	57.8	58.1	-2.9	-2.5	-2.8	0.4	0.1	-0.3
		Standard Deviation	5.6	5.6	4.7	5.2	A = B = C = D					
	#2	Mean	65.9	64.3	62.5	56.7	1.6	3.4	**9.2**	1.8	**7.6**	**5.7**
		Standard Deviation	4.9	7.0	6.5	10.5	A = B = C >> D					
	#3	Mean	57.1	53.6	49.0	43.1	3.5	8.1	**14.0**	4.6	**10.5**	**5.9**
		Standard Deviation	5.0	6.2	8.6	10.7	A = B; A >> C ; B = C >> D					
	#4	Mean	63.0	55.3	48.1	43.8	**7.7**	**14.9**	**19.1**	**7.2**	**11.4**	4.3
		Standard Deviation	6.2	7.1	11.1	8.9	A >> B >> C = D					
Trucks	Sample Size (N)		7	5	8	10						
	#1	Mean	58.0	56.4	59.1	58.1	1.6	-1.1	-0.1	-2.7	-1.7	1.0
		Standard Deviation	4.9	8.1	3.8	4.7	A = B = C = D					
	#2	Mean	63.4	58.2	64.9	64.4	5.2	-1.4	-1.0	-6.7	-6.2	0.5
		Standard Deviation	7.1	11.9	5.9	5.5	A = B = C = D					
	#3	Mean	55.4	47.0	52.3	51.3	**8.4**	3.2	4.1	-5.3	-4.3	1.0
		Standard Deviation	4.5	9.6	6.9	5.0	A=C=D; C=D=B; A>>B					
	#4	Mean	61.0	48.2	50.4	51.3	**12.8**	**10.6**	**9.7**	-2.2	-3.1	-0.9
		Standard Deviation	3.7	12.1	9.7	3.8	A >> D = C = B					

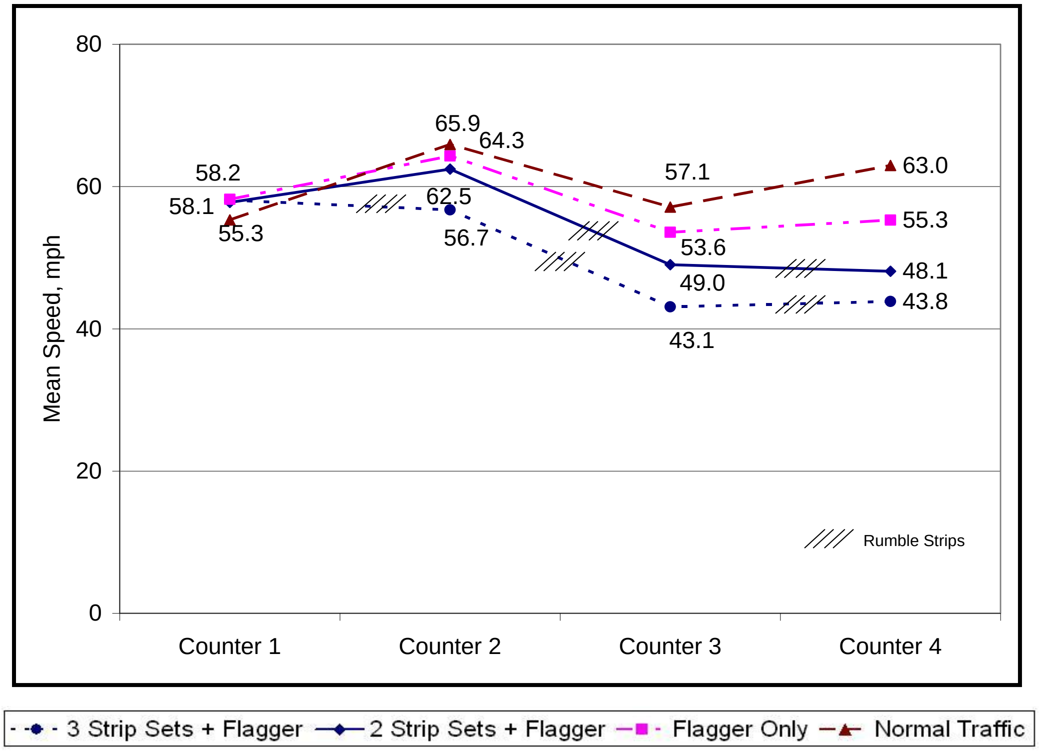

FIGURE 4.6
Mean speed distributions with various traffic control scenarios (Site 1, cars)

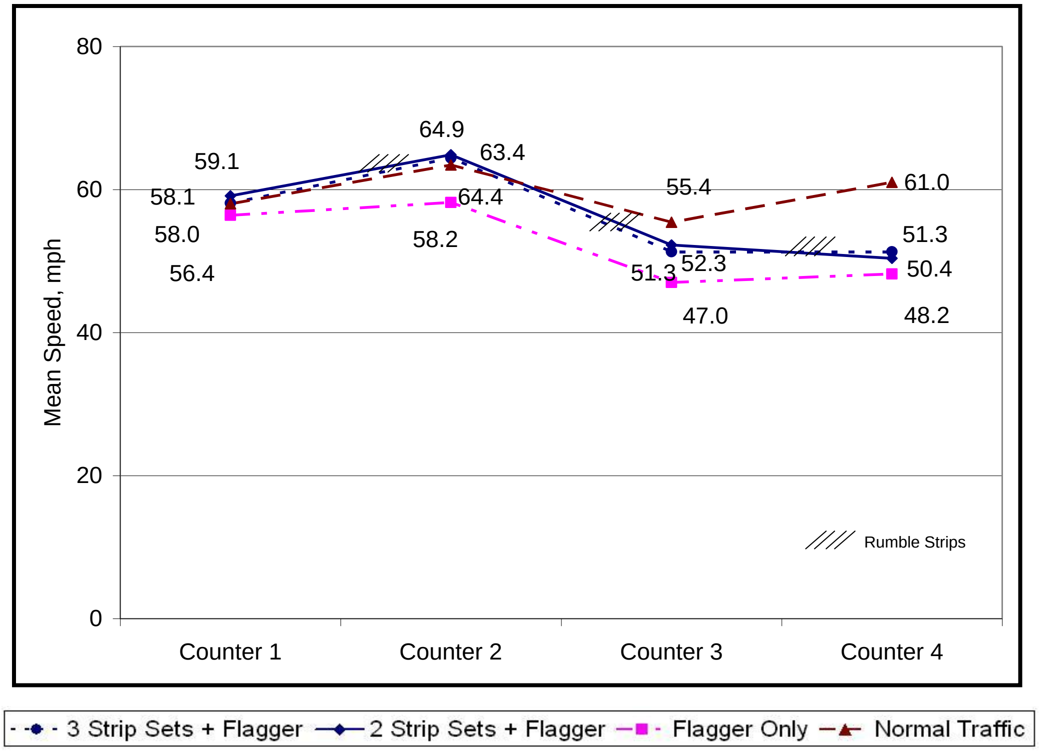

FIGURE 4.7
Mean speed distributions with various traffic control scenarios (Site 1, trucks)

When three sets of PPRSs were in place (Site 1, Scenario D), the mean speeds of cars were reduced by 7.6, 10.5 and 11.4 miles per hour when the vehicles were going through the first, second, and third set of PPRSs (speed data from Counters 2, 3 and 4 respectively). When only two sets of PPRSs were in place (Scenario C), the mean speeds were reduced by 4.6 and 7.2 miles per hour at Counters 3 and 4, respectively, but these reductions were not statistically significant at Counter 3. It is possible that the benefit of adding the third set of PPRSs at Site 1 helped offset the additional length of the advance warning area at this location.

4.3.1.2 Site 2

At the second site, the mean speeds of cars significantly decreased when the traffic control devices were in place, as shown in Table 4.3 and Figures 4.8 and 4.9. Compared to the

TABLE 4.3
Average speed and speed reductions due to traffic control methods (Site 2)

Vehicle Type	Counter	Scenario	Normal Traffic (A)	Regular Flagger Control (B)	2 Strip Sets +Flagger (C)	Mean Speed Reduction and LSD test Result (A)-(B)	(A)-(C)	(B)-(C)
Cars	Sample Size (N)		68	50	53			
	#1	Mean	60.2	55.9	54.9	**4.3**	**5.3**	1.0
		Standard Deviation	4.6	6.3	6.4		A >> B = C	
	#3	Mean	59.0	51.0	43.2	**8.0**	**15.7**	**7.7**
		Standard Deviation	6.4	7.0	5.9		A >> B >> C	
	#4	Mean	61.0	44.1	34.6	**16.9**	**26.5**	**9.5**
		Standard Deviation	7.6	7.0	6.6		A >> B >> C	
Trucks	Sample Size (N)		12	5	11			
	#1	Mean	56.8	54.2	50.0	2.6	6.8	4.2
		Standard Deviation	8.1	4.3	6.4		A = B = C	
	#3	Mean	58.9	48.6	43.1	**10.3**	**15.8**	**5.5**
		Standard Deviation	4.3	3.7	5.8		A >> B >> C	
	#4	Mean	59.8	41.2	36.2	**18.6**	**23.6**	5.0
		Standard Deviation	4.8	4.7	5.8		A >> B = C	

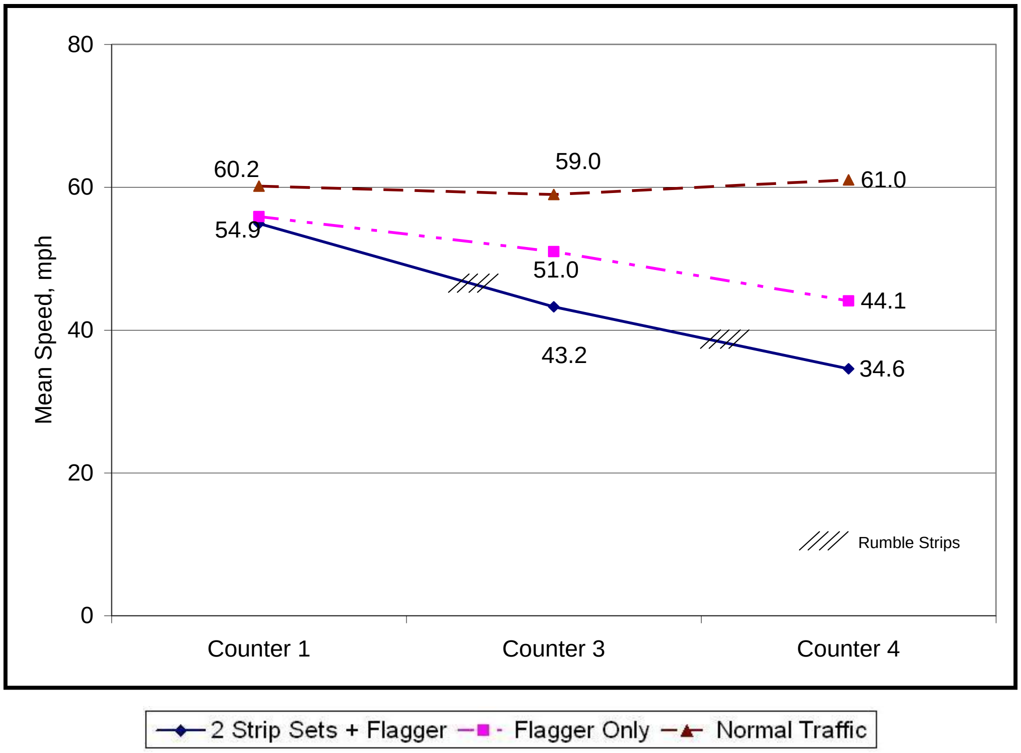

FIGURE 4.8
Mean speed distributions with various traffic control scenarios (Site 2, cars)

