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16. Abstract

Thousands of crashes occur in work zones each year, leading to numerous fatalities and injuries. A sizeable portion of these crashes can be attributed to excessive speed, which emphasizes the need to motivate drivers to comply with speed limits in work zones. Motivating drivers to comply with traffic regulations is an extremely important yet challenging task in reducing the potential for conflicts and is critical to the safety of both motorists and workers. This research project was conducted to determine effective measures to motivate and encourage drivers to observe posted speed limits in work zones. Findings from literature and a survey of Department of Transportation (DOT) personnel indicate that a wide variety of methods have been tested to improve compliance. Methods for establishing work zone speed limits differ from state to state. Survey respondents widely regarded enforcement as the most effective treatment, but desired other effective methods to reduce costs and improve worker and officer safety. Three devices were tested in this project: speed display trailer, changeable message sign with radar, and orange-border speed limit sign. Results indicate that devices with the ability to display drivers' speeds have a noticeable effect on improving compliance. Orange borders greatly improve the visibility and conspicuity of speed limit signs, but they do not have a consistent measurable effect on compliance. In the absence of active enforcement, data from this project indicate that drivers are likely to drive as fast as they feel comfortable regardless of the posted speed limit.

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IDENTIFICATION AND TESTING OF MEASURES TO IMPROVE WORK ZONE SPEED LIMIT COMPLIANCE

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DISCLAIMER

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The research team recognizes Darren McDaniel, the project director; Elizabeth Boswell, the program coordinator; and current and former project advisors Doug Skowronek, Javier Murillo, Keith Dunmire, and Ken Boehme. Researchers thank these members of the Project Monitoring Committee for their time in providing direction and comments for this project.

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CHAPTER 1
INTRODUCTION

OVERVIEW

Motivating drivers to comply with traffic regulations is an extremely important yet challenging task. Further, motivating drivers to comply with regulations within work zones is critical to the safety of both highway workers and motorists traveling through the work zones.

According to the Texas Department of Public Safety (DPS), more than 9500 crashes occurred in work zones on the state highway system in 2000, which resulted in 143 fatalities and approximately 9900 injuries. Speed was cited as a contributing factor in approximately 42 percent of these crashes (*1*).

Improving compliance with work zone speed limits is a vital step to improving work zone safety and reducing the number of injuries and fatalities that occur within them. The problem is not new, and many efforts have been made to address the problem. These efforts have had varying degrees of effectiveness; some should be utilized on a more widespread basis, while others should be refined or discontinued. However, identifying the proper treatments to use at a given work zone is sometimes difficult. A project engineer needs to know all of the available treatments and then determine which are appropriate for existing conditions.

To address these concerns, the Texas Department of Transportation (TxDOT) sponsored Project 0-4707: Development of Measures for Motivating Drivers to Comply with Speed Limits in Work Zones. The goal of TxDOT Project 0-4707 is to determine effective measures to motivate and encourage drivers to observe posted speed limits in work zones by:

- evaluating traditional measures including speed limit enforcement and traffic control devices,
- identifying new technologies that may be suitable for work zones,
- field testing two to three promising devices, and
- developing guidelines for recommended work zone designs based on literature review and field testing.

ORGANIZATION OF REPORT 0-4707-1

This report, Research Report 0-4707-1, describes activities and findings over the two-year life of the project. In addition to this introductory chapter, there are six other chapters and two appendices.

Chapter 2 summarizes the findings from the literature review and state-of-the-practice on work zone speed limit laws and treatments to improve compliance. Chapter 3 describes two concurrent surveys of personnel from the TxDOT and other state DOTs; the results of the surveys and researchers' conclusions are presented there. Chapter 4 describes the process of selecting devices for testing in this project, based on perceived effectiveness, installation requirements, and likelihood of future implementation. Chapter 5 discusses the field studies performed in this project, including site selection and data collection procedures. Chapter 6 contains the results from data analysis, and Chapter 7 presents the research team's findings and conclusions.

Appendix A lists the full text of the questions used in the DOT surveys, as presented to the survey participants on the survey web site. Appendix B contains a draft chapter the authors propose to include in the TxDOT work zone safety and mobility manual currently under development. Appendix B also serves as the documentation and submission of Product #P1 for Project 0-4707: research recommendations in a format appropriate for inclusion in the forthcoming manual containing TxDOT's state-level work zone safety and mobility policy.

CHAPTER 2
LITERATURE REVIEW

INTRODUCTION

Roadway construction under traffic conditions has become commonplace due to the maintenance, repair, and reconstruction of existing roadway facilities. The potential for conflicts increases when construction activities and traffic share the right-of-way. According to the Texas Department of Public Safety, 9523 crashes occurred in work zones on the Texas state highway system in 2000, which resulted in 143 fatalities and 9899 incapacitating, non-incapacitating, and possible injuries. Speed was cited as a contributing factor in approximately 42 percent of these crashes (*1*).

National statistics indicate that 1079 fatalities resulted from motor vehicle crashes in work zones in 2001, and 249 of these resulted from large truck crashes (*2*). These statistics emphasize the need to motivate drivers to comply with speed limits in work zones.

In order to develop a method, or system of methods, for reducing speeds in work zones, it is necessary to have a proper understanding of the issues related to work zone speeds. This document contains a review of laws related to work zone speed limits, enforcement methods, and previous studies on speed reduction methods.

WORK ZONE SPEED LIMIT LAWS

Laws in Texas

The Texas Legislature has mandated that within the state of Texas, work zone speed limits (WZSLs) are established by a minute order of the Texas Transportation Commission or by city ordinance. The project engineer makes a recommendation to the Commission based on the:

- nature and duration of the project,
- extents of the work zone, and
- traffic and roadway characteristics within the work zone.

The Commission or city then sets the WZSL, which may be posted during the specified time of the project and within a specified area, defined from a beginning milepost to an ending milepost. No variable speed limits are allowed; the Commission or city sets one value for the WZSL that is in effect for the entire project. The Commission or city also defines buffer areas leading up to the work zone. During the project, the project engineer has the discretion to adjust posted regulatory speed limits between the normal speed limit for that section of roadway and the lesser WZSL approved by the Commission or city.

The current process provides for the Commission or city to set WZSLs for construction projects. However, there is no such allowance for maintenance projects, which are often of shorter duration and provide less advance notice than a construction project, but still utilize lane closures and require workers to be in close proximity to through traffic. Texas law allows work crews to post lower advisory speeds for these types of conditions, but they do not carry the same force of law as a regulatory WZSL *(3)*.

In 1998, Texas implemented a "double-fine" law for traffic violations in work zones. This law doubles the minimum and maximum fines applicable for traffic violations that occur in a work zone where workers are present. A recent study by Ullman, Carlson, and Trout reviewed this law to assess its effects and identify possible improvements *(3)*. Based on their review, they made four legislative recommendations:

- Eliminate the worker presence requirement from the double-fine law (to simplify enforcement and generate respect for the work zone as a whole, not just when workers are present).
- Increase the minimum fines for a work zone violation (in comparison to the current $2 minimum, based on the violation).
- Modify the double-fine law to require a fine or greater court costs to be assessed on motorists who commit a work zone violation and require that they take a defensive driving class to dismiss the charges (to extend the spirit of the double-fine law to all violators).
- Develop legislation to allow a reduced regulatory speed limit to be posted in certain maintenance work zones (to promote consistency between construction zones and maintenance zones and place emphasis on the need for reduced speed where workers are in close proximity to traffic).

Ullman, Carlson, and Trout also examined three other types of laws, which were not recommended for adoption in Texas. "Payback" legislation uses the extra revenue from work zone fines to fund additional enforcement efforts; however, since local municipalities rely on these traffic fines, it would likely face strong opposition to passage. "Reckless endangerment" legislation provides a stiffer penalty on a motorist who has a crash in a work zone that injures workers; its intention is not necessarily to reduce crash potential or reduce vehicle speed. "Failure to obey" legislation is similar to endangerment legislation in that it imposes an additional penalty on a driver who does not obey the instructions of a flagger and causes a crash. The authors anticipated that these latter two types of legislation would be very difficult to implement effectively and would not necessarily be an effective deterrent (*3*).

Laws Elsewhere

A search of the National Work Zone Safety Information Clearinghouse produced a summary of enhanced fine legislation related to work zone speeds in each state (*4*). The summary reveals that 31 states have a double-fine law, in general. Some states modify the double fine to specify a minimum or maximum fine (i.e., double fine up to $1,000, six months in jail, or 120 hours of community service in Nevada). Four more states have a fine equal to the base fine times a different multiple (i.e., base times 1.5 in Louisiana) or plus some amount (i.e., base plus $250 in North Carolina). Fourteen states have fines in fixed amounts not directly related to the base fine (i.e., $200 for first offense and $350 for subsequent offenses in Illinois). One state, Hawaii, does not have enhanced fines in work zones. In addition to speeding, some states also include other work zone violations for enhanced fines (i.e., failure to merge in Indiana). Eleven states specify that "all traffic violations" or "all moving vehicle violations" are valid offenses for enhanced fines.

The National Work Zone Safety Information Clearinghouse also has information on other work zone legislation (*5*). Seven states (Indiana, Kentucky, Maine, Minnesota, Montana, Nebraska, and Rhode Island) allow WZSLs to be set or reduced without a traffic and engineering investigation. These states put various limits on that authority, setting boundaries and maximum differences from normal speed limits. For example, Maine's law states that WZSLs can be set between 25 and 55 mph, with a maximum speed limit reduction of 10 mph. Montana's law states that the DOT or local authority must set the WZSL based on traffic conditions or the condition of the construction, repair, maintenance, or survey project. Four states (Michigan, Montana, Oregon, and Washington) have laws against the reckless endangerment of highway workers; maximum fines vary from $300 and 90 days in jail in Montana to $7,500 and 15 years in prison (for a fatality) in Michigan. Oregon also has a law against refusing to obey a flagger, with penalties identical to the reckless endangerment law. Utah has a similar law, which states that a person may not willfully fail or refuse to comply with any lawful order or direction of a peace officer, fireman, or flagger at a highway work zone. Finally, South Dakota has a law authorizing agents of DOT employees to issue citations for speeding within work zones; workers must be present and signs indicating the work area are required for citations to be given.