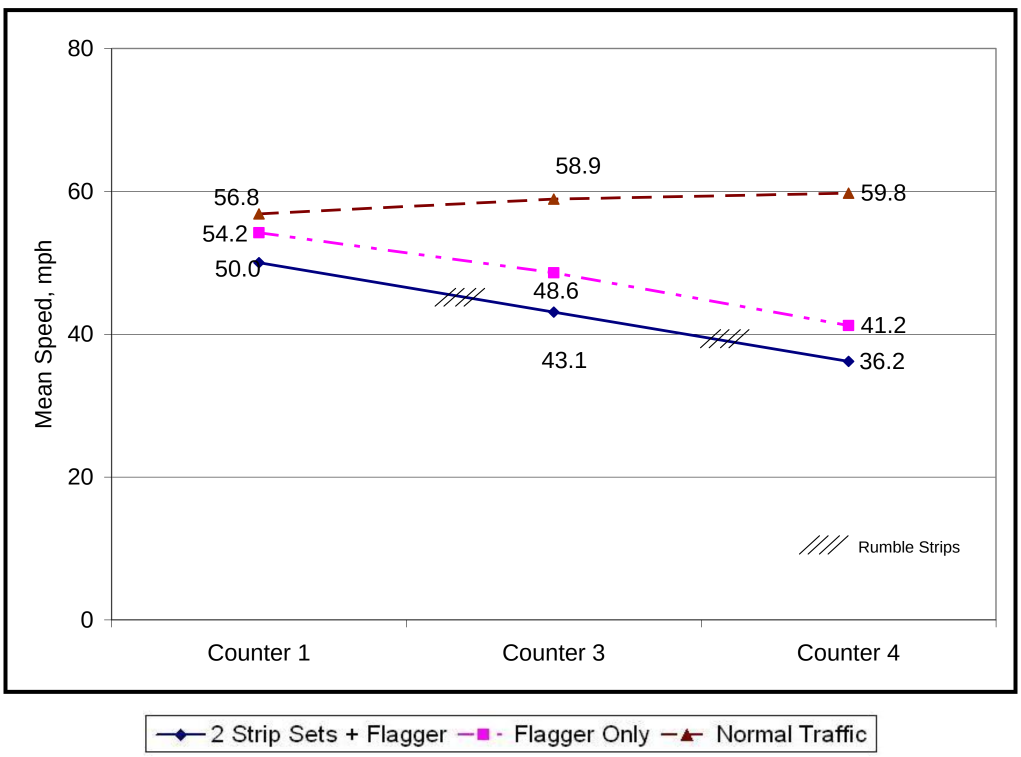

FIGURE 4.9
Mean speed distributions with various control scenarios (Site 2, trucks)

regular flagger control scenario (B), the PPRSs significantly reduced the mean speeds of cars at Counters 3 and 4 by 7.7 and 9.5 miles per hour respectively. The PPRSs also reduced the mean speed of trucks by 5.0 and 5.5 miles per hour at Counters 3 and 4 respectively, but the speed reduction observed at Counter 4 location was not statistically significant.

4.3.1.3 Site 3

At the third site, the speed reductions observed at Counters 3 and 4 were significant for all vehicles when the PPRS were installed as shown in Table 4.4 and Figures 4.10 and 4.11. Compared to the regular flagger control, Scenario B, the PPRS reduced the mean speeds of cars at Counters 2, 3, and 4 by 6.1 to 10.6 miles per hour. The PPRS also significantly reduced the mean speeds of trucks by 9.1 and 11.7 miles per hour at Counters 3 and 4, respectively.

TABLE 4.4
Average speed and speed reductions due to traffic control methods (Site 3)

Vehicle Type	Counter	Scenario	Normal Traffic	Regular Flagger Control	2 Strip Sets +Flagger	Mean Speed Reduction and LSD test Result		
			(A)	(B)	(C)	(A)-(B)	(A)-(C)	(B)-(C)
Cars		Sample Size (N)	22	31	31			
	#1	Mean	52.5	51.2	47.4	**1.3**	**5.1**	3.7
		Standard Deviation	9.2	7.9	7.4	A = B; A >> C; B = C		
	#2	Mean	47.0	42.4	36.3	**4.5**	**10.6**	**6.1**
		Standard Deviation	7.9	5.8	6.2	A >> B >> C		
	#3	Mean	46.2	37.7	27.1	**8.5**	**19.2**	**10.6**
		Standard Deviation	8.0	7.0	6.5	A >> B >> C		
	#4	Mean	49.6	39.3	29.5	**10.3**	**20.1**	**9.8**
		Standard Deviation	7.5	6.5	5.4	A >> B >> C		
Trucks		Sample Size (N)	5	7	5			
	#1	Mean	51.2	41.6	48.6	9.6	2.6	-7.0
		Standard Deviation	8.1	8.8	9.7	**A = B = C**		
	#2	Mean	46.8	36.9	40.2	**9.9**	6.6	-3.3
		Standard Deviation	6.4	7.4	4.3	A = C; A >> B; C = B		
	#3	Mean	48.4	35.9	26.8	**12.5**	**21.6**	**9.1**
		Standard Deviation	4.0	4.5	6.5	A >> B >> C		
	#4	Mean	52.6	37.3	25.6	**15.3**	**27.0**	**11.7**
		Standard Deviation	2.3	6.0	7.8	A >> B >> C		

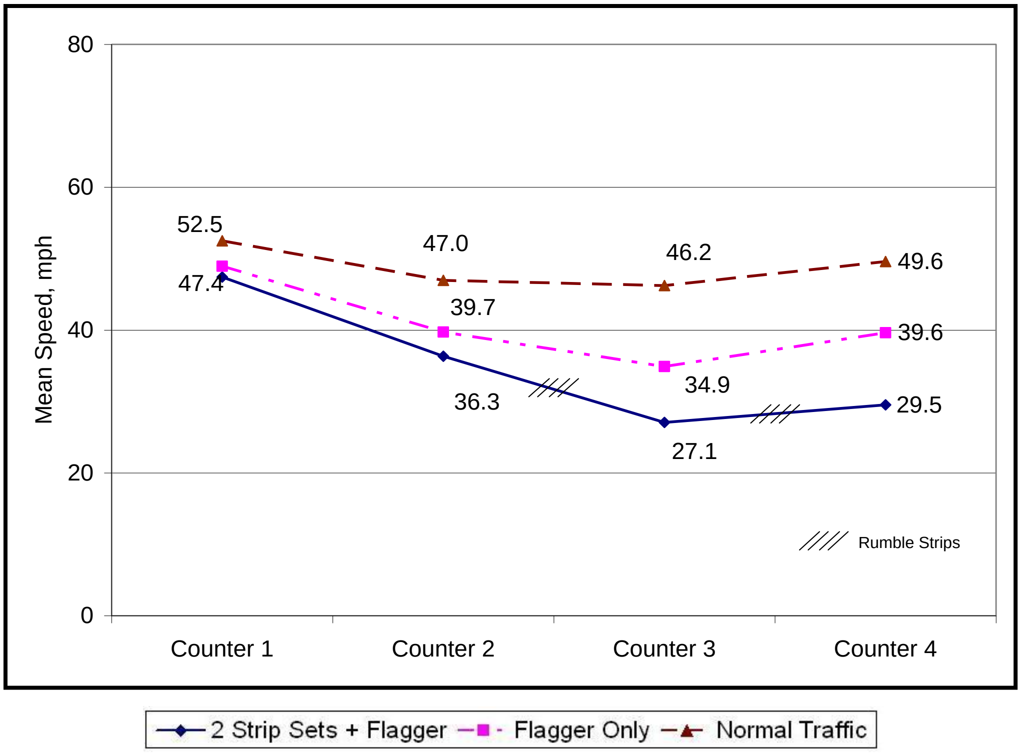

FIGURE 4.10
Mean speed distributions with various traffic control scenarios (Site 3, cars)

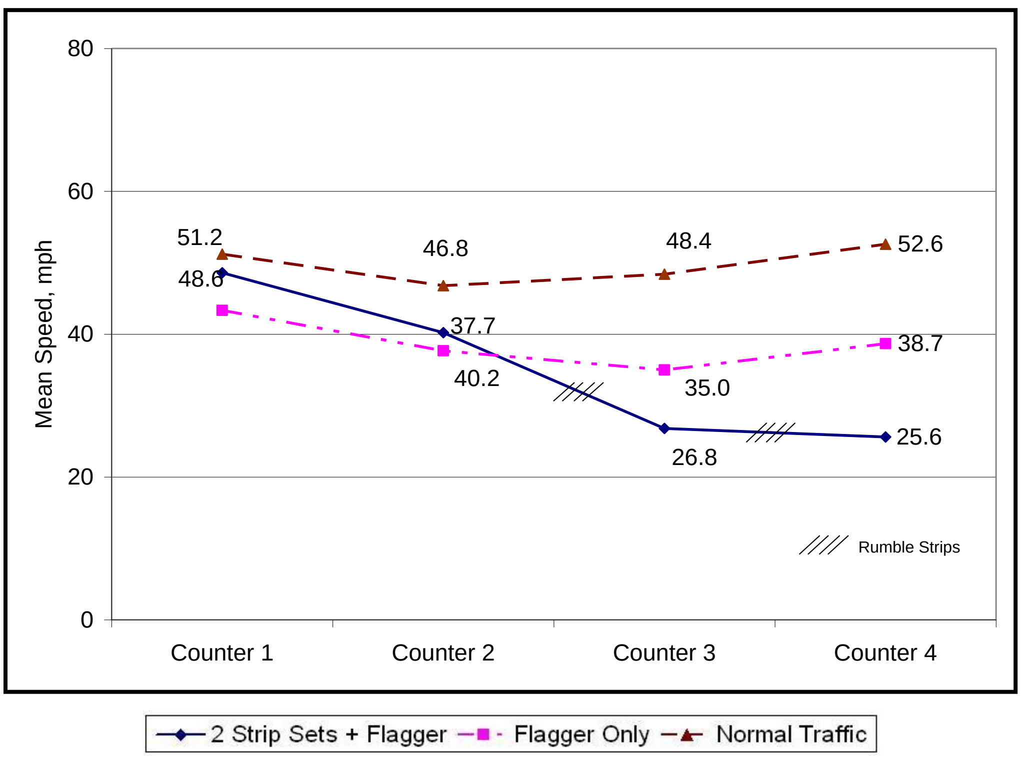

FIGURE 4.11
Mean speed distributions with various traffic control scenarios (Site 3, trucks)

It was observed that overall mean speeds decreased when traffic control devices were implemented except for trucks observed at the first site. The mean speeds of all vehicles at the farthest location (Counter 1) from the work zone at each site were not significantly different among all scenarios with the traffic control (Scenario B, C and D). Consequently, if the PPRSs were installed properly, they could create a 6.1 to 10.6 miles per hour speed reduction for cars as compared to the regular flagger control alone at short-term maintenance work zones. The speed reductions observed in an elongated traffic control area (Site 1) were more effective when three sets of PPRS were in place than installing only two sets. The speed reductions for trucks were not statistically significant at the first site. The 5.0 to 11.7 miles per hour mean speed reduction of trucks at the second and third were statistically significant.

4.3.2 Drivers' Behavior

The impact of the presence of the PPRSs on driver behavior was also studied. Generally, when drivers approached the first set of PPRSs, a majority of drivers hit their brakes but rarely changed lanes to avoid the rumble strips. However, some swerving around the PPRSs was observed; the number and type of adverse driving actions observed (with percentages shown in parentheses) is shown in Table 4.5. Swerving or other observed erratic behaviors are an undesirable reaction to traffic control devices, and so instances of such behavior were watched for in this research. Note the total time observed for driver behaviors through video were different from the total time of travel speed data collection. The video data included all time periods once the rumble strips were placed. The travel speed data collected through counters excluded the period of crew and flagger breaks.

TABLE 4.5
Observed driver behaviors with rumbles strips in place

Site	Total Time Observed	Scenario	Strips set	Cars N	Cars Brake light applied	Cars went around the strips	Trucks N	Trucks Brake light applied	Trucks went around the strips
Site 1	155 mins	Three Rumble Strips Set	Strip#1	70	29 (41)	0	18	1 (6)	0
			Strip#2	70	48 (59)	1 (1)	18	14 (78)	0
			Strip#3	70	38 (54)	9 (13)	18	11 (61)	3 (17)
	60 mins	Two Rumble Strips Set	Strip#1	NA	NA	NA	NA	NA	NA
			Strip#2	26	4 (15)	1 (4)	7	3 (43)	0
			Strip#3	26	13 (50)	6 (23)	7	2 (29)	1 (14)
Site 2	75 mins	Two Rumble Strips Set	Strip#2	56	29 (52)	1 (2)	10	3 (30)	0
	85 mins		Strip#3	64	28 (44)	0	5	3 (60)	1 (20)
Site 3	105 mins	Two Rumble Strips Set	Strip#2	64	37 (58)	2 (3)	5	3 (60)	0
	125 mins		Strip#3	98	58 (59)	7 (7)	8	5 (63)	0

At the first site, when three sets of PPRSs were installed, about 41 percent of car drivers hit their brakes for the first set of PPRSs. This percentage increased to 59 percent as drivers approached the second set, then decreased to 54 percent for the third set. Only one car driver went around (by swerving into the oncoming lane of traffic) the second set of PPRSs, but nine drivers went around the third set. Trucks, on the other hand, had a more drastic change in their braking reactions in response to the PPRSs. Only one truck driver applied their brakes for the first set, but 14 of the 18 drivers (78 percent) observed used his or her brakes for the second set, then still about 61 percent of truck drivers applied their brakes and three avoided the strips altogether for the third set of PPRSs.

When only two sets of PPRSs were used, the percentage of car drivers that braked increased from 15 percent for the first set (Counter 2) to 50 percent for the second set (Counter 3) of PPRSs. The number of drivers who went around the strips also increased from one driver for the first set to six drivers for the second set of PPRSs. However, only one truck driver was observed to swerve around the strips at the second set.

At the second site, the percentages of vehicles going around the PPRSs were lower than at the other sites. One possible explanation for that could be because the second site appeared to have a higher opposing traffic volume, although no counts of opposing traffic was taken so this cannot be confirmed. At the third site, the reaction of car drivers braking was similar to the second site, with about the same percentage (58 and 59) at each set of PPRSs. Unlike at the second site, there was a larger number of car drivers going around the second set of PPRSs, possibly because the traffic volume at the third site appeared low compared to the traffic volume at the second site. Truck drivers also had nearly the same percentage (60 and 63) braking at each set and none avoided the PPRSs.

Overall, 27 out of 544 (about five percent) car drivers avoided the PPRSs when the PPRSs were installed. The sets of PPRSs that were closest to the flagger location (e.g., the second or third set of PPRSs a driver would traverse) were most likely to be avoided by drivers. Truck drivers had a similar percentage (five percent, five out of 96) of going around the PPRS. The highest rate of going around PPRSs for car drivers was 23 percent at Site 1 when two sets of PPRSs were installed. This result presents a concern that drivers may not understand that the PPRSs are meant to be traversed, and supplementary information may need to be provided such as a “Rumble Strips Ahead” sign or equivalent. It is also possible that the black color of the strips may confuse drivers into believing that the PPRSs are pieces of tire tread or other road debris.

4.4 Field Evaluation Summary

The results of this field evaluation revealed that if the PPRSs were set up properly, they could create a 4.6 to 11.4 miles per hour speed reduction for cars, compared to the regular flagger control only, at short-term maintenance work zones. The effects of the PPRSs on truck speed reductions were not significant at one of the test sites, but they still created 5.0 to 11.7 miles per hour mean speed reduction for trucks at the other two sites. Although the speed reduction for trucks was not significant at one of test sites, the highest percentage (78 percent) of truck drivers applying their brakes at the location of the PPRS was found at that site. It indicates that the PPRSs still appeared to gain the attention of truck drivers even though the effects were not shown in the speed reduction.

The PPRS proved to be effective in reducing drivers' speeds and getting their attention before entering a work zone compared to when only signage and flaggers were present. Importantly, they appeared to gain the attention of truck drivers who were apt to cause a fatal crash if they were to fail to notice a queue ahead of a flagger station.

Overall, about five percent of drivers swerved around the PPRS, indicating that additional driver information may be needed to assure the public that these devices are intended to be traversed. Future research into appropriate signage or other supplemental traffic control is needed to minimize drivers avoiding the PPRS.

Chapter 5: Conclusions and Recommendations

5.1 Conclusions

Any device to be used in short-term work zones should command the respect of drivers, be durable, have an easily understood meaning, be low cost, be quick and easy to install and remove, and be reusable.

Based on available research located in a literature review, a nationwide survey, and a field test of an innovative device available on the market, the application of some of these traffic safety devices are recommended in addition to standard traffic control devices.

5.1.1 Adhesive Rumble Strips

The previous research on the adhesive rumble strips, such as orange rumble strips and Rumblers, found that these types of rumble strips could create speed reductions, but the reductions were varied, and some states were found them to be ineffective, especially for trucks. The survey also found that 36 percent of states that had experience with temporary rumble strips commented that these types of rumble strips were ineffective for achieving speed reductions. Several studies found that they can create speed reductions of over eight miles per hour, but due to the time required for installation, and these devices not being reusable, they have tended to only be used in long-term work zones.

5.1.2 Portable Plastic Rumble Strips

A closed course test found that the portable plastic rumble strips were more effective on cars than trucks for generating in-vehicle vibration and increasing the in-vehicle sound level. This product has been demonstrated in some states and was considered as an effective device in achieving speed reductions. This study furthermore investigated the effect of the PPRSs at three short-term maintenance work zones. The results found that if the PPRSs were set up properly, they could create a 7.6 to 10.6 miles per hour speed reduction for cars compared to the regular flagger traffic control only. The effects of the PPRSs on truck speed reduction were not significant at one of the test sites, but they still created 5.0 to 11.7 miles per hour mean speed reduction for trucks at the other two sites. Although the speed reduction for trucks was not significant at one test site, the highest percentage (78 percent) of truck drivers hitting their brakes at the PPRSs locations was observed at that site. This indicates that the PPRSs still gained the attention of truck drivers even though the effects were not shown in the form of a speed reduction.

The PPRS proved to be effective in reducing drivers' speeds and getting their attention before entering a work zone, more than when only signage and flagger were present. Importantly, PPRS appeared to gain the attention of truck drivers who have a greater potential to cause a fatal crash if they fail to notice a queue in advance of a flagger station.

Two sets of four rumble strips at 36 inches spacing are recommended to be used in short-term work zones in addition to the standard traffic control devices. However, since about five percent of drivers were swerving around the PPRSs during the field test, additional driver information may be needed to assure the public that these devices are meant to be traversed. Additionally, future research into appropriate signage or other supplemental traffic control is needed to minimize drivers avoiding the PPRSs.

5.1.3 Intrusion Alert System

Although intrusion alarms systems ideally can provide workers an alert when any vehicle intrudes into the work zone, their application and effectiveness are still limited. The survey found that 44 percent of states with experience in these systems commented that this device was ineffective. Specifically, demonstration of the SonoBlaster reportedly revealed that the alarm sound was not loud enough at noisy work zones, and the time for installing and removing the units was too long. Other issues, such as false alarms, maintenance, and installation time, were chief among the concerns for states in avoiding using these devices. The application of this device at short-term work zones is not recommended until the product is improved and successful field trials validate the improvements.

5.1.4 Portable Changeable Message Signs

The PCMSs were commonly used in all states and were considered very effective not only in directing drivers' path but also influencing traveling speeds and percentage of speeding vehicles. Their effectiveness in achieving speed reductions was found to be more significant when PCMSs were incorporated with radar drones. Although most states reported that they usually only applied PCMSs in long-term projects, the potential of applying the PCMSs at short-term work zones was still considerable.

5.1.5 Portable Speed Monitoring Displays

Previous research and survey found that the PSMDs were effective in achieving both speed reductions and decreasing the percentage of speeding vehicles. A negative impact was also found by some states that such devices may encourage young (aggressive) drivers to increase their speed. Although most states said that PSMDs were only used in work zones lasting more than one day, it was still possible to utilize them in short-term maintenance work zones because of the short installation time required.

It is recommended that the monitoring displays be installed in portable signs (as shown in Figure 2.4) instead of being installed on stand-alone trailers due to cost considerations and the resulting effort required for installation, and could be embedded as an option into standard traffic control plans for short-term work zones.

5.1.6 Radar Drones

Radar drones have been tested in many studies and were found to create varied speed reductions. However, most responses from state transportation agencies commented that this device was not effective. That is because the radar drones only affected the drivers who have radar detectors. For most of drivers without radar detectors, the effects were limited, and may have degraded over time.

5.1.7 Vehicle-Activated Signs

Previous research found the VASs were effective in reducing speeds and also the percentage of vehicles exceeding the speed limit. Although not many states have applied this technology, it also could be a potential device to be used in short-term work zones because this device was easy to install and maintain. They could also be included as an option to be imbedded into the standard traffic control plans for short-term work zones, specifically to target the fastest drivers.

5.1.8 CB Wizard Alert System

The user surveys from a previous study showed a very high percentage of drivers considered the message through CB Wizard alert systems to be effective. More than 50 percent of the responding states considered this device effective. However, most of them indicated that this device tends to be used only in long-term work zones, and would be more likely to be effective when the target audience is drivers of heavy trucks. The application of this device in short-term work zones may be limited due to these factors.