The Minnesota Department of Transportation (Mn/DOT) has published a stand-alone document for establishing WZSLs. *A Guide to Establishing Speed Limits in Highway Work Zones* (6) discusses advisory speed limits based on:

- road conditions,
- worker presence and safety,
- work zone speed limits, and
- temporary speed limits in a construction zone.

Table 2-1 provides a summary for establishing the various speed limits. The *Guide* also contains a brief synopsis of applicable state laws and a description of extra enforcement options and compensation.

In 1999, Migletz et al. developed a procedure for determining work zone speed limits during the design or construction phases of a construction project *(7)*. The procedure classifies work zones by the potential hazard present, as represented by the location of work activities or traffic controls in relation to the traveled way, instead of the prevailing speed of traffic. Using findings from related studies, researchers developed guidelines for implementation.

DRIVER COMPLIANCE

Motorists tend to slow down in the presence of police enforcement. The magnitude of the speed decrease depends on the relative level of the speed limit and the perceived severity of the threat. A 1982 Federal Highway Administration (FHWA) study reported that, in most cases, the decrease in speed is less than 3 mph, but reductions up to 10 mph have been observed *(8)*. Other studies have reported even greater speed reductions during stepped-up enforcement efforts.

These reductions included 10 to 15 percent reductions in speed depending upon the type of enforcement used. A marked police vehicle parked with lights flashing and simulating an arrest produced the largest speed reduction.

Table 2-1. Summary for Establishing Speed Limits in Highway Work Zones in Minnesota (6).

METHOD	DESCRIPTION	EXAMPLES	AUTHORITY
Advisory Speed Limits (Road Conditions)	For driver safety, warning signs with speed advisory plates call for the driver to reduce speed to safely negotiate a potentially hazardous condition caused by the work activity. **Advisory speed limits should be the first consideration.**	Bump, low shoulders, drop-offs, bypass indicating the curve, narrow lanes, no shoulders, sight distance restrictions, or poor road surface.	Established by the district or local road authority.
Advisory Speed Limits (Worker)	For worker safety at spot locations and under temporary conditions. Warning signs alert motorists that there are workers ahead.	Maintenance or construction operations at spot locations.	Established by the district or local road authority.
Work Zone Speed Limits	For worker safety, regulatory speed zones generally established in short-term stationary construction or maintenance work zones. Intended for use where the work area and workers are adjacent to traveled lane(s) open to vehicular traffic. **Posted only during continuous worker activity when workers are present and adjacent to moving traffic.** Not to be used on mobile or moving operations, or when flaggers are used to provide control on a lane closure on a two-lane two-way roadway.	Pavement repair, bridge repair, loop detector installation, turn lanes, mill and overlay projects, concrete joint repair, and crack sealing with multiple operations.	Established by the district or local road authority.
Temporary Speed Limits in a Construction Zone	Regulatory speed zones intended for **24-hour continuous posting** established in long-term projects where it is imperative for the motorist to reduce speed in order to safely navigate through hazards over the length of the project.	Bypasses, shoulder drop-offs, narrow lanes, grade separations, and pavement repair.	Established by the commissioner as recommended by the district traffic engineer.

The distance that the speed reduction effect extends from the enforcement symbol depends on the frequency or strategy of patrol, the patrol method, the traffic situation, and other factors. In most cases, this distance is less than 3 miles on either side of the symbol, but one study found an effect up to 4 miles upstream of the enforcement unit and 10 miles downstream *(8)*.

Other than enforcement (or the threat thereof), the other primary factor that affects drivers' compliance with WZSLs is the risk of collision or injury. Elements contributing to this risk include:

- traffic volume,
- roadway cross-section (lane and shoulder widths),
- road surface conditions,
- weather conditions,
- awareness of the posted speed limit,
- awareness of workers and equipment present in the work zone and their proximity to traffic, and
- advance notification of the upcoming work zone.

A 1984 TxDOT study had the objective of determining or developing effective methods of slowing traffic to an acceptable speed in work zones (9). Researchers considered cost, motorist and worker safety, institutional constraints, and probability of success in obtaining the desired speed. The results indicated that flagging and law enforcement were very effective methods of speed control in work zones. An innovative flagging approach, the flagging method described in the *Manual on Uniform Traffic Control Devices* (MUTCD flagging), a police traffic controller, and a stationary patrol car were found to be very effective treatments on most highway types. The results were inconclusive with respect to changeable message signs (CMS).

The remaining sections of this report examine these motivating methods in greater detail.

ENFORCEMENT STATE-OF-THE-PRACTICE

Funding of Work Zone Enforcement

Extra enforcement in work zones can either be provided on a cooperative or dedicated basis. Cooperative enforcement entails the use of on-duty officers that simply increase their regular patrol area to include the work zone. In contrast, dedicated enforcement agreements provide additional officers specifically for the purpose of enforcing the work zone (*10*). In almost all cases off-duty officers are utilized for the additional enforcement.

Most funding for additional officers in work zones comes from state construction funds slated for the particular project (*11*). Additional funding sources, such as utilizing revenues from work zone fines, are also available in some states (*10*). The state DOT performs the actual hiring of the officers in about half the cases and the contractor in charge of the construction project hires the officers in the remaining cases (*12*).

Enforcement Practices in Work Zones

Previous studies indicate that police officers utilize three main types of enforcement activities: stationary, traffic control, and mobile. The stationary technique entails positioning the police vehicle in a highly visible portion of the work zone. The officer remains in the vehicle and uses its presence to help control speeds through the work zone. Officers involved with traffic control are out of their vehicles, providing instructions to motorists as they pass through the work zone. Finally, the mobile technique entails having one or more officers continually drive through the work zone, and, if necessary, pull over vehicles that violate the laws within the work zone.

A recent survey of state law enforcement personnel found that of the states surveyed, the stationary technique was most commonly used. Nine states responded that they also use the mobile technique through the work zone (two states use this technique exclusively). Four states reported that the enforcement presence in the work zone was effectively increased simply by increasing the number of police patrols in the area near the work zone. In fact, one state extended the additional patrols to cover the area just prior to and just after the work zone. In general the officers felt that the mobile patrols were more effective because of the flexibility that "being on the move" provided (*12*).

Effectiveness of Extra Enforcement

Several studies document the effect that extra enforcement has on the safety and operations within the work zone environment. Results show that stationary enforcement techniques tend to be the most effective in reducing speeds through the work zone. Such techniques have been found to reduce speeds by up to 12 mph in some cases. The mobile enforcement techniques, preferred by officers, reduce speeds by less than 5 mph throughout the work zone. The speed reductions were most dramatic for the drivers that could "see" the enforcement vehicle in the traffic stream (*10*).

While most transportation departments and law enforcement agencies feel that increased enforcement in work zones increases the safety of the work zone, direct measurements of accident reductions are not easily found in the literature. One North Carolina study found that although the number of crashes actually increased during extra enforcement periods, the number of fatal crashes within the work zone declined (*13*). To make more definitive conclusions, researchers need additional studies that relate measurable speed reduction and a decrease in certain erratic maneuvers within the work zone to a reduction in crashes.

Potential Methods to Enhance Enforcement

A recent Texas Transportation Institute (TTI) study (*14*) provided some suggestions on four strategies that agencies could use to enhance the effectiveness of enforcement:

- work zone length restrictions and shoulder enforcement areas,
- staging pads for enforcement personnel,
- real-time notification of the presence of workers, and
- real-time remote speed enforcement.

The first strategy dealt with limiting the distance that a lane could be closed within a work zone or providing periodic shoulder areas so that enforcement vehicles have the ability to pull over offending vehicles if necessary. Second, the provision of staging areas near the start of the work zone was also suggested to allow enforcement personnel a safe area to observe traffic flows. Third, the use of advanced technologies to notify motorists when workers were present would also serve to notify enforcement officers who would have to certify the presence of workers for a double fine. The final strategy considered the use of remote speed enforcement from an off-site location; this would allow automated recording of speeds at the point of violation, but the enforcement officer would be able to pull over offending vehicles outside of the work zone.

Pullout Enforcement Areas

Concerning the first strategy, the TTI study did further research on the spacing and length of shoulder enforcement areas, surveying the interests of both enforcement agencies and construction contractors (*15*). The need was to balance the contractor's desire for a work zone with minimal disruption and the agencies' need for a safe place to issue citations to offenders. The survey responses led the researchers to recommend spacing shoulder pullout areas between

2.0 and 3.0 miles. Additionally, this provides an indication of the length of work zone that can reasonably accommodate enforcement activities. The researchers also performed a review of the *Green Book* for acceleration/deceleration guidelines and a study of the driving behavior of passenger car drivers after a traffic stop in non-work zone locations. Based on these elements, the researchers concluded that a 0.25-mile long pullout area would be sufficient for a highway work zone with a speed limit of 60 mph; the ideal length would be 1700 ft (*15*).

Remote Speed Enforcement

The concept of effective speed enforcement in work zones is related to the ability of an enforcement officer to verify a violation and then safely issue the citation. To address this problem, researchers proposed the concept of remote speed enforcement (*14*). Remote speed enforcement (or automated speed enforcement) devices utilize a radar or lidar unit that detects speeds of oncoming traffic. The device takes a picture of the vehicle's license plate (and of the driver if needed in certain jurisdictions). Figure 2-1 shows an example of such a picture (altered in this document to obscure the license plate and the specific data of the subject vehicle). Typically, law enforcement officials use these photographs to mail traffic citations or warnings to the registered owner of the vehicle. The system offers a chance to improve work zone safety since officers do not have to pursue, or attempt to pull over, vehicles within the work zone.

A similar idea was proposed to use an officer with a remote device to enforce WZSLs (*16*). An officer positions the device upstream of the work zone to "watch" for violators; the officer then waits downstream to issue citations to violators. When an upstream violation occurs, the device records the picture and sends the image to the officer, who issues the citation; this keeps the actual enforcement activity out of the work zone where conditions restrict movements. A field test of a remote enforcement system produced results such that downstream observers could identify between 84 and 88 percent of vehicles based on transmitted images. The results were unaffected by the distance between the camera and observer; the results were also independent of whether vehicles were photographed from the front or the back. Discussions with law enforcement officers led to the conclusion that there was significant potential for use, but there may be some initial legal challenges to the use of this system until it is accepted by the courts. Some officers felt the system could be used in the existing legal structure and would provide a safety benefit to enforcement personnel. However, other officers felt that some modifications would be necessary before the system could be used in Texas. DPS representatives felt that it would need to be tested in the courts in order to assess the legal ramifications of the system (*16*).