5.1.9 Truck Mounted Attenuators

TMAs were used in short-term work zones by every state, especially for moving work zones, and considered to be effective. Previous studies found that TMAs could reduce both the number of crashes and resulting property damage.

5.1.10 Mobile Barriers

Mobile barriers have been tested or used in at least four states, and test results found that this device was very effective and could be suitable for short-term and moving work zones. However, based on the survey results, it appeared that the price of the available mobile barrier units was the critical factor for states making procurement decisions and determining applications for such devices.

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Appendix A: Nationwide Survey Results

Question 1: (Policy and strategy)
Does your state have an established policy or strategy on reducing speed or using positive protection devices in temporary work zones where the working duration is one day or less?

Response on Police or Strategies:

State	Police/Strategy
AZ	No
CT	We have developed a Guidelines booklet that has been placed in every D.O.T. vehicle so that when there is any question about a certain job to be performed that day the supervisor/crew leader can refer to this booklet for help in deciding the proper pattern to apply.
DE	The Delaware Department of Transportation has developed specific maintenance of traffic cases for the purposes of providing positive protection within temporary work zones. There are cases provided for lane and shoulder closures with durations of less than one day. The cases can be found in our state Manual on Uniform Traffic Control Devices. The Delaware MUTCD can be found at the following link: http://www.deldot.gov/information/pubs_forms/manuals/de_mutcd/index.shtml These cases are applied to both rural and urban areas and there are different cases for multilane and two-lane roadways. All cases apply to roadway construction, maintenance and utility work. We also utilize these cases for emergency MOT situations.
FL	FDOT's Drop-Off Requirements is required regardless of the work duration or the setting. Link to FDOT's Drop-Off Requirements: http://www.dot.state.fl.us/rddesign/rd/rtds/08/600.pdf
GA	We have a specification for reducing the speed limit in TWZ. (see attached section 150.02.B.4.c) We don't typically require positive protection for short duration type projects. The use of temporary barrier walls in Georgia is based on an Engineering Study. We sometimes include a pay item for the use of Law Enforcement Officers (LEO's) on interstate highways. This is decided at the Field Plan Review.
IA	The Department's policy regarding speed limits in temporary traffic control zones is based on Part 6 of the MUTCD. See Sections 6B.01, and 6C.01 of the MUTCD for additional background information. More detail in survey
IN	We have a statute that allows us to place a reduced speed flasher sign for work sites. The sign must be 10 MPH lower than the normal posted speed, but must be no more than 45 MPH. This is good for any type of work zone.

Response on Police or Strategies (Continued):

State	Police/Strategy
KY	To my knowledge, we do not have a policy for reducing speeds in work zones with durations of a day or less. There is the option to reduce the speed limit by either 10 MPH (conventional roads of 55 MPH or less) or 15 MPH (Interstates and Parkways with posted speed limits of 70 MPH) if desired, but this is usually done for projects of extended durations. Additionally, law enforcement may be used on any project, but this is at the discretion of the contractor.
MA	On high speed, high volume roadways moveable impact attenuators are being used between the end of the buffer zone and the start of the work area. These devices can and have been used on other roadways that are deemed necessary by the designer and/or resident engineer. The Temporary Traffic Control Plans (TTCP) are designed based on the existing or prevailing speed limit whenever possible so that traffic can maintain an appropriate speed. On the majority of the high speed roadways (usually NHS roadways) in Massachusetts police and their cruisers are positioned within the delineation to give motorists an incentive to keep their speeds down.
MD	The SHA does not have such a policy or strategy.
ME	A temporary construction zone speed limit is a regulatory speed limit that indicates the maximum legal speed through a construction site or on a designated detour. This speed is displayed by use of a black on white speed limit sign in conjunction with a black on orange “Work Zone” plate. These speed limits may be used when the provisions of the work-hour speed limit do not apply and the physical features and conditions of the construction site or detour require a lower posted speed. They shall be removed or covered during times when this condition does not exist. Temporary Construction Zone speed limits are normally determined during the design phase by an engineering and traffic investigation. (they attach a police/strategy, but not answer the survey)
MI	Positive protection is not called for on operations of one day or less. Speed reductions are recommended when a lane or part of a lane is closed. For speed limits that are 45 mph. or lower, speeds may be reduced 10 mph. Speed limits cannot be lower than 25 mph. For speed limits of 50 mph. or higher, speeds may be reduced 10 mph. Additionally, any posted work zone speed 50 or higher is , any posted work zone speed 50 or higher is required to post “Where Workers Present 45” signing.

Response on Police or Strategies (Continued):

State	Police/Strategy
MN	No established policy or strategy for short duration work zones or for longer duration work zones. We do have a “Guideline for Establishing Speed Limits in Work Zones” which documents when and how to provide reduced speed limits, but no formal policy on when it is required. Refer to the following document: http://www.dot.state.mn.us/trafficeng/otepubl/wzspeedlimit/index.html We have no formal policy for positive protection (such as barrier) for short term, but it would be discouraged for one day projects because of the hazardous nature of placing the barrier would negate the benefits for a one day operation in most cases. Other devices are being considered as additional safety devices for short term work zones, but no formal policy has been established for using these devices at this time.
MO	Depending on the work, groups, and location is when different strategies are used. Normally, Construction projects will reduce work zone speed using the following table in standard drawings on page 5 of 8: http://www.modot.org/business/standards_and_specs/documents/61610.pdf Maintenance normally does not reduce the speed limit, but may dependent on type of work. Positive protection (channelizers, barriers) is usually based on work type. Example: major bridge repair or replacement will use barriers, dependent on road volume channelizers may be reduced or not used (lower volume).
MS	We have a policy that allows a 10 mph reduction for construction or maintenance operations that encroach into the clear zone. It can be used regardless of the working duration. Speeding fines are doubled when workers are present. There is no policy for short duration positive protection.
NC	Although we haven’t finalized our policy, for very short-term duration activities we do allow for work zone “variable” speed limit reductions. These reductions can be in place for activities of 30 days or less at a spot location. The speed limit is reduced using either portable changeable message signs or portable mounted signage. We would use Truck Mounted Impact Attenuators for positive protection for these short-term activities in lieu of other more time consuming strategies such as portable concrete barrier.
NE	We do not have an established policy for these short duration activities. Generally our strategy is to reduce the speed through all work zones. If the work is one day or less then the use of truck mounted attenuators becomes more appropriate as opposed to concrete barriers. This strategy is applied the same in most settings. Most of this would be considered maintenance work- as most reconstruction work has a longer duration than one day

Response on Police or Strategies (Continued):

State	Police/Strategy
NJ	Using Police at the site is usually the standard for these type work zones.
NY	Yes, Our speed reduction policy is contained in EI 08-030. It is consistent with the National MUTCD guidance to minimize obstructions to normal flow of traffic. We found that widespread speed limit reductions in work zones were not effective without police presence. I'm not sure what you mean by "positive protection" but we recently implemented policy and specifications for use of barrier or shadow vehicles with truck mounted impact attenuators in mobile , short duration, and stationary work zones. We require barrier vehicles when we can't provide the minimum buffer space requirements from the MUTCD. In some cases, especially higher speed highways, we require barrier vehicles regardless of buffer space.
OH	The Ohio MUTCD and our Traffic Engineering Manual establish standards for the use of traffic control devices within our work zones. Outside of the requirements set forth in these manuals, ODOT does not have a statewide policy specifically for short-term work zones. Several of our twelve districts have adopted district-specific rules for short-term work. For example, a couple of our districts require the use of a truck-mounted attenuator when executing short-term operations (usually maintenance) on freeways. ODOT uses various outlets (websites, television, radio, etc.) to provide advance notice of upcoming short-term work that may impact traffic. The advance notice allows motorists the opportunity to plan their route accordingly if necessary. The OMUTCD is available for viewing at http://www.dot.state.oh.us/Divisions/HighwayOps/Traffic/publications2/OhioMUTCD/Pages/default.aspx The TEM is available at http://www.dot.state.oh.us/Divisions/HighwayOps/Traffic/publications2/TEM/Pages/default.aspx
OK	There is no written policy on short term duration. The strategy has been on case by case situation, depending on project location, duration, past collision history and ADT. We are now working to establish new policy. The existing policy for using positive barrier in a work zone is based on our design manual guide line of 1999. Below is the existing policy in regard to PCMB. For short duration we do not use PCMB. "Due to the complex maneuvers required by drivers at crossover, it is ODOT'S policy to use portable concrete median barriers (PCMB) through the crossover. In addition, PCMB should also be used in entire length of the project if the project length is two miles or less and the average daily traffic (ADT) is 10,000 vehicle or grater. When a project is longer than two miles, PCMB will only be used in the crossover" Even though this has been the design guideline, but we have been using the positive barrier on case by case project situation. For example on all interstate projects regardless of traffic volume and length of the projects we have been using PCMB.

Response on Police or Strategies (Continued):

State	Police/Strategy
TN	Currently, at a minimum, all temporary traffic control must meet the requirements of the "Manual for Uniform Traffic Control Devices for Streets and Highways", Federal Highway Administration.
TX	Our policy allows a construction speed zone to be requested on specific projects. Approval, most often a 10 mph reduction, would come from the Texas Transportation Commission by commission minute or from a city ordinance if the project lies within an incorporated city limit. This process does not lend itself to routine short term maintenance operations. However, once a construction speed zone is approved, it is allowed to be implemented on the project whenever it is appropriate, such as for lane closures, encroachments or lane shifts. Obviously, these operations may at times be short term by definition. Our Work Zone Safety and Mobility Guidelines and our Traffic Control Plan Standard Sheets give guidance on the use of Truck Mounted Attenuators. This is the most common form of positive protection devices used for our short term operations. Longer term operations would be more likely to use barriers, etc.
VA	Very rarely do we reduce the posted speed limit for a short term work zone. If speed control is an issue for a particular site, the use of law enforcement in the work zone is normally implemented. This takes pre-planning on the part of the work crew, and arrangements must be made days in advanced to ensure the presence of a Virginia State trooper. The use of positive protection devices such as concrete barrier service is usually applied in work zones lasting longer than two weeks. We do require the use of TMA vehicles in all lane closures on multiple lane roadways with posted speeds of 45 mph or greater. We have also used, on a limited basis, speed display trailers to encourage motorist to slow down to the posted speed limit, as well as drone radar devices to activate radar detectors (even though radar detectors are illegal in VA).
WA	I have attached WSDOT manual M54-44 as a more informative approach to answer this question. The information in Chapter 3, short duration work zones has specific information on WSDOT's policy and strategies.
WV	1. We have a Highway Commissioner's orders' for speed limit reduction in a work zone for a controlled access and non-controlled access highways. This policy applies to all construction and maintenance projects that meets at least one of the following: a. Closure of a travel lane. b. Reduction of existing lane width. c. Temporary detour of the existing travel lanes. 2. We also have a Traffic Director (police officer) policy for any closure that occurs on our expressways or corridors. My opinion, this is the most effective means of reducing speed in work zones.

Question 2: (Innovative traffic control device usage and effectiveness)
What systems does your agency use to alert approaching drivers or warn workers of errant vehicles for temporary work zones?

Responses on the use of Temporary Rumble Strips: (N/A indicates no further comment available)

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
AZ	✓				Used on limited basis to reduce speed of traffic in advance of work zones	N/A
CT				✓	N/A	not plan to
DE			✓		N/A	N/A
FL	✓				FDOT is currently trying removable reusable rumble strips for 2 lane, 2 way, flagging operations. This is a developmental spec, and we have not received a lot of feedback yet from the field. Link to FDOT Design Standard: http://www.dot.state.fl.us/rddesign/rd/rtds/08/600.pdf Link to FDOT Developmental Spec for Temporary Raised Rumble Strips: http://www.dot.state.fl.us/specificationsoffice/OtherFDOTLinks/Developmental/Files/Dev546.pdf	N/A
GA				✓	N/A	GDOT does not use rumble strips on short duration projects. We occasionally use formed in place rumble strips for long term projects on the approach to a “run around”/traffic diversion detour.
IA				✓	N/A	The Iowa DOT is looking into using temporary portable rumble strips, but no policies or procedures are developed yet.
IN				✓	N/A	
KY					N/A	KYTC does not use this device in temporary work zones.
MA				✓	N/A	N/A

Responses on the use of Temporary Rumble Strips (Continued): (N/A indicates no further comment available)

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
MD	✓				Deploy on work zone approaches and within work zones to alert motorist to driving conditions and reduce travel speeds. This strategy is derived from SHA's Work Zone Safety Tool Box (link included).	ATM Remov. Rumble Strips 12' long, 4" wide, 150 mils Initial speed reduction at installation of rumble strips, but travel speeds return to "normal". Primary objective is to alert motorists of work zone conditions; secondary affect may be speed reduction, however slight.
ME				✓	N/A	N/A
MI	✓				On an as needed basis determined by the designer. Recommended on freeway approaches to lane closures.	**ATM :** 9@1.5 Ft. 700 Ft. from taper 9@5 Ft. 1400Ft. from taper 9@10 Ft. 2800 Ft. from taper .25 inch thick
MN		✓			N/A	Mn/DOT tested various temporary rumble strips in the past and found nothing that worked successfully. We have heard about a new product from PSS Inc. which looks promising. We anticipate trying this product on a test basis with our maintenance forces after they provide additional guidance on its application procedures.
MO		✓			MoDOT has used the orange rumble strips in a couple projects. Not enough to set a policy or strategy. MoDOT has seen RoadQuake in action and we are interested in the product. We bought several sets of strips.	**Rumbler 4'x4"x 1/4"** The product stayed in place and was simple enough to place, but needed a lane drop. The reduction of speed was minor. Removing the product took longer than installing. The product was not usable after the removal. **RoadQuake 10'x1'x3/4"** We have brought enough strips to study several work zones this summer. If the product is positive in slowing traffic and getting their attention, we would implement the use of thicker rumble strips.

Responses on the use of Temporary Rumble Strips (Continued): (N/A indicates no further comment available)

State	Usage situation: Are currently Using	Usage situation: Have used in past but not now	Usage situation: Not using but plan to	Usage situation: Not using	Strategy/policy of using	Brand/Size and Effectiveness/ comments
MS			✓		N/A	N/A
NC		✓			The strategy was to alert the drivers of an upcoming work zone where queueing was often prevalent and the vertical alignment often disguised where the beginning of the queue was located.	**Heated In Place** 12' x 4" x 120 mils Were effective in providing an audible as well as a visible warning…..not sure if crashes were eliminated, but certainly were a good application for it's location
NE				✓	N/A	N/A
NJ		✓				Tried in a number of years ago. The performance was not good with truck traffic, as they were picked off the road
NY				✓	Do not use. Our maintenance people would be concerned with the extra work involved and exposure to traffic while installing them.	
OH				✓	N/A	N/A
OK			✓		N/A	N/A
TN				✓	N/A	N/A
TX			✓		Listed as an approved strategy in our Work Zone Safety and Mobility Guidelines.	Premark In-lane Rumble Bars (Flint Trading) Rumbler (Swarco) We use these products but they are not portable, so they are typically used in long-term applications, often at problematic geometric locations or intersections requiring reduced speed.

Responses on the use of Temporary Rumble Strips (Continued): (N/A indicates no further comment available)

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
VA		✓			We have used these devices in the past to determine their effectiveness in raising driver's awareness.	**1.ATM Tape** Used on projects lasting longer than 3 consecutive days to improve motorist awareness and reaction, not for speed control. Used on some two lane, one way traffic conditions in advanced of portable traffic signals. 2.**Part of a SHRP projec**t, 12' long by 2' wide. Used on short daytime work operations. Workers did not like handling the devised due to their weight. Truck traffic caused some devices to bunch up in the roadway, causing a hazard. Other motorist either slowed down and stopped in the road to see what they ran over, or avoided the devices by traveling in the opposite direction of travel.
WA		✓			none, tested many types and found various issues that detract for effective use………too expensive, no noticeable rumble effect, difficult to install, etc.	N/A
WV	✓				The strategy is that it alerts the driver and reduces speed	Thermoplastic markings (See attached detail)

Responses on the use of Intrusion alarms to alert workers of errant vehicles: (N/A indicates no further comment available)

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
AZ				✓	N/A	N/A
CT		✓				Tried this product around ten years ago through our Safety Division. It worked ok but was not what the Department would fund for our Maintenance workzones
DE			✓		N/A	N/A
FL				✓	no plant to use	FDOT has no plans to use these devices because of the concern with false alerts, maintaining them, and guidance on when to use them.
GA				✓	GDOT does not use intrusion alarms.	
IA				✓		the Iowa DOT is not interested in using these types of devices
IN	✓				N/A	Currently Testing the Sonoblaster – no results yet
KY				✓	N/A	KYTC does not use this device in temporary work zones.
MA				✓	N/A	N/A
MD	✓				Currently seeking to use device in on a pilot test project	**Sonoblaster** Test deployment situation in progress; no information on effectiveness to date.
ME					N/A	N/A
MI			✓		Recommended for use in areas that have had previous history of intrusions. Could also be used to alert workers of entering construction traffic	
MN				✓	N/A	we have not utilized any of these devices to-date, and we not sure of future plans
MO				✓	N/A	N/A
MS			✓		N/A	N/A

Responses on the use of Intrusion alarms to alert workers of errant vehicles (Continued):

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
NC				✓	N/A	Intrusion Alarms has some limited application, but don't have that many work zone intrusions and devices as currently marketed are placed at the taper of the lane closure which is limiting in their effectiveness. Therefore, we haven't moved forward with using this device in contract or maintenance projects.
NE				✓	N/A	We have some "SonoBlaster" devices from FHWA, but haven't used them yet. We haven't had much success in finding a recommended placement for the devices.
NJ		✓				Tried in the past, was found not to be effective.
NY				✓	Do not use. We tried some devices but found them to be impractical.	Trial use did not go well. The unit was placed by itself behind (upstream of) a mobile work zone and was constantly struck. It should be part of a series of channelizers rather than a sole device.
OH			✓		N/A	These devices haven't been used in Ohio, but ODOT is currently participating in an intrusion alarm demonstration that is being evaluated by FHWA. ODOT is placing "SonoBlaster" devices onto an active construction project to monitor their performance and effectiveness.
OK				✓	N/A	N/A
TN				✓	N/A	N/A
TX	✓				Approved strategy in Work Zone Safety and Mobility Guidelines	**1.SonoBlaster (Transpo Ind.**) Using as part of FHWA SonoBlaster Demonstration, no opinion yet on effectiveness. **2.Pnue. Tubes on AFADs (Intelle-strobe)** Often effective in sounding alarm for drivers attempting to bypass the gate arm on the AFAD (Interim Approval) on one-lane two-way traffic control. Also is handy for flagger to sound alarm.

Responses on the use of Intrusion alarms to alert workers of errant vehicles (Continued):

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
VA		✓			We have used these devices in the past to determine their effectiveness in raising worker's awareness.	**1.Not sure, part of SHRP project** Not effective – false alarms caused by work vehicles breaking the beam made workers less attentive (crying wolf syndrome) to future alarms. Workers were "trained" not to bother looking up after a while. **2.Not sure, part of SHRP project** Not effective – false alarms caused by work vehicles breaking the beam made workers less attentive (crying wolf syndrome) to future alarms. With the use of shadow vehicles in advanced of wz operations, these intrusion alarm devices provided little benefit to work crews.
WA		✓			N/A	WSDOT has tested many of these devices in past years and have found them to be ineffective or problematic. Even the devices that "work" do not provide enough work zone coverage or enough reaction time for workers.
WV		✓			To alert workers that a vehicle was not on intended path of travel	N/A

Responses on the use of CB wizard Alert Systems: (N/A indicates no further comment available)

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
AZ				✓	N/A	N/A
CT				✓	N/A	N/A
DE				✓	N/A	N/A
FL				✓	N/A	N/A
GA				✓	N/A	GDOT does not use on short term projects
IA				✓	N/A	the Iowa DOT is not interested in using these types of devices
IN	✓				No formal Department policy exists for this technology. In general terms, the Traffic Management Business Unit (TMBU) will utilize the statewide network of fixed Highway Advisory Radio (HAR) stations to relay lane restricting Interstate Highway work zone information to approaching motorists. These HAR stations are integrated into the Department's Automated Traveler Information System (ATIS). The ATIS system supports the automated creation of automated template based messages for lane restricting activities such as construction and maintenance work. Additionally with the assistance of the local District Communications Department, custom recorded messages can be created and scheduled on any of the HAR stations.	This was used on a construction project along I-70 in the late 1990s. The system was found to be too limited in only targeting commercial vehicles. Also, at the time of this systems use there did not exist a method to remotely change the content of the message. This system is currently not in use by the Department.
KY				✓	N/A	KYTC does not use this device in temporary work zones.
MA			✓		N/A	N/A
MD			✓		Use one to two miles in advance of rural (preferred) work zones where truck traffic is at least 10% of the AADT.	Device currently deployed on pilot test site; no information is currently available regarding its effectiveness.

Responses on the use of CB wizard Alert Systems (Continued):

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
ME					N/A	N/A
MI				✓	N/A	N/A
MN				✓	N/A	N/A
MO		✓			N/A	Missouri used the CB Wizard Alert system on a project. The system performed well and trucker had a positive response. We have not use the system since.
MS			✓		N/A	N/A
		✓			Utilized on projects where specific audiences were targeted for project information. The CB Wizard is an excellent tool for communicating with commercial truck traffic…whereas the HAR is a tool for all motorists and can be used to communicate specific work zone information such as traffic queues, altered alignments, etc.	Excellent for communicating with commercial truck traffic
NE	✓				N/A	Our striping crews use the CB wizard to warn truckers of the work they are approaching. It has been effective.
NJ				✓	N/A	N/A
NY				✓	Do not use. It would be impractical to install these devices for a short term work zone. We have used highway advisory radio in long term work zones.	N/A
OH	✓				One of our districts used this device on two-lane highways where ODOT would receive a lot of complaints about trucks damaging private property to avoid a closed roadway. Another district is using the device in combination with numerous signs & various media outlets (television, internet, etc.) to keep trucks from using a bridge until repairs can be made.	The number of "stuck truck" complaints decreased dramatically after the district began using the CB Wizard. The only complaint was from a citizen that regularly uses a CB radio from his home – he was annoyed with the frequency of the messages.