Figure 2-1. Sample Remote Enforcement Picture (*16*).

Comprehensive Enforcement Programs

Good coordination between the department of transportation and the enforcement agency is essential for maximizing the effect of work zone enforcement. Several examples of well coordinated enforcement activities can be found throughout the United States. The Maryland State Police have a full-time liaison to the State Highway Administration. This liaison is able to influence construction phasing and work zone establishment early in the project to ensure that work zones are designed to allow for effective enforcement. The New Jersey State Police, who have an entire construction unit that is responsible for working with the Department of Transportation, use a similar program. Their involvement helps to establish consistent enforcement practices in work zones throughout the state. In both states these special police units work and train with the construction personnel to maximize the effectiveness of the enforcement.

The officers assigned to these special programs also train additional police officers that help enforce larger or additional work zone projects on an overtime basis (*17*).

A special program in South Dakota known as the DOTCOP program greatly expands the pool of available officers to enforce a work zone. Any sworn officer (i.e., local police, school police, sheriff's deputies), either active or retired, can participate in the DOTCOP program. Officers in this program have jurisdiction limited to the work zone area and are outfitted in special uniforms and vehicles. While no formal studies have been completed, the South Dakota Highway Patrol believes the program has been successful in improving safety and reducing speeds (*14*).

SPEED REDUCTION METHODS

Outside of enforcement efforts, agencies have used other methods and devices in an attempt to motivate drivers to comply with WZSLs. Most of these methods are intended to increase a driver's awareness of the existence of the work zone, the reduced speed limit, and/or the presence of workers. Other methods utilize roadway design elements to encourage or force drivers to slow down within a work zone or on the approach to a work zone. The following section examines a few of the more common speed reduction methods and some innovative treatments in recent studies.

Changeable Message Signs

A commonly used device to increase driver awareness in work zones is the CMS. Much research and field testing has been done concerning the effectiveness of CMSs; a few of the findings will be reported here.

CMSs can provide drivers with real-time information about conditions, and can be particularly useful at work zones where unexpected traffic or detour situations exist. The decision to use CMSs is based on a number of factors including availability, reliability of equipment, and installation and maintenance costs (*18*). Portable CMSs (PCMSs) are often used to display a reduced advisory speed and/or statement to reduce speed or proceed with caution. These signs perform a function similar to traditional signing, but the increased conspicuity of the sign and the flashing messages of bulb-matrix signs make them potentially more effective in reducing work zone speeds. Previous research indicates that CMSs provide modest speed reductions in some cases. Also, CMS effectiveness may diminish over time as drivers become accustomed to the presence of the sign. In addition, there are concerns whether officers can enforce the advisory speed presented by a CMS similar to a statutory speed limit.

A 1984 TTI study evaluated two CMS treatments differing in the type of message presented (9). One presented a speed and information message (i.e., DETOUR AHEAD 35 mph), while the other presented only a speed message (i.e., 35 mph). The two treatments resulted in approximately the same reduction in speeds, 0 to 5 mph. There was no change in speeds on an urban freeway with the speed-only message, while the largest change occurred on a rural freeway using either message.

Speed Display Trailers/CMS with Radar

McCoy, Bonneson, and Kollbaum conducted a study to determine the effects of speed monitoring display systems (*19*). The systems measure the speeds of approaching vehicles and show these speeds to traffic on a digital display panel adjacent to a static sign displaying a regulatory or advisory speed limit. The system is intended to slow traffic by making drivers aware of their speeds in relation to the posted speed limit. Researchers also expected that the use of radar would cause some drivers using radar detectors to slow down as well. In a field test on an interstate highway in South Dakota, mean approach speeds were reduced by 4 to 5 mph, and the percentages of vehicles exceeding the advisory speed limit of 45 mph were reduced by 20 to 40 percentage points.

Pesti and McCoy evaluated the long-term effects of speed monitoring displays (*20*). Three display trailers were deployed for five weeks in two work zones on an interstate highway in Nebraska. Upon analyzing the mean, 85^{th} percentile, and standard deviation of approach speeds and the percentage of vehicles complying with the speed limit, researchers determined that display trailers were effective in lowering speeds, increasing uniformity of speeds, and increasing speed limit compliance. The combined long-term effect of the display trailers showed statistically significant improvement in both speed reduction and speed limit compliance. One week after removal of the display trailers there were still statistically significant speed reductions and compliance increases, although they were less pronounced than during the deployment.

Wang et al. examined the effects of a CMS with radar (CMR) (*21*). For vehicles traveling 5 mph or more above the speed limit, the CMR displayed the message “You Are Speeding, Slow

Down Now." If no vehicles were present or vehicles were within the 5-mph threshold, the CMR displayed the message "Active Workzone, Reduce Speed." The researchers found that the CMR provided significant speed reduction, on the order of 7 to 8 mph. Speed variances were reduced at both the CMR location and the area adjacent to the active work area. The CMR did not display a novelty effect during the study, in that speeds did not return to previous levels after removal of the device.

Innovative Signs

Agencies have tried many devices to encourage drivers to reduce speeds on roadways and within work zones. Some of the more innovative signing is illustrated in Figures 2-2 to 2-4.

Figure 2-2. Innovative Use of Speed Display.

Figure 2-3. Innovative Static Message Sign.

Figure 2-4. Innovative Message on CMS.

Wang et al. also examined the effects of an innovative message sign, similar to that shown in Figure 2-3, but a diamond-shaped sign rather than rectangular *(21)*. Based on a suggestion that an attention-getting work sign such as "Slow Down, My Dad Works Here" (written in a childlike font) may positively influence speed reduction, researchers decided to include it in their study. The use of innovative message signs resulted in a speed reduction of 0.2 to 1.8 mph during daylight conditions for one site but had little effect at a second site. The signs generally had little effect at night. Several weeks following deployment of the signs, work zone speeds continued to decrease, relative to speeds observed immediately after implementation.

Flagging Treatments

A 1984 TTI report summarized the efforts of a study testing two types of flagging procedures, MUTCD flagging and innovative flagging *(9)*. MUTCD flagging was the "alert and slow" signal detailed in the then-current edition of the MUTCD. The flagger slowly waved the flag in a sweeping motion with an extended arm from shoulder level to straight down without raising the flag above a horizontal position. The flagging maneuver was performed continually whenever traffic was present.

The innovative flagging procedure was a modified version of the MUTCD treatment. The flagger performed the MUTCD flagging motion to get the attention of drivers and then established eye contact with the drivers. Having established eye contact, the flagger motioned for drivers to slow by raising and lowering his/her free hand, palm down, several times. The flagger then pointed to the adjacent speed sign to indicate the appropriate speed. Under light traffic volumes, the flagger could direct the innovative signal to each driver. When traffic volumes were heavy, the signal was presented to drivers leading platoons and to as many additional vehicles as possible.

In a field test of the two flagging procedures, the innovative flagging treatment resulted in larger speed reductions than MUTCD flagging at five of six study sites, with reductions in mean speed of 4 to 16 mph (*9*).

The biggest disadvantage of flagging is that, like enforcement, it still requires stationing someone at a strategic location and it still entails an extra cost to the project. In addition, flagging is tedious and physically taxing work; a flagger can become distracted or fatigued, reducing the effectiveness of the method. Finally, flagging is only appropriate for work zones on certain types of roadways, particularly rural two-lane roadways.

Lane Narrowing

The 1984 TTI study also tested two effective lane width reduction treatments, one with a 12.5-ft lane width and the other with an 11.5-ft lane width (*9*). Researchers used cones as the narrowing device for both treatments. At freeways and urban arterial sites, the cones were placed on both edgelines but not on the lane lines. At two-lane, two-way highway sites, cones were placed on the edge of the travel lane and on the centerline. For a given site, the two treatments had approximately the same effect on speeds, with observed reductions of 0 to 8 mph. There were slightly higher reductions for the 11.5-ft width, but the reductions were neither statistically nor practically significant. A related finding was that even though the mean speeds were reduced, the speed variance actually increased.

An important finding in this study was that cones proved to be somewhat hazardous devices for effectively reducing lane widths below 12 ft. At the 11.5-ft width, drivers hit cones frequently and on one occasion knocked them into the travel lane, causing erratic maneuvers and stoppage of traffic. Concrete barriers could be used in these cases in lieu of cones, although the ease of portability would be lost.

Late Merge

The "late merge" concept was originally developed and implemented by the Pennsylvania Department of Transportation (PennDOT) to improve vehicle operations at work zone merge areas, which would conceivably reduce road rage caused by queue jumping. In the

PennDOT application, static signing is used to instruct drivers to remain in both lanes until they reach the merge point. At the merge point, a second static sign instructs motorists to take turns proceeding into the work zone activity area (*22*,*23*). Though the primary purpose of this concept is to improve merging behavior, a side benefit could be significantly reduced speeds entering the work zone.

The University of Nebraska performed an evaluation of the late merge concept on a four-lane rural interstate highway. Researchers found that the technique led to a capacity approximately 18 percent higher than a traditional merge situation. Researchers also reported approximately 75 percent fewer merging conflicts and 30 percent fewer incidents of lane straddling. A statistical analysis of the data produced speed distributions for congested (late merge) and uncongested (normal merge) flow. The mean speed for the congested flow was approximately 34 mph lower than the uncongested mean speed (*22*).

Ultimately, this strategy is designed to improve vehicle operations in the traffic queue upstream of a work zone lane closure. Therefore, it is most effective for temporary short-term lane closures where traffic demands are expected to exceed the capacity of the work zone over the entire duration of the work activity. Despite the potential benefits of the strategy, a TTI study concluded that contractors appear to be somewhat hesitant to employ the technique on projects where the traffic control plan has already been prepared and approved (*23*). It would be necessary to specifically integrate the strategy into the traffic control plan documents of future projects for implementation to move forward.

Transverse Striping

Another method with potential for work zone speed control is transverse striping. In this method, stripes are placed at decreasing spacings across the travel lanes in advance of a work zone. When a vehicle approaches the stripes, the driver receives a visual illusion that the vehicle is accelerating, with an anticipated result that drivers will slow down. Testing of transverse striping at work zones has found them to be generally ineffective in reducing vehicle speeds. At best, transverse striping has limited potential as a work zone speed control method. It requires significant time and effort to install, which makes it applicable only to long-term work zones. In addition, the stripes must be maintained throughout the project to avoid liability concerns (*18*).

Rumble Strips

Rumble strips are another means available for work zone speed control; however, there has been little research on rumble strips in work zone environments. Tests of rumble strips in non-work zone situations suggest that they may be able to reduce speeds under certain conditions, but the amount of reduction may not be practically significant, generally 1 to 2 mph (*24*). As with transverse striping, rumble strips are essentially limited to long-term work zones because of the required time and effort to install and remove them. It is likely that their effectiveness would decrease over time for regular/local drivers (*18*).

Other Methods to Enhance Motorist Awareness

Table 2-2 displays a brief summary of other methods to alert motorists to work zone conditions, compiled primarily from procedures used in Europe (*14*). These methods were not examined in detail due to various implementation issues that would have to be resolved prior to testing in the United States.

Comparisons of Multiple Methods

A 1984 TTI study compared four methods of speed reduction in work zones on urban freeways; rural freeways; urban arterials; and two-lane, two-way highways (*9*). Flagging was the most effective method of speed reduction, yielding changes of 3 to 16 mph. Enforcement had similar effectiveness, with reductions of 3 to 14 mph. Changeable message signs resulted in a change of 2 to 5 mph, followed by lane width reduction at 0 to 8 mph. Generally, the speed control treatments were less effective on urban freeways and more effective on two-lane, two-way highways.

A more recent TTI study evaluated traffic control devices for rural high-speed maintenance work zones (*25*). Limited field evaluations of the most promising devices were conducted, with the research specifically focused on the application of innovative traffic control devices to rural maintenance work zones. The work zones typically occurred on low-volume roads with a posted speed limit of 70 mph. The maintenance activities occurred during daylight hours, and the traffic control was set up in the morning and removed by dusk. Additionally, regulatory speeds could not be reduced due to the short nature of the maintenance activities; there were limited resources for police enforcement; and workers were in a more exposed position than at a long-term work zone. Therefore, it was important that workers were visible to motorists and that motorists were aware of the upcoming work zone. The October 2000 report noted that the following devices were found to be effective at improving safety in temporary maintenance work zones:

- fluorescent yellow-green worker vests and hard hat covers,
- portable variable message signs, and
- speed display trailers.

Table 2-2. Summary of European Work Zone Strategies (*14*).

EUROPEAN WORK ZONE PROCEDURE	POTENTIAL BENEFIT IN WORK ZONE OPERATIONS	ISSUES TO RESOLVE PRIOR TO TESTING
Yellow pavement markings (with and without removal of other markings)	Delineation through work zones	Does not currently conform to the MUTCD.
Overhead signs for information	Increased driver communication; lane-specific	Deployment on existing sign bridges impact driver workload and ease of installation
Sign information specific to travel lane	Operational and flow characteristics adjustable by lane	Depending upon information provided, check compliance with MUTCD
Prevalence of symbol signs due to diverse languages	Potential positive impact on driver comprehension	Check compliance with MUTCD
Portable sign gantries	Location-specific information	Equipment availability; deployment and operation guidelines
Dedication of primary and secondary alternate routes on permanent trailblazer signs	Identifies major desirable alternate routes in advance	Check compliance with MUTCD; coordination with other agencies
Use of portable queue detectors	Real-time driver information	Accuracy of information
Narrower lanes in work zones for autos only; truck lane slightly wider for truck and auto use	Increased options for work zone traffic control plans	Consider safety issues and compliance with MUTCD
Portable rumble strip-type devices used in lane closures	Potential positive impact on alerting drivers entering work zone	Does not currently conform to MUTCD

Of the devices evaluated in the project, the speed display trailer had the largest impact on traffic speeds. Speeds before the taper were reduced by 5 mph, and speeds within the work zone were reduced by 3.5 mph. Additionally, the trailer was easily set up and removed from the site, and it appeared to be an appropriate device to improve work zone safety in rural maintenance areas. Additionally, several devices showed some promise but needed to be further defined, studied in greater detail, or evaluated on a more quantitative basis. The devices include:

- fluorescent orange signs,
- radar-activated flagger paddles,
- radar drone, and
- retroreflective magnetic strips for work vehicles.

It should be noted that in 2002 TxDOT changed their standard for work zone signing to fluorescent orange microprismatic retroreflective sheeting. Further, some of the devices evaluated were not found to be appropriate and/or effective for use in maintenance work zones. However, while these devices may not have been useful in high-speed temporary work zones, they may have some application in other types of work zones. These devices include:

- portable rumble strips,
- Safe-T-Spins, and
- worker strobe lights.

These devices were evaluated based on their impact on traffic speeds, conflicts, and a variety of other measures *(25)*.

Additionally, research on regulatory sign comprehension for non-work zone areas shows that many drivers interpret the sign "Speed Zone Ahead" to mean there would be extra police presence when compared to "Reduced Speed Ahead" *(26)*. Simple wording changes may increase the threat of enforcement and motivate speed reductions.

An Iowa State University study in 2000 surveyed state transportation agencies nationwide to examine work zone speed reduction policies and procedures *(27)*. There were 12 speed reduction strategies identified in the report:

- regulatory signs,
- advisory signs,
- CMS,
- police enforcement,
- ghost police car,
- flaggers,
- speed display,
- drone radar,

- rumble strips,
- lane narrowing,
- pavement markings, and
- highway advisory radio.

Of the 12 strategies, the uses of regulatory speed limit signs and police enforcement were the most common practices reported by the agencies. However, only 7 percent of the participating agencies consider the use of regulatory signs to be an effective speed reduction strategy, compared to 70 percent that consider police enforcement to be effective. Over half of respondents (18 of 34) used CMS systems, and a significant portion use CMS in conjunction with radar to detect and display speeds of approaching vehicles. The remaining strategies either received six or fewer responses from agencies that used them, or respondents considered the strategy ineffective (*27*).

Other Programs and Systems

Many states have programs related to safety within highway work zones, focusing on two main areas: innovative traffic control devices and increased enforcement. These programs often entail the use of more than one device or a system of devices. For example, in an announcement in May 2001, the Arkansas Highway and Transportation Department asked motorists to plan ahead for an aggressive interstate rehabilitation program that would eventually affect 380 miles of Arkansas interstate. Resources to help motorists navigate the work zones in a safe manner included roadway signage, highway advisory radio (HAR) broadcasts, work zones with variable road signs indicating conditions ahead, and a detailed lane closure report on the Arkansas interstate web site. The department emphasized that motorists should pay special attention to merging left at the earliest opportunity to minimize delays and prevent crashes (*28*).

Michigan's Department of Transportation (MDOT) implemented innovative techniques for traffic control and safety in work zones during the summer of 2002. In southwest Michigan, MDOT used temporary orange and white transverse rumble strips applied to the roadway to provide a visual and physical reminder to motorists that they were approaching a work zone and needed to slow down. MDOT used moveable barrier walls in mid-Michigan to keep three lanes open northbound and two lanes open southbound during the first half of the week and then reversed for the weekends. This decision allowed for a better flow of traffic based on peak travel patterns. Interstate signs in mid-Michigan used radar to display a vehicle's speed and alerted the motorist to slow down if his speed was too high. A pilot project sponsored by the Federal Highway Administration used portable changeable message signs to electronically change the speed limit on an interstate near Lansing. The system altered the speed limit based on traffic volume, traffic speed, and weather conditions. MDOT also had the capability of adding the variable of worker presence. On another interstate, MDOT employed portable changeable message signs using radar, microwave sensors, and wireless communication to tell motorists how many minutes it would take them to reach the end of the work zone. Another system utilized a series of five trailers with flashing lights and signs that said "Left Lane Do Not Pass When Flashing." The purpose of this system was to have motorists merge early enough to prevent backups that often occur when drivers wait until the last minute to merge *(29)*.

In April 2001, the Illinois State Police (ISP) reminded motorists to use extra caution throughout the highway construction season, noting that the ISP would increase enforcement efforts in work zones as construction projects increased around the state. The ISP noted they would work special patrols in addition to regular patrols to identify motorists who did not reduce their speed while traveling through work zones. The ISP director also noted that motorists caught speeding in a work zone would receive a minimum fine of $150 (with no warning tickets issued), a mandatory court appearance, and no court supervision *(30)*.

The Iowa Department of Transportation enacted lower speed limits for certain work zones on interstate and other multilane highways in June 2001. This change affected construction and maintenance work zones on highways that had a 60 or 65 mph speed limit under normal conditions. The lower speed limits were in effect when one or more of the lanes were closed and workers were present. Officials also reminded motorists that enforcement of traffic laws, including speeding, would be emphasized. Under the extra-enforcement program, off-duty Iowa State Patrol troopers and other law enforcement officers were hired for enforcement of traffic.

CHAPTER 3
DOT SURVEY

INTRODUCTION

Researchers conducted a web-based survey to gather information on current practices concerning the improvement of compliance with work zone speed limits. This survey had two components: an in-state survey and an out-of-state survey, each with a slightly different set of questions. Potential participants were initially notified by e-mail and asked to complete the appropriate survey via an internet link included in the text of the e-mail. Copies of the initial e-mails, sent in December 2003, are shown in Figures 3-1 and 3-2 below. The initial out-of-state contact was used to request responses for surveys on two unrelated projects; the information for the unrelated survey has been omitted in Figure 3-1 for brevity.