Responses on the use of CB wizard Alert Systems (Continued):

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
OK	✓				We are using this device on case to case base depending on traffic volume, past crash history, and geometric of the project.	It has been very effective. When this device was used on project reduction of speed and work zone collision have been noticed.
TN				✓		
TX	✓				Traffic Radio and Highway Advisory Radio are approved strategies in our Work Zone Safety and Mobility Guidelines (rarely used for short term work)	Hard wired HAR : In place in a few locations which could be utilized for short term work zones, most often used for alternate route information during incidents, etc.
VA	✓				Used where there are heavy truck volumes, mostly on high speed (limited access) highways.	Moderate to very effective. Have been used in SW Virginia for years, especially for major events like the Bristol NASCAR races or major construction projects on I-81. Very visible results (trucks moving over sooner, slowing down, or taking alternate routes around congested areas) and by comments made by truckers while monitoring CB radio.
WA	✓				none…….case by case use	Only initial trail use, no formal evaluation
WV				✓	N/A	N/A

Responses on the use of Portable Highway Advisory Radio: (N/A indicates no further comment available)

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
AZ				✓	N/A	N/A
CT				✓	N/A	N/A
DE	✓				Using the DelDOT owned AM radio station, WTMC 1380AM, we notify drivers of all work zones statewide.	N/A
FL		✓			N/A	FDOT has used this device in the past and found it to be less effective, so FDOT is now using the existing dynamic message signs or installing temporary ones. Also, anyone in the state can call 511 for construction information
GA				✓	N/A	
IA				✓	N/A	the Iowa DOT is not interested in using these types of devices
IN	✓				N/A	Portable HAR stations are not currently in use by the Department but could be easily added using the same control methodology that exists for the fixed stations currently being operated
KY				✓	N/A	N/A
MA			✓		N/A	N/A
MD				✓	N/A	N/A
ME					N/A	N/A
MI				✓	N/A	N/A
MN		✓			N/A	We have had poor experience in the past with HAR and Mn/DOT is reluctant to use the device at this time. However, we are watching the technology improve and may find appropriate usage for HAR and/or CB wizard in the future.
MS				✓	N/A	N/A

Responses on the use of Portable Highway Advisory Radio (Continued):

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
NC		✓			N/A	Good for all forms of traffic, but has limitations on broadcast distances and the AM frequencies have poor reception until you're close to the devices. Also have the issue of the drivers willingness to tune into an AM frequency when the majority of drivers are listening to a higher quality frequency or other devices altogether (FM, satellite radio, IPOD, CD player, etc).
NE				✓	N/A	N/A
NJ	✓				Use on certain long term projects. Not short term.	N/A
NY				✓	Do not use. It would be impractical to install these devices for a short term work zone. We have used highway advisory radio in long term work zones.	N/A
OH	✓				N/A	Some of our districts feel that this device can be useful in some short-term situations. Our office has tuned in to some of the stations while performing work zone reviews (on long-term zones) and found that the signals are typically weak and the messages are usually outdated. The lack of text-to-speech technology and lack of a grounded signal contribute to the shortcomings.
OK				✓	N/A	N/A
TN				✓	N/A	N/A
TX				✓	N/A	N/A
VA	✓				N/A	Continue to use, but placement is critical in getting a strong signal out. Messages also need to be up to date. The public will call if they are not, so someone is listening to the messages. Mostly used on interstate type projects, although have been successfully used on primary route, long term projects.

Responses on the use of Portable Highway Advisory Radio (Continued):

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
WA	✓				N/A	Effective when used in an appropriate work zone strategy. Those work zones that depend highly on driver information to be successful can be improved using HAR's. Especially those work zones that are managed to provide drivers with alternates routes or open/close periods that give drivers the opportunity to make effective decisions. Just general project information does not seem to be an effective use.
WV				✓	N/A	N/A

Responses on the use of Changeable message signs:

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
AZ	✓				Driver information, speed reduction	Used extensively with considerable effect/benefit
CT	✓				To allow the traveling public the opportunity to avoid a traffic tie-up(work zone) or accident and give a possible detour if any.	These units portable and fixed are used throughout the state. They are very effective.
DE	✓				They are used as required by the project designers	These devices work extremely well in broadcasting site specific restrictions, closures, etc.
FL	✓				FDOT is currently using this device with the Motorist Awareness System. Link to Motorist Awareness System: http://www.dot.state.fl.us/rddesign/rd/rtds/08/670.pdf	N/A
GA	✓				The decision to use PCMS on projects is determined in the Field Plan Review meeting. GDOT's standards for lane closures on interstate and multi-lane divided highways requires a PCMS be positioned on the outside shoulder one mile in advance of the lane closure denoting a message "left/right lane closed one mile ahead".	GDOT uses PCMS typically on our multilane highways to advise motorist of lane closures, traffic shifts and/or detour ahead. We recently revised our specifications to always require their use on interstate and multi-lane divided highways one mile in advance of lane closure. This stemmed from feedback from motorist. We've received no complaints since we implemented this requirement.
IA	✓				the Iowa DOT is using portable changeable message signs on a project by project basis. See the attached Developmental Specification DS-01072	
IN					Used to provide nonstandard info and to get attention	Highly effective if used properly
KY	✓				Changeable message signs are used frequently, but are probably rare for work zones with durations of a day or less	N/A

Responses on the use of Changeable message signs (Continued):

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
MA	✓				(1), These are used to give advanced information to the motorists of any changes to traffic patterns or alternative routes. (2). The plan is to have these on certain projects where speed appears to be a factor and we can document the data and provide additional police presence to patrol the roadway. (3). These have been used in the past to alert those vehicles using radar detectors that there could be speed monitoring ahead and to slow down.	N/A
MD	✓				Install device in advance of work zone queue to warn of slowing traffic or recommend the use of alternate routes, use to notify of changing conditions (late lane merge), and in tandem with radar as a “driver feedback system” for speed awareness	Good effectiveness and versatile; deployment limited to wider shoulders.
ME	✓				N/A	N/A
MI	✓				Used to advise motorists of new/changing conditions in work zones.	Effective when used in real time applications
MN	✓				N/A	Very effective if used properly with current messages. PCMS in advance of our mobile operations and short term stationery work zones are optional in most cases for multilane roadways but required for night operations and our Metro District always uses them on high volume roadways as part of their district policy.
MO	✓				N/A	Missouri uses the CMS regularly to provide information before the start of a project and during the project. We do not use the CMS on every project, but on some that districts deem important. http://epg.modot.org/index.php?title=616.3_Changeable_Message_Signs_%28CMS%29

Responses on the use of Changeable message signs (Continued):

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
MS	✓				N/A	Standard for all construction projects and routinely used in maintenance operations
NC	✓				Changeable Message Signs are used extensively in our work zones to provide information to motorists. These can be either programmed messages about work zone conditions, lane closure information, real time travel info, speed limit info, etc.	Probably the single most effective tool to communicate with the motoring public due to it's varying capabilities, size and visibility. We use the portable CMS in nearly all work zone applications.
NE	✓				PCMS are used to supplement static signs and used for short duration signing needs.	These have been found to be fairly effective
NJ	✓				Not used as a standard on all short term projects	N/A
NY	✓				We use in both long term and short term work zones, primarily in long term due to deployment issues. We use PVMS as a work zone intrusion countermeasure, especially radar speed display equipped units. We have some truck mounted units which are appropriate for short term, short duration and mobile work.	Widespread use. We use various options such as remote control capability and radar/speed display capability. Considered effective if not overused or left in one location for too long.
OH	✓				ODOT utilizes the policies/strategies outlined in the OMUTCD.	These signs have proven to be an effective means of communication in various long-term work zone applications. They're also often used on interstates and other high-traffic areas to give motorists one or two weeks of advance notice of upcoming short-term work.
OK	✓				This device has been used on almost all projects.	It is very effective
TN	✓				None formalized	Very effective at keeping the motoring public aware of current and future roadway events.
TX	✓				Traffic Control Plan Standard Sheets require PCMS for lane closures on freeways. Approved strategy in Work Zone Safety and Mobility Guidelines.	Highly visible, versatile for conveying a wide variety of information.

Responses on the use of Changeable message signs (Continued):

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
VA	✓				To enhance static signing by reinforcing current conditions in the work zone.	Used on all type of roadways to give advanced notification of work zone activities. Very effective device based on observing motorist actions once the messages have been viewed. Changeable Message Signs – we often use our permanent CMS signs on interstates to advice of work zone activities and travel conditions – seem to be effective.
WA	✓				PCMS's have become an almost routine device. See attached M54-44 section on PCMS's	Very effective
WV	✓				N/A	Somewhat effective- can be overused, and messages become standard and repetitive of what is on the static signs. This is a standard item that is used on the design of West Virginia work zones, it is standard on expressway and corridor work zones.

Responses on the use of Portable Speed Display Trailers:

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
AZ	✓				N/A	Used moderately
CT	✓				N/A	These are used in certain rural work zones and are also effective. (Have realized a 10 mph reduction in speed when activated).
DE	✓				N/A	We find that sometimes motorists tend to test the limits of these devices to see how high they can get the speed. I have not found these devices to be totally effective.
FL	✓				FDOT is currently using this device with the Motorist Awareness System. **Other:** Portable Regulatory Signs	FDOT is currently using this device with the Motorist Awareness System.
GA	✓				N/A	GDOT is currently developing a specification for the use of Portable Speed Display Trailers. Their use will be determined at the Field Plan Review.
IA				✓	N/A	N/A
IN		✓				Not in use currently, mixed results in past
KY	✓				Can also be used but, again, are probably rare for work zones with durations of a day or less.	N/A
MA	✓				(2) We are in the process of utilizing these devices and we are looking forward to examining the data they provide.	N/A
ME					N/A	N/A
MI	✓				N/A	Effective if used in conjunction with police presence or enforcement.
MN	✓				N/A	We found these to be very effective in lowering speed past workers. Unfortunately, they have not been deployed routinely for short term work zones because we did not have many of them in our fleet. We are currently purchasing at least 2 units for each district to increase the usage of these devices.