Happy Holidays,
The Texas Transportation Institute is conducting a couple of research projects for TxDOT for which we would like to get input from the states about their current practices. There are two surveys, one addressing signs and markings for freeway connector ramps and the other addressing driver compliance with work zone speed limits. A short description of each of these surveys is provided below, along with a web address where the survey can be completed on-line. We hope that the on-line format of the survey minimizes the effort needed for you or your staff to respond. I hope that you can find an opportunity to complete this survey or that you will ask one or more of your staff to complete the survey. We would like to have responses by January 23, 2004, if at all possible.

...*(details for unrelated survey omitted)*...

Driver Compliance with Work Zone Speed Limits
This survey is part of a research project to identify and evaluate methods to increase compliance with work zone speed limits. The survey's primary objective is to assess the current state-of-the-practice of establishing and enforcing speed limits, and using various speed control devices and strategies to improve speed limit compliance in work zones. The intended recipient of this survey is someone who has knowledge of your practices for setting work zone speed limits and the devices used to indicate such speed limits. The survey is located at http://san-antonio.tamu.edu/4707/survey.asp. There are 12 questions in the survey. Please contact Marcus Brewer if you have any questions (979-845-2640 or m-brewer@tamu.edu).

Thank you in advance for your cooperation and please feel free to contact me or the individuals shown above if you have any questions.

Figure 3-1. Initial Contact E-mail for Out-of-State Survey.

A member of the TTI research team sent the out-of-state survey requests; requests for out-of-state respondents were sent to 55 representatives from 47 states. The TxDOT Project

Director sent the in-state survey requests; a request for in-state survey responses was sent to the district engineer in each of the 25 TxDOT districts.

For the out-of-state survey, there were 15 responses from 15 states. For the TxDOT survey, 18 responses were received from 14 districts. The following pages summarize the responses received in each survey. Appendix A contains the complete lists of questions from both surveys as they were presented to the survey participants.

> Happy Holidays,
> The Texas Transportation Institute is conducting a research project for TxDOT on **Driver Compliance with Work Zone Speed Limits** for which we would like to get input from the districts about their current practices. This survey is part of a research project to identify and evaluate methods to increase compliance with work zone speed limits. The survey's primary objective is to assess the current state-of-the-practice of establishing and enforcing speed limits, and using various speed control devices and strategies to improve speed limit compliance in work zones.
>
> The intended recipient of this survey is someone who has knowledge of your practices for setting work zone speed limits and the devices used to indicate such speed limits. Feel free to forward this e-mail to area engineers and others that might also be responsible for work zone speed limits.
>
> The survey is located at http://san-antonio.tamu.edu/4707/survey.asp. There are 12 questions in the survey. Please contact Marcus Brewer if you have any questions (979-845-2640 or m-brewer@tamu.edu). We hope that the on-line format of the survey minimizes the effort needed for you or your staff to respond. We hope that you can find an opportunity to complete this survey or that you will ask one or more of your staff to complete the survey. We would like to have responses by January 23, 2004, if at all possible. Thank you in advance for your cooperation and please feel free to contact us if you have any questions.

Figure 3-2. Initial Contact E-mail for TxDOT Survey.

OUT-OF-STATE SURVEY

The out-of-state survey was composed of 12 questions, four of which had multiple parts. The survey asked respondents to comment on procedures for setting WZSLs, devices and methods used to notify drivers of WZSLs and other conditions, and circumstances under which they utilize enforcement in speed zones. This section presents the questions and the distribution of answers. All distributions are based on a set of 14 responses (n = 14) unless otherwise specified.

Question 1: How do you determine the appropriate work zone speed limits on your projects?

The most common strategies (36 percent each) were to reduce the regulatory speed limit by 10 mph and to rely on engineering judgment, either with or without a formal engineering study. Another 14 percent said they decided on a case-by-case basis with no specific procedures, and the remaining 14 percent indicated that they avoided the use of reduced WZSLs whenever possible. Figure 3-3 illustrates the distribution of answers.

Question 2: a) Have you used variable speed limits (i.e., speed limit varying over time in response to changes in traffic conditions)? b) If so, please explain the procedure used to determine how the speed limit is changed.

The vast majority of respondents to Question 2a (13 of 14) stated that they have not used variable speed limits. The one that used variable speed limits stated in Question 2b that it was a very basic application of the concept, in that it was only a reduction in speed used during work hours; however, that particular agency was revising its guidance to include the use of variable WZSLs. There were four other responses, by non-users, to Question 2b. One stated that his agency was conducting a study on the use of variable WZSLs, and a second stated that implementation of variable WZSLs using an electronic monitoring system was scheduled for the 2004 construction season. The remaining two responses stated that they would not recommend a variable WZSL due to the potential for motorist confusion and/or difficulty of enforcement.

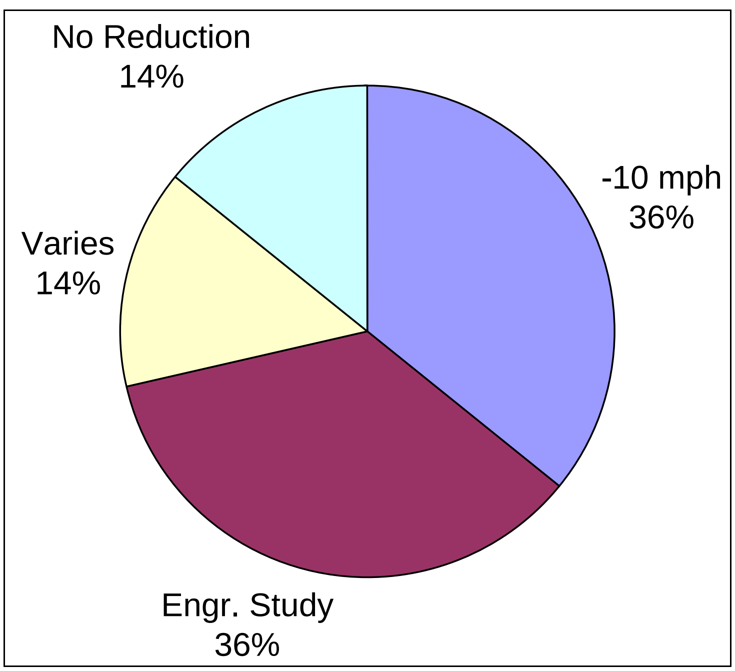


Figure 3-3. Answers to Out-of-State Survey Question 1.

Question 3: What devices do you use to notify the driver of a lower work zone speed limit? (These devices may include, but are not limited to: post-mounted static signs, portable changeable message signs, speed display trailers, flashing beacons, and other devices.)

Respondents were able to choose more than one device, but all respondents indicated the use of static signs. Other common answers were portable changeable message signs, flashing beacons and/or flags, and speed display trailers. Figure 3-4 displays a graphical representation of the answers.

Question 4: For the devices used in Question 3 above, at what locations relative to the work zone are these devices located (i.e., 1000 ft upstream of work zone, start of lane reduction taper, beginning of work zone, etc.)? For multiple devices, what spacing interval is used between devices?

There was a wide variety of answers to this question, with no answer clearly preferred over the others. The distribution shown in Figure 3-5 represents the answers given as the predominant location for the device first seen by a driver approaching the work zone.

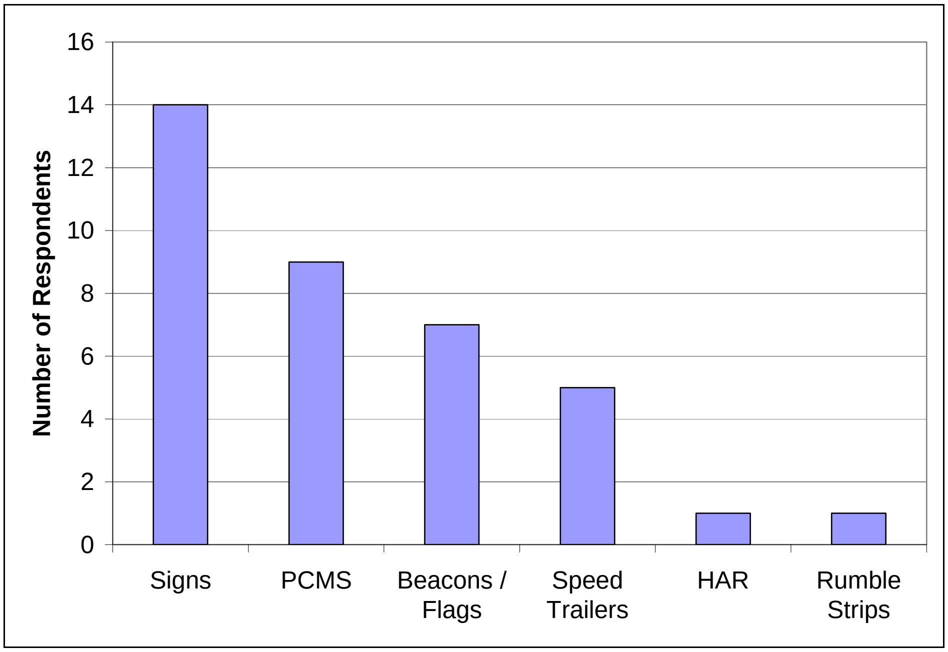


Figure 3-4. Answers to Out-of-State Survey Question 3.

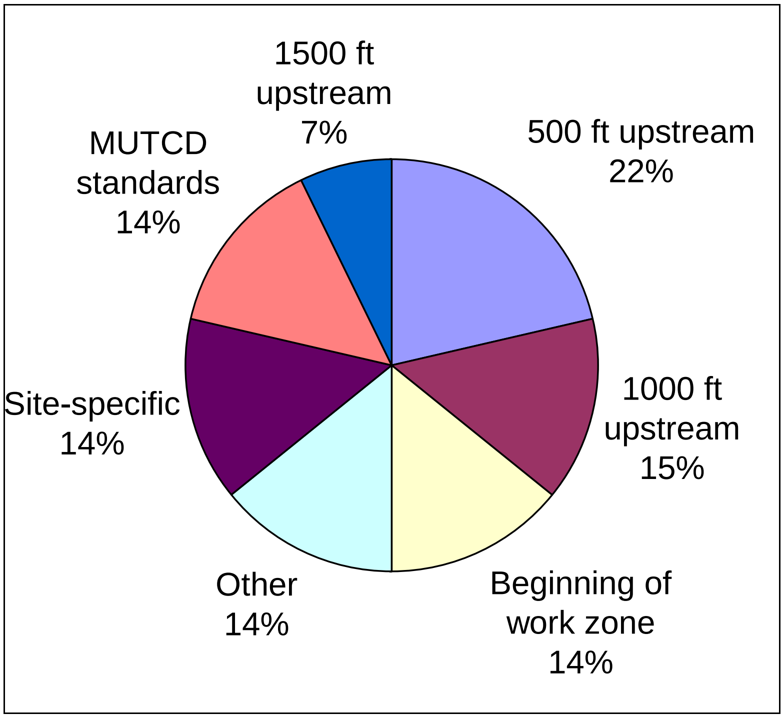


Figure 3-5. Answers to Out-of-State Survey Question 4.