Responses on the use of Portable Speed Display Trailers (Continued):

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
MO	✓				N/A	Our highway patrol will place these trailers in areas that experience high rate of speed. When used the police may or may not be at the work zone, but they will visit the work zone to keep the traveling public off guard. HP is normally located after (downstream) of the PSDT.
MS				✓	N/A	N/A
NC				✓	N/A	N/A
NE	✓				We have used speed display trailers to supplement advisory speed plaques in areas where drivers need extra warning.	They seem to work well.
NJ				✓	N/A	Not often used in work zones.
NY	✓				N/A	Considered effective. We just got a contract to purchase for our maintenance people.
OH				✓	N/A	N/A
OK	✓				We have used this device on few projects	N/A
TN	✓				Limited use.	Effective at reducing speed.
TX	✓				N/A	Used a great deal in some parts of the state, sporadically in others. Seem to be effective in lowering speeds by a few mph. Usually used in high speed areas.
VA	✓				Used on some Primary and secondary roadway type work zones with greater success during first couple of days. Helps to mix in law enforcement from time to time to keep motorist honest. On a couple of secondary projects, it was felt that the devise encouraged speeding by young drivers ("how fast did you get it to read?")	N/A
WA	✓				N/A	Only minor use, but shows promise

Responses on the use of Portable Speed Display Trailers (Continued):

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
WV	✓				N/A	Somewhat effective, but needs to be accompanied with a Traffic Director. This is a standard item that is used on the design of West Virginia work zones, it is standard on expressway and corridor work zones.

Responses on the use of Radar Drone:

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
AZ				✓	N/A	N/A
CT				✓	N/A	N/A
DE				✓	N/A	N/A
FL				✓	N/A	N/A
GA				✓	N/A	N/A
IA				✓	N/A	N/A
IN	✓				N/A	Radar drones, while not specifically specified for use, at times are included in the contractor provided portable CMS. This is an effective method of gaining the attention of approaching motorists who have radar detectors in their vehicles.
KY					N/A	N/A
MA		✓			Radar Drone	(3) With the laser detectors being used and the low number of radar detectors being out on the road these devices are becoming out of date.
MD			✓		Radar Drone	Currently in pilot test project; however, no information is available regarding its effectiveness at this time.
ME					N/A	N/A
MI				✓	Radar Drone	Not used. Trial project was not effective
MN					N/A	N/A
MO					N/A	N/A
MS					N/A	N/A
NC		✓			N/A	Have used the drone radar on a couple of projects, but needs to be installed where there's a lower percentage of commuter traffic otherwise, they'll wise up to the alarm. Also need an audience where you're targeting the most aggressive speeder since they'll more than likely have the radar detection devices in their vehicles. The majority of drivers do not have these devices

Responses on the use of Radar Drone (Continued):

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
NE	✓				Several projects have used a radar drone as well. We don't have a policy about when and where to use it though.	N/A
NJ					N/A	N/A
NY	✓				Radar Drone	Used infrequently. Inconsistent effectiveness and only reaches people with radar detectors. Might be appropriate for moving operations where drivers do not get accustomed to them at specific locations.
OH					N/A	N/A
OK					N/A	N/A
TN					N/A	N/A
TX	✓				Radar Drone	Sees occasional use in Texas, optional strategy, sometimes installed in traffic control contractor's vehicles. No policy. May be of some benefit in high truck traffic areas
VA		✓			Radar Drone	Have used with limited success – 2-4 mph reduction in speeds. Requires position changes to make motorist believe enforcement is in the area. Works best when used with periodic visible law enforcement.
WA		✓			Radar Drone	Evaluation done years ago……not currently in use
WV					N/A	N/A

Responses on the use of Truck Mounted Attenuators:

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
AZ	✓				N/A	Used extensively with considerable effect/benefit
CT	✓				These help keep our employees safe from potential errant vehicles that may encroach our work zone.	These are used in all of our work zones where there is a potential need to have a protective crash cushion (depending on the work being performed and the area work is being done, low speeds and rural roads may not need one).
DE	✓				Truck mounted attenuators are required for lane and shoulder closures on all limited access roadways within the State and on all highways which have four or more lanes that have a posted speed limit of 45 MPH or greater.	These devices are very effective. We have had a few of these devices hit in a crash and they have performed very well.
FL	✓				FDOT is currently using truck-mounted attenuators for mobile operations. Link to FDOT Design Standards for mobile operations: http://www.dot.state.fl.us/rddesign/rd/rtds/08/607.pdf http://www.dot.state.fl.us/rddesign/rd/rtds/08/619.pdf Link to Specs for Truck Mounted Attenuators: http://www.dot.state.fl.us/specificationsoffice/Implemented/WorkBooks/JanWorkBook2009/files/SS1020000.pdf	N/A
GA	✓				Our specifications require the use of a truck mounted attenuator for interstate and limited access roadways when pavement markings are being placed. We recently revised our specifications to allow their use on guardrail replacement projects not to exceed 48 hours in one location (alternate for another type of crash cushion for protection of exposed ends of guardrail). We have not used mobile work zone barrier on short duration projects	There have been accidents within a mobile operation where the truck mounted attenuator was hit yet protected workers and other equipment.

Responses on the use of Truck Mounted Attenuators (Continued):

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
IA			✓		N/A	N/A
IN	✓				Used per the MUTCD and the INDOT Work Zone Safety Manual	Highly effective. Trailer units becoming more popular
KY	✓				Commonly used on work zone projects. Can be used on projects that have durations of a day or less. Would be used at the discretion of the contractor unless required.	N/A
MA	✓				As mentioned before these devices are mainly used on high speed high volume limited access roadways but can and have been used elsewhere	These work very well in fact recently had one prevent a very serious accident. We are also using the towable type attenuators.
MD	✓				Use for all installation/removal or temporary traffic control devices where minimum posted speed is 55 mph.	**Good effectiveness.** This includes the trailer-truck mounted attenuators currently in use.
ME					N/A	N/A
MI	✓				Required for all mobile operations	Very effective tool.
MN	✓				Mn/DOT policy requires TMAs on vehicles in mobile operations on state highway work zones. But our MnMUTCD shows them as optional (should condition) since many locals do not utilize them yet. Refer to our Field Manual for standards. http://www.dot.state.mn.us/trafficeng/otepubl/fieldmanual2007/index.html We currently have TL-2 units on most of our fleet, but we are working on drafting a new policy which will phase in TL-3 units, and start with freeway and expressway operations as the first priority. No compliance date has been determined yet.	N/A

Responses on the use of Truck Mounted Attenuators (Continued):

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
MO	✓				N/A	MoDOT uses both Trailer and Truck Mounted Attenuators. They have protected many work zones. We use the TMA's in many applications. http://epg.modot.org/index.php?title=Category:612_Impact_Attenuators
MS	✓				Used for most maintenance mobile operations	N/A
NC	✓				Truck Mounted Impact attenuators are used as positive protection for moving and mobile operations as well as lane closure activities on control of access facilities. We have used moveable barrier on past projects, but only on a limited basis	A very effective safety device for the worker inside of a lane closure or for the moving caravan. These devices have dramatically improved work zone safety for these types of operations. They also provide foot workers excellent safety during the installation and removal of lane closures.
NE	✓				All mobile operations have a TMA, some work zones will employ them as well based on the type of work and the amount of protection already provided.	**Very effective.**
NJ	✓				Required for all operations.	**Used on all short term projects.**
NY	✓				Consider their use where workers are not protected by temporary barrier. Required where buffer space requirements cannot be met and on freeways. **Also using trailer mounted impact attenuators as an alternative to truck mounted**.	Very effective in blocking access to work zone and reducing accident severity. Cost is a concern to our maintenance people and Utility companies working under permit.
OH	✓				ODOT currently does not have a statewide policy regulating the use of TMAs. Some of our larger districts require them for mobile operations on freeways. Others allow them as long as the TMAs are installed and used per the manufacturer's specifications.	N/A

Responses on the use of Truck Mounted Attenuators:

State	Usage situation				Strategy/policy of using	Brand/Size and Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
OK	✓				We require TMA to be used on all projects. Work zone on all projects will be evaluated to see if this device needed	We have not had any negative comments about this device. Placing this device correctly on work zone is very important. Through work zone inspection we have been correcting their proper placement
TN	✓				**None formalized**	**Effective for non observant drivers**
TX	✓				Work Zone Safety and Mobility Guidelines and TCP Standards give guidance for TMAs.	Very effective when properly located.
VA	✓				TMA's – Shall be used when closing a lane on a multi-lane roadway with posted speed of 45 mph or greater, and for any mobile operation which occupies a portion of the travel lane.	Very effective, we have averaged 3 or more TMA crashes a year over the last 6 years which if the TMA had not been used, would have resulted in multiple fatalities.
WA	✓				See M54-44 section on TMA's	Very common and effective
WV	✓				To provide protection of workers and motorists.	This is a standard item that is used on the design of West Virginia work zones, it is standard on expressway and corridor work zones

Responses on the use of Balsi Beam or Mobile Barrier

None of the responding states have used this device in the past because of the high cost. *Florida* has not used this device and do not plan to in the near future. *New York* has not used due to cost and patent issues but we are interested to use it to prevent drivers from re-entering the closed lane. Have not used. *Virginia* Would like to see the cost of the device come down.

Responses on the use of Other Innovative Devices:

State	Usage situation				Strategy/policy of using	Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
AZ					N/A	N/A
CT					N/A	N/A
DE	✓				We utilize the Delaware State Police within our work zones to assist with positive protection. The presence of a police vehicle does not necessarily slow vehicles down, but it does help to bring more attention to the presence of a work zone.	
FL					N/A	N/A
GA					GDOT has used some portable type ITS systems (i.e. "Smart Work Zone") on some select long term projects but not on short term projects. We believe that when used, it benefits the local motorist because when prompted of lane closures or delays they would exit at another interchange and detour the work zone via other routes they were familiar with. Non-local motorist would continue through the work site. It did deter rear in collisions where motorist were advised ahead of time of reduced travel speed ahead.	None other than your typical advance warning signing, arrow panels or flagging operations. We had two test projects for the use of an automated flagger device. We have not included this in our specifications. When we tested this, we still required they have certified flaggers on site in case the automated flagger failed to work. The test projects were resurfacing type projects (one plant mix and the other surface treatment). After the surface treatment job started we discontinued its use because it took too long to keep moving the automated flagger (fast operations requiring the flagger station to change). We do allow portable temporary traffic control signals only on two-lane two-way roadways. Very seldom do we set this pay item up on a project. We have used it on some select bridge deck rehab type projects.
IA					N/A	N/A

Responses on the use of Other Innovative Devices (Continued):

State	Usage situation				Strategy/policy of using	Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
IN					Vehicle Probes for Delay Calculation and Upstream Communication to Approaching Vehicles	The Department is experimenting with an in-house design and deployment of a travel time delay system for work zones. The system is based on the 2008 ITE Journal article written by employees of INDOT and Purdue University. Detection of unique Bluetooth enabled device signatures from passing vehicles and subsequent pattern matching provide for calculation of travel times between two locations. These computed travel times are compared to the base travel time and result in delay times being communicated on portable changeable message signs. This system is undergoing a field operational test along a Interstate Highway work zone in Northwest Indiana. Findings from this test intend to be published in an upcoming technical journal paper.
KY					Flaggers Cones/Barrels Temporary Signing	Flaggers can be used at the discretion of the contractor. Typically used on two-lane roads where one lane is closed. Cones/barrels are used according to the Department's Standard Drawings. Depending on the roadway, cones may be used in place of barrels. Temporary signing is used. Signs are placed in advance of the work zone according to the Departments' Standard Drawings.
MA		✓			N/A	N/A
MD			✓		Currently in pilot test project; however, no information is available regarding its effectiveness at this time.	
ME					N/A	N/A

Responses on the use of Other Innovative Devices (Continued):

State	Usage situation				Strategy/policy of using	Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
MI			✓		Vehicle Activated Signs	Currently being developed.
MN	✓				Vehicle Activated Signs	We have Intelligent Work Zone systems which provide this type of system. Refer to our IWZ Toolbox for more systems we have deployed with successful results. We promote the usage of IWZ systems in our work zones, but the high cost of some systems prevents their usage in short term durations. http://www.dot.state.mn.us/trafficeng/workzone/iwz/MN-IWZToolbox.pdf
MS					N/A	N/A
NC					Smart Work Zone Technology Icone Technology	We've used smart work zone technology to provide travel time, alternate route info., weather related information, etc. in work zones. Basically, used roadside sensors to detect and send travel speeds information for processing the time information to a algorithm and then place this information on changeable message signs. Generally, these applications were well received by the public and they understood these were real-time messages instead of programmed messages. Currently, working with FHWA on a research project to determine work zone applications for these devices. In particular, we are interested in capturing data to establish our work zone performance criteria. These device acquire speed data and transmit the data (cellular/satellite) to a server for storage. They are also equipped with GPS technology enabling self location and uses the technology to view from internet. The web address is www.iconetraffic.com. California DOT is also participating in this research project in an effort to determine applications for their work zones

Responses on the use of Other Innovative Devices (Continued):

State	Usage situation				Strategy/policy of using	Effectiveness/ comments
	Are currently Using	Have used in past but not now	Not using but plan to	Not using		
NJ					N/A	N/A
NY	✓				N/A	N/A
OH					N/A	N/A
OK					N/A	N/A
TN					N/A	N/A
TX	✓				ITS/TMC	Where existing ITS features and Traffic Management Centers are in place, they can be very effective in providing messages to motorists via DMS signs or Lane Control Signals to assist short term work.
VA					Traffic Flares	Have used traffic flares to slow motorist down, especially in nighttime operations. Motorists slow down to see what is going on. In some areas, chemical light sticks have been tried, but we have no data yet on their effectiveness.
WA					AFAD (red/yellow lens type)	Use for high speed 2 lane highway flagging. Very effective and removes the flagger from a hazardous location
WV					N/A	N/A

Question 3: Has Your Organization Conducted Field Trials or Closed-Course Research For These or Other Devices?

Responses on New innovative test and evaluation:

State	Device/ Brand/Size	Research Title	Evaluated Results	Report available
AZ		N/A	N/A	N/A
CT		N/A	N/A	N/A
DE		N/A	N/A	N/A
FL	Dynamic Lane Merge	Evaluation of Safety and Operational Effectiveness of Dynamic Lane Merge System in Florida		Pending
GA		N/A	N/A	N/A
IA		N/A	N/A	N/A
IN		N/A	N/A	N/A
KY		N/A	N/A	N/A
MA		N/A	N/A	N/A
MD		Work Zone Safety Tool Box	http://www.marylandroads.com/Safety/oots/trafficsignalsandlaws/WorkZoneSafetyToolbox.asp	N/A
ME		N/A	N/A	N/A
MI		N/A	N/A	N/A
MN	PCMS DG3	We evaluated several PCMS devices for readability using employees driving past the devices on a closed course and providing a distance where the device was "readable" to them. We evaluated clear view fonts, DG3 sign sheeting, conspicuity lights on warning signs and other devices in a one day demo. Various reps from agencies reviewed devices day and night.	From the data we selected devices to be included on our Approved Product List for PCMS. From the surveys completed and data recorded we made decisions on various WZ practices, device standards, and material approvals.	http://www.dot.state.mn.us/trafficeng/workzone/pcms-review.html other reports may be found on our Work Zone webpage: http://www.dot.state.mn.us/trafficeng/workzone/index.html#handbook those reports include AutoFlagger (AFAD) and Dynamic Late Merge Results

Responses on New innovative test and evaluation (Continued):

State	Device/ Brand/Size	Research Title	Evaluated Results	Report available
MS		N/A	N/A	N/A
NC	1.SmartZone 2. CMS Speed Reductions	Evaluation of Smart Zones in NC	N/A	N/A
NJ	N/A	N/A	N/A	N/A
NY	N/A	N/A	N/A	N/A
OH	N/A	N/A	N/A	N/A
OK	N/A	N/A	N/A	N/A
TN	N/A	N/A	N/A	N/A
TX		TTI 0-1879-S TTI 0-4748-S TTI 0-4692-S TTI 0-4728-S	N/A	N/A
VA	N/A	N/A	N/A	N/A
WA	N/A	N/A	N/A	N/A
WV	N/A	N/A	N/A	N/A

Question 4: What Does Your Organization Consider to Be The Most Effective Devices or Processes to Reduce or Manage Work Zone Speeds in Short Term Work Zones?

Responses on opinion of most effective devices:

State	Effectiveness/ comments
AZ	Uniformed law enforcement seems to have the greatest impact on speed reduction in work zones. This option is used extensively and has been for many years in Arizona. Photo enforcement is also an option, though relatively new.
CT	See our guideline booklet that is attached.
DE	N/A
FL	FDOT does not have any for short term work zones.
GA	Law Enforcement Officers in conjunction with our reduced speed zone specification as noted in the attachment. You can visually see the motorist reduce their speeds when a LEO is present and a sign visible indicating hefty fines if caught speeding through a work zone. We've used it for 10+ years. The reduced speed zone is used on every project but the LEO's are only used occasionally on interstate type projects (typically for long term projects). However, when LEO's are not set up as a pay item, we still get assistance from local LEO's. Most area offices have developed a working relationship with the local LEO's. On their own, they sometimes monitor our work zones. On occasions, our local Area Engineers may ask them to monitor our work zone if they have time.
IA	We use a combination of PCMS, extra enforcement for longer term work zones. Short term work zones use our typical traffic control standards (TC-series of Standard Road Plana) these can be found at the following website. http://www.iowadot.gov/erl/index.html
KY	Police/vehicle enforcement officers can be used and are the most effective means at reducing vehicle speeds. The general presence of a police officer seems to positively affect motorist speeds. Additionally, radar trailers can also have an impact on vehicle speeds. These measures have been used for several years, and are routinely used today
MA	The blue flashing lights on the police cruisers at this time seem to be the most effective though not all the time. This application has been going on for many, many years on the high speed high volume roadways. Police and/or their cruisers had been used on just about every project in every year. We are hoping that with the new reader boards we can reduce the number of police and concentrate them on problem areas.
MD	The most effective process for reducing work zone speeds is the deployment of law enforcement personnel (LEO) in work zones. Standards/details for this process are included in SHA's Work Zone Safety Tool Box, listed at the above link. The basis for our determination that LEO deployment is the most effective speed reduction process is based on interviews with workers and the LEOs themselves. Currently, there is no quantitative data.
ME	

Responses on opinion of most effective devices (Continued):

State	Effectiveness/ comments
MI	Speed surveys are conducted annually to determine if posted speed limits are appropriate. Whenever possible, speed limits established that are too low are revised to match motorist speeds in the work zone (85th percentile) without violating state or federal laws. Crashes (rear end and sideswipe same) are lagging indicators of speed differential, one of the primary contributors to work zone crashes. With proper monitoring and establishment of a more realistic speed limit in work zones, these crash types continue a downward trend.
MN	We have a well established and funded program for extra enforcement for our long-term construction projects, but short term maintenance projects do not have funds for extra enforcement and have always been a concern for speeding. During the 2009 season, we will be starting a new "informal" partnership program with our State Patrol for "extra enforcement" within our short term maintenance work zones. A few districts will be supplying the patrol a daily list of maintenance work zones on their in-vehicle CAD (computer aided dispatch) system. The patrol has agreed in some areas around the state to seek out these locations if they need a place to stop and do paperwork. This will not provide actual enforcement since the officer may not be watching the traffic, but their presence within the work zone reduces speed more than anything else. Our maintenance forces will not have patrol available for long periods of time, everyday or every job, BUT previously, they never had patrol near their work zones, so this will be an improvement and for NO added cost.
MS	We have not tried anything for short term work zones. Targeted speed enforcement has only been used on long term work zones.
NC	1) Haven't done a lot in this area, but we have some limited data supported it's application. Primarily, we use CMS's to perform short term speed limit reductions. However, we have also used portable signs on a couple of projects as well. These are used for periods not to exceed 30days and are not displayed when the lane closures are removed or when workers aren't present. We have received a lot of positive input from the field personnel, but haven't captured a lot of actual speed data on these applications. I'm attaching the information we do have to date. 2) We primarily use these applications on interstate resurfacing and interstate rehabilitation projects where lane closures are used everyday and most often removed everyday.
NJ	The use of Police in the work zone and truck mounted attenuators on the short term projects are effective as they are mobile. In use since the 1990's. So often as the standard have no numbers.
NY	Radar equipped PVMS and police enforcement are our most effective tools and they are marginal at best and of limited practicality for short term work zones due to deployment issues. Work zone speed control remains a difficult issue, even on longer term work zones.
OH	While ODOT doesn't have an official police regarding short-term work zones, we try to ensure that our internal work crews follow safe practices by providing multiple training sessions on the proper setup of work zones. These employees also receive laminated pocket guides (7" x 3.75") that contains key standards and typical applications that they may come across in the field. As mentioned in question #1, ODOT makes an effort to provide advance warning of short-term projects, particularly on interstates.

Responses on opinion of most effective devices (Continued):

State	Effectiveness/ comments
OK	Most beneficial device used for short term work zone has been TMA and channelizing device. Depending on project, duration, and the location of the project Police surveillance also been utilized to reduce the speed and make the work zone safer.
TN	Uniformed Traffic Control Officer In Use for several years Most Interstate and multilane highway projects
VA	We have higher standards for traffic control devices and how they are installed than found in the MUTCD. Our Part VI is called the Virginia Work Area Protection manual, attached is the link to our manual and out typical traffic control layouts: http://www.virginiadot.org/business/resources/WAPM-2005-Revised10_05.pdf Examples of higher requirements: Use of 48” x 48” warning signs Use of additional signs for lane closures (all roadways) Closer spacing of channelizing devices Use of 36” cones on all roadways Larger arrow panel displays Use of PCMS Use of TMA’s Use of drums (with 6 inch stripes) in unmanned WZ’s Required use of Buffer spaces Longer tapers (1000’ minimum) for high speed roadways Flagger certification requirement Worker training requirement Use of preformed tape pavement markings
WA	We manage work zones speeds by designing or implementing work zones based on the assumption that traffic will not slow. We apply devices and equipment to give the best warning and protection at posted highway speeds. Other than extensive use of law enforcement in work zones, all other devices or strategies (except physical roadway restrictions) are not reliable in ensuring that drivers will voluntarily reduce there speed.
WV	N/A

K-TRAN

KANSAS TRANSPORTATION RESEARCH AND NEW-DEVELOPMENT PROGRAM

Kansas
Department of Transportation