Question 5: If you use Portable Changeable Message Signs (PCMS) for driver notification, what are your typical messages?

Respondents were free to choose more than one answer to this question. Five respondents (36 percent) each chose “Reduced Speed Ahead” and “Speed Limit XX” as commonly used messages. There were two responses listing “Road Work Ahead” as prevalent and one that chose “Please Slow Down.” Three other responses provided answers of a different nature, generally indicating that there was no prescribed message or set of messages; rather, these agencies determined the message on a sign based on the project being performed and the conditions surrounding the work zone. Finally, four other survey participants provided no response to this question. The answer distribution is shown graphically in Figure 3-6.

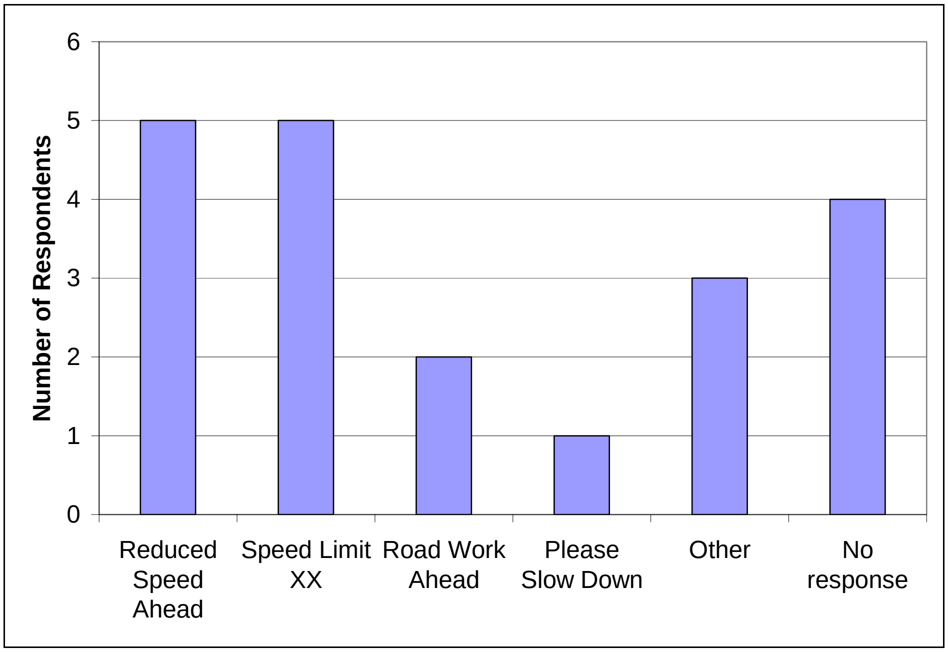


Figure 3-6. Answers to Out-of-State Survey Question 5.

Question 6: a) Have you used PCMS with radar/speed display capabilities? b) If so, what messages do you use?

Approximately two-thirds of the respondents (9 of 14) indicated that they had used PCMS with radar capabilities, also known as PCMR. Similar to Question 5, the nine respondents to Question 6b had the ability to choose more than one message for their answer. The vast majority of answers were related to the speeds of vehicles in the work zone, displaying drivers' speeds, the posted speed limit, or messages urging drivers to slow down. The exact distribution of answers is provided in Figure 3-7.

Question 7: a) Have you used static signs with innovative messages (i.e., "Give 'Em a Brake", "Slow Down -- My Daddy Works Here", etc.)? b) If Yes, what messages have you used?

Almost 80 percent of respondents to Question 7a (11 of 14) stated that they have used innovative messages on signs. Of those 11 users, 10 of them stated in Question 7b that they used the "Give 'Em a Brake" message or a variation of that message. Again, respondents were allowed to choose more than one message; their answers are shown in Figure 3-8.

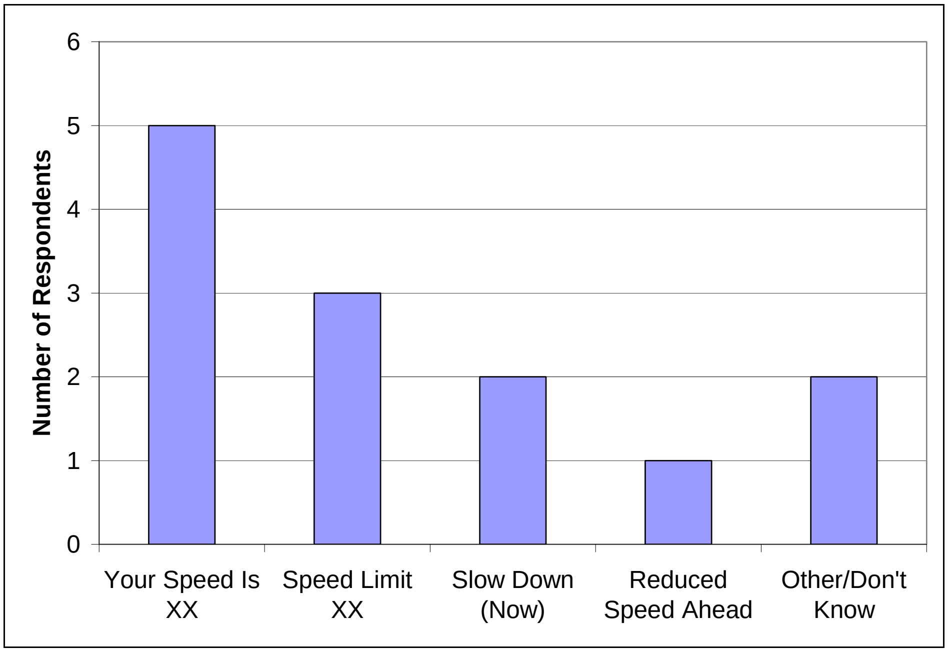


Figure 3-7. Answers to Out-of-State Survey Question 6b.

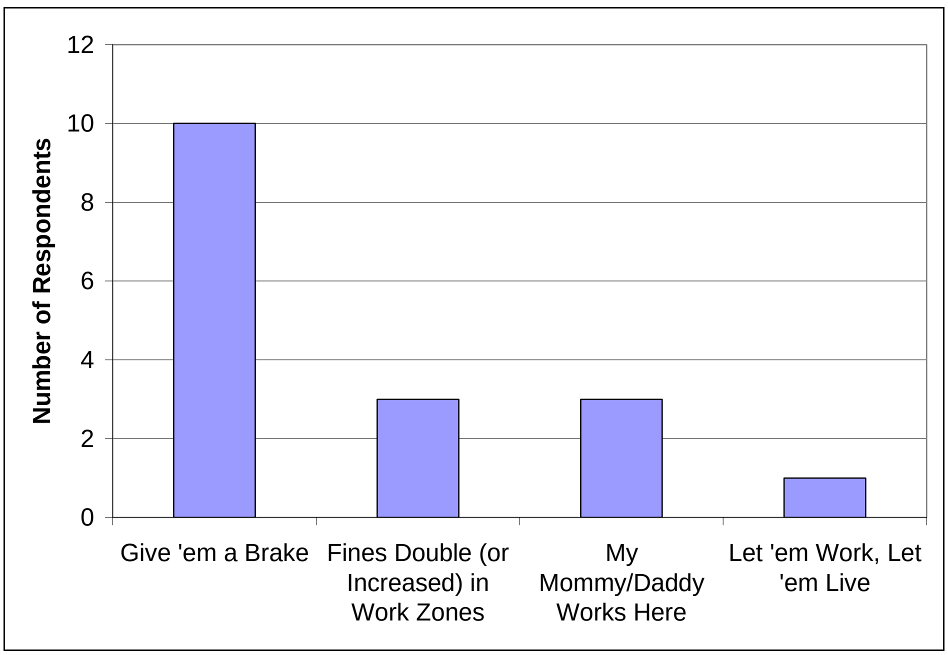


Figure 3-8. Answers to Out-of-State Survey Question 7b.

Question 8: Which of the following strategies do you use for speed control and/or improved compliance, and how effective are they?

	Have used this strategy?	*Strategy was effective? (if used)*
Lane Narrowing	☐	◎ *Yes* ◎ *Partially* ◎ *No*
Longer Speed Zone Transitions	☐	◎ *Yes* ◎ *Partially* ◎ *No*
Flagging (as a Speed Control Method)	☐	◎ *Yes* ◎ *Partially* ◎ *No*
PCMS (as a Speed Control Method)	☐	◎ *Yes* ◎ *Partially* ◎ *No*
Rumble Strips	☐	◎ *Yes* ◎ *Partially* ◎ *No*

Respondents to the first part of Question 8 were able to select as many of the five strategies as they wished. For each strategy used, respondents were then asked to describe how effective they believed the strategy was. Ten of the 14 respondents selected at least one strategy, while four selected none of them. However, some respondents provided their opinion of the effectiveness of some strategies even if they did not indicate they had used them. Thus, there are two distributions for the second part of Question 8, one for strategy users and one for all responses. Answer distributions for Question 8 are shown in Table 3-1.

Table 3-1. Answers to Out-of-State Survey Question 8.

Question 8a (n = 14)
"Which of the following strategies do you use for speed control and/or improved compliance?"

	Responses	Percent
Rumble Strips	7	50%
Lane Narrowing	6	43%
PCMS	5	36%
Flagging	5	36%
Longer Speed Zone Transitions	2	14%
None of the Above	4	29%

Question 8b — Users Only (n = variable)
"Was the strategy effective?"

		Yes		Partially		No	
	n	Responses	Percent	Responses	Percent	Responses	Percent
Rumble Strips	7	2	29%	4	57%	1	14%
Lane Narrowing	6	1	17%	5	83%	0	0%
PCMS	5	0	0%	5	100%	0	0%
Flagging	5	2	40%	3	60%	0	0%
Longer Speed Zone Transitions	2	0	0%	2	100%	0	0%

Question 8b — All Responses (n = 14)
"Was the strategy effective?"

	Yes		Partially		No	
	Responses	Percent	Responses	Percent	Responses	Percent
Rumble Strips	2	14%	4	29%	3	21%
Lane Narrowing	1	7%	6	43%	2	14%
PCMS	0	0%	6	43%	2	14%
Flagging	2	14%	4	29%	1	7%
Longer Speed Zone Transitions	0	0%	2	14%	4	29%

The following list contains the comments submitted by seven of the respondents after answering Question 8, not listed in any particular order.

- "Other than law enforcement, we tried drone radar units with limited success."
- "We have done no studies to support that any strategy was effective or not. It is just my judgment that the PCMS is somewhat effective."
- "Rumble strips only lowered the speed about 3 or 4 mph. The speed picked back up after 2 miles beyond the rumble strips."
- "Rumble strips were used only on the approach to a curve that required a reduced curve advisory speed."
- "We have not found any single device that works to the degree that our people or the contractor want. If we have to slow traffic down, we use a human-a flagger or a cop."
- "Any method is much more effective when used in conjunction with law enforcement present on the site."
- "We have not used any of these strategies."

Question 9: What other methods of influencing work zone speeds have you used? Did you find them effective?

By far the most common response was an application of law enforcement, with 9 of 14 responses. Most of them indicated that it was fairly effective, and some suggested that it was virtually the only effective method for motivating compliance. Figure 3-9 shows the complete distribution of answer categories.

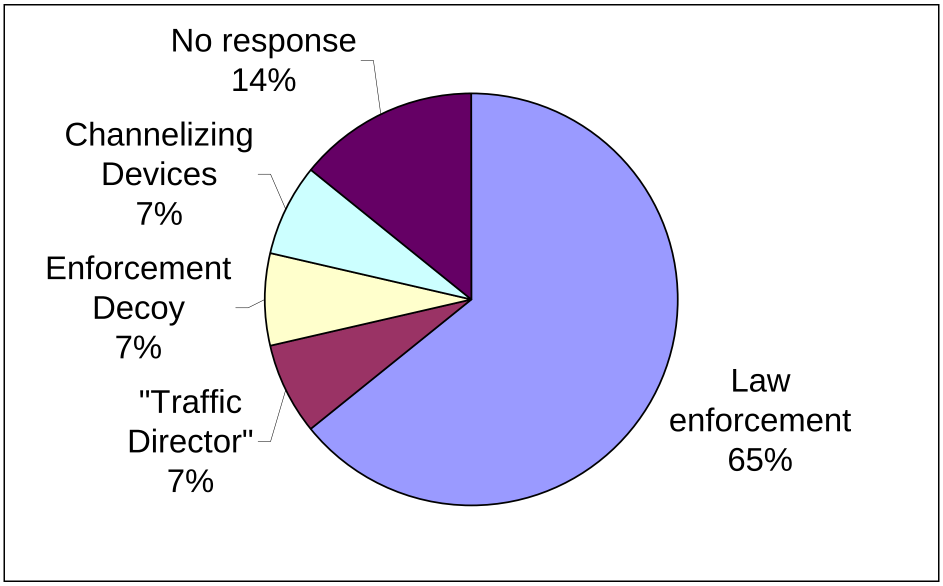


Figure 3-9. Answers to Out-of-State Survey Question 9.

Question 10: How do you determine where and when to use enforcement of work zone speed limits?

Half of the respondents (7 of 14) stated that they used enforcement mainly on certain roadway classes, usually broadly defined as "high speed" or "high volume." These roadway classes were also commonly described as locations where workers were at higher risk. Of the remaining responses, four stated that they used enforcement on a case-by-case basis, often with some subjective set of criteria. Two directly stated that it was usually up to the project or area engineer, and the remaining respondent stated specifically that enforcement was used for projects involving lane closures. This distribution is presented graphically in Figure 3-10.

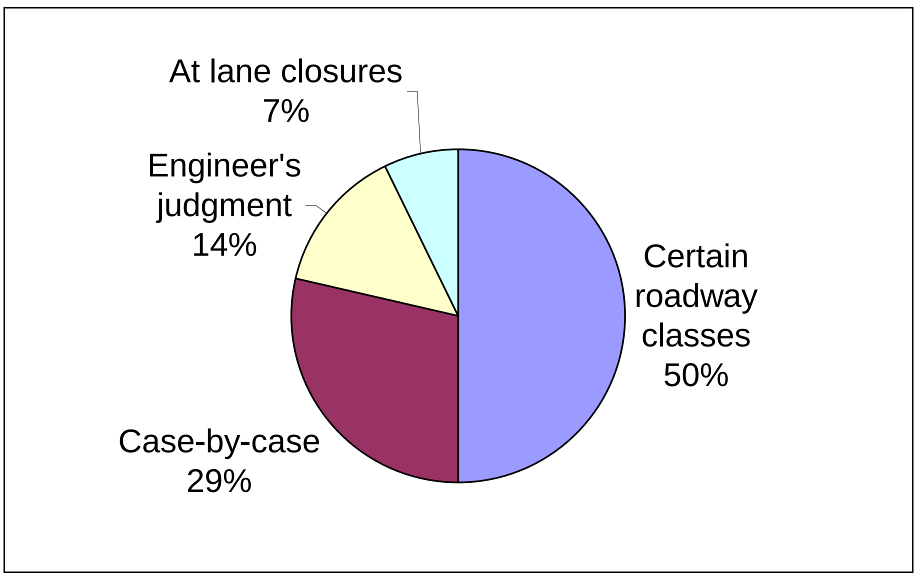


Figure 3-10. Answers to Out-of-State Survey Question 10.

Question 11: How are arrangements made to provide for enforcement activities in work zones (i.e., contractor is responsible to schedule enforcement officers and pay for their time; DOT has a contract or joint program with Highway Patrol to coordinate and fund work zone enforcement; etc.)?

Most respondents (9 of 14) stated that they had a joint program or agreement with their respective enforcement agencies to schedule enforcement officers and provide funding. Of the remaining five responses, four indicated that it was the contractor's responsibility to arrange for enforcement activity as desired. See Figure 3-11 for the distribution of responses.

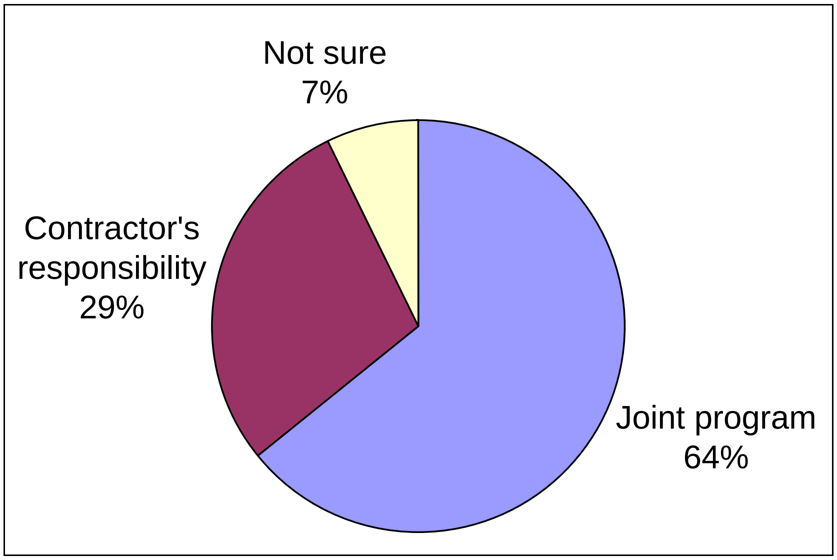


Figure 3-11. Answers to Out-of-State Survey Question 11.

Question 12: Who performs the actual enforcement (i.e., local police, state highway patrol, etc.)?

Respondents were able to give more than one answer for this question. Most (11 of 14) stated that they utilized the services of their state's highway patrol, which was the predominant participating agency in responses with multiple answers. Five out of 14 stated that they also used the local police department or local sheriff for enforcement duties. Finally, three of 14 respondents stated that they employed off-duty officers from one of the various agencies to conduct enforcement. This distribution is shown in Figure 3-12.

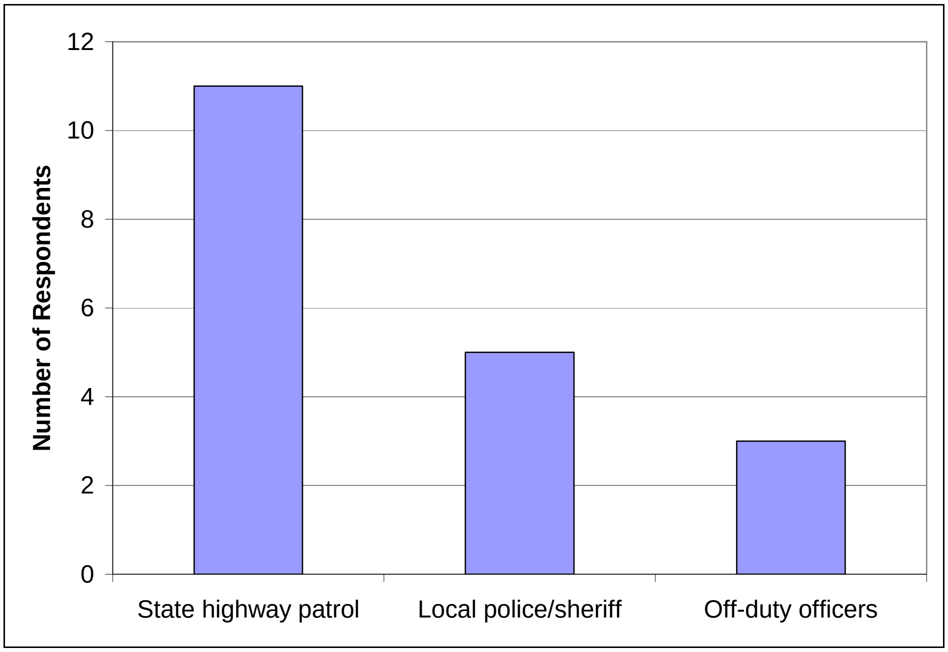


Figure 3-12. Answers to Out-of-State Survey Question 12.

TXDOT SURVEY

The survey of TxDOT districts was composed of 12 questions, three of which had multiple parts. The survey asked respondents to comment on procedures for setting WZSLs, devices and methods used to notify drivers of WZSLs and other conditions, and circumstances under which enforcement is utilized in speed zones. This section presents the questions and the distribution of all answers to the TxDOT survey. All distributions are based on a set of 16 responses (n = 16) unless otherwise specified.

Question 1: How do you determine the appropriate work zone speed limits on your projects?

Respondents provided a variety of answers for this question, none of them predominant over the others. The most common answer was "engineering judgment," given in about one-third of the responses (6 of 16). Other answers, shown in the distribution in Figure 3-13, include 10 mph below the speed limit, and the TxDOT Traffic Engineering work zone standard sheets; these answers were each given by four respondents. Two respondents stated that they try to avoid the use of regulatory WZSLs altogether.

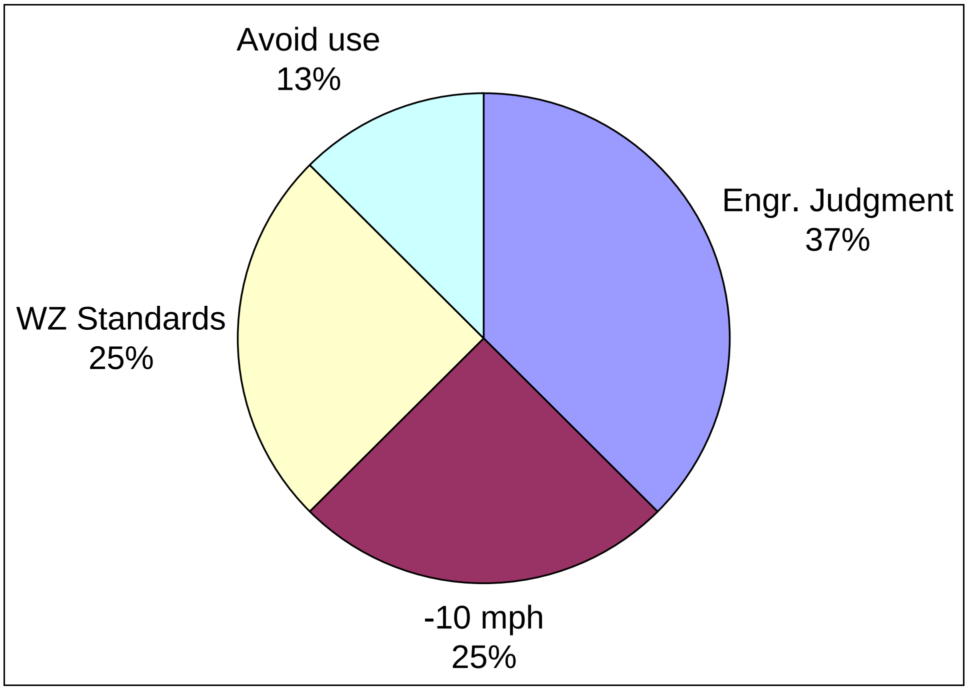


Figure 3-13. Answers to TxDOT Survey Question 1.

Question 2: Do you post and remove the work zone speed limit according to the status of the actual work being performed? (For example, on a work zone 10 miles in length, do you post the work zone speed limit for all 10 miles for the entire duration of the project, or do you move the extents of the speed limit to cover the portion of the work zone where work is taking place?)

Over half of the respondents (9 of 16) stated that they preferred to move the extents of the WZSL to correspond to actual work being performed. A few other factors were also mentioned in these responses, however. While respondents preferred the practice of moving the WZSL, several respondents mentioned that it was within the purview of the contractor to physically move the signs; if the practice was not enforced, the contractor might be likely to leave the signs up for the whole distance of the project for the entire duration. Also, those who said that they would move the WZSL specified that they might also leave a WZSL in place if road conditions were not restored to normal, regardless of the absence or presence of workers or equipment. Thus, if a resurfaced section of roadway did not have appropriate permanent striping, the WZSL might remain in effect.

Two of the 16 respondents stated that they posted WZSLs over the entire limits for the duration of the project. One respondent said that the WZSL would be posted not necessarily in areas where work was being done, but in “areas of concern;” that is, areas with sharp curves, narrow lanes, or similar conditions that would make it difficult to travel through the work zone at the regulatory posted speed. The remaining four survey participants provided no response to this question. Figure 3-14 graphically presents the distribution of answers to Question 2.

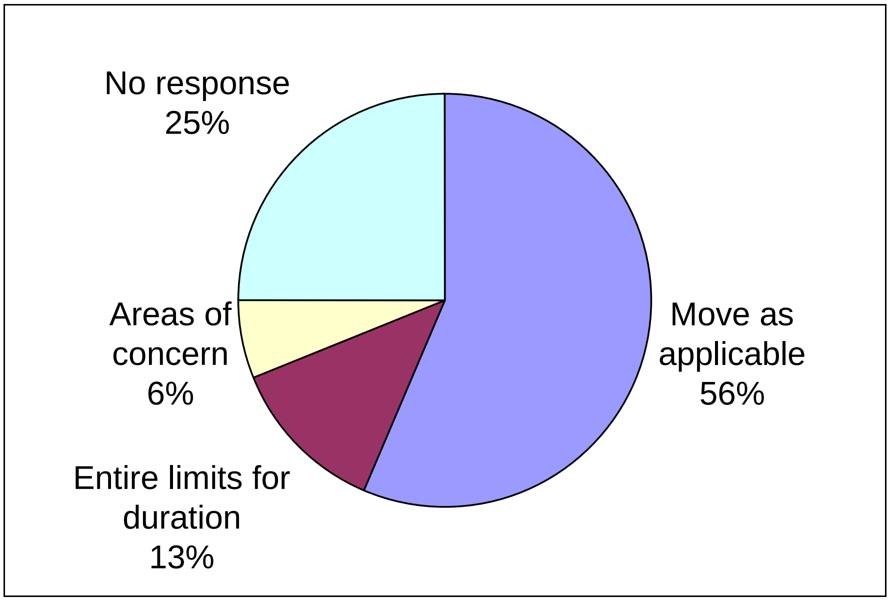


Figure 3-14. Answers to TxDOT Survey Question 2.

Question 3: What devices do you use to notify the driver of a lower work zone speed limit? (These devices may include, but are not limited to: post-mounted static signs, portable changeable message signs, speed display trailers, flashing beacons, and other devices.)

Respondents were allowed to answer as many as they wished. By far the most common answers were static signs, PCMS, and speed display trailers; each was given by over half of the respondents. One respondent each mentioned flashing beacons and rumble strips. The distribution of responses is shown in Figure 3-15.

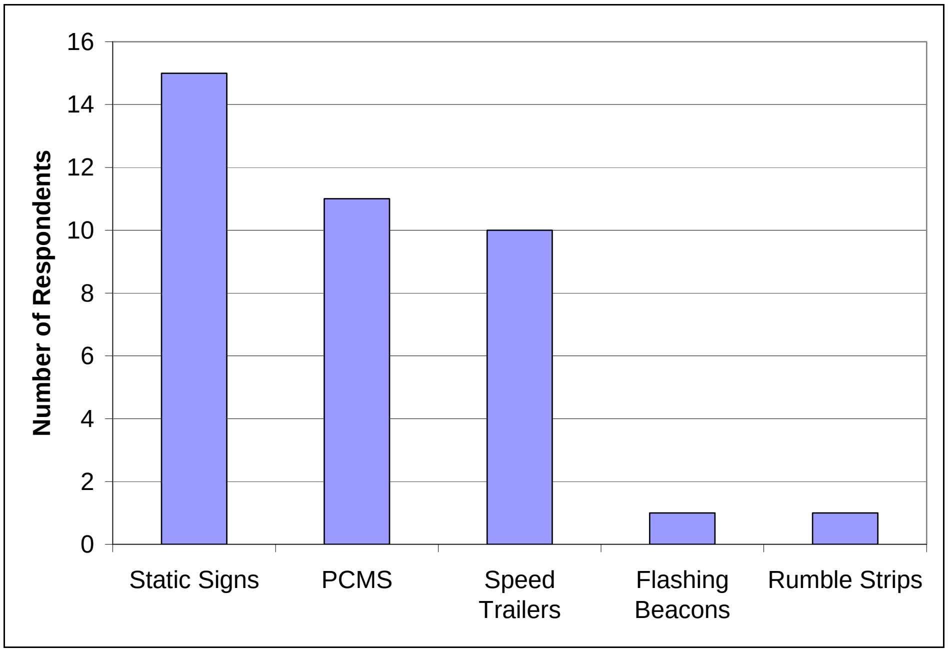


Figure 3-15. Answers to TxDOT Survey Question 3.

Question 4: For the devices used in Question 3 above, at what locations relative to the work zone are these devices located (i.e., 1000 ft upstream of work zone, start of lane reduction taper, beginning of work zone, etc.)? For multiple devices, what spacing interval is used between devices?

Answers were distributed fairly evenly, and respondents were able to choose more than one distance, depending on the devices used in Question 3. The distribution shown in Figure 3-16 represents the answers given to Question 4.

Question 5: If you use Portable Changeable Message Signs (PCMS) for driver notification, what are your typical messages?

Similar to Questions 3 and 4, respondents were allowed to select multiple messages. Most responses dealt with the speed of approaching drivers, while other messages were intended to inform the driver of upcoming road conditions. Some messages in the "Other" category included "Detour Ahead," "Drive Safely," and "Be Prepared to Stop." The answer distribution is shown in Figure 3-17.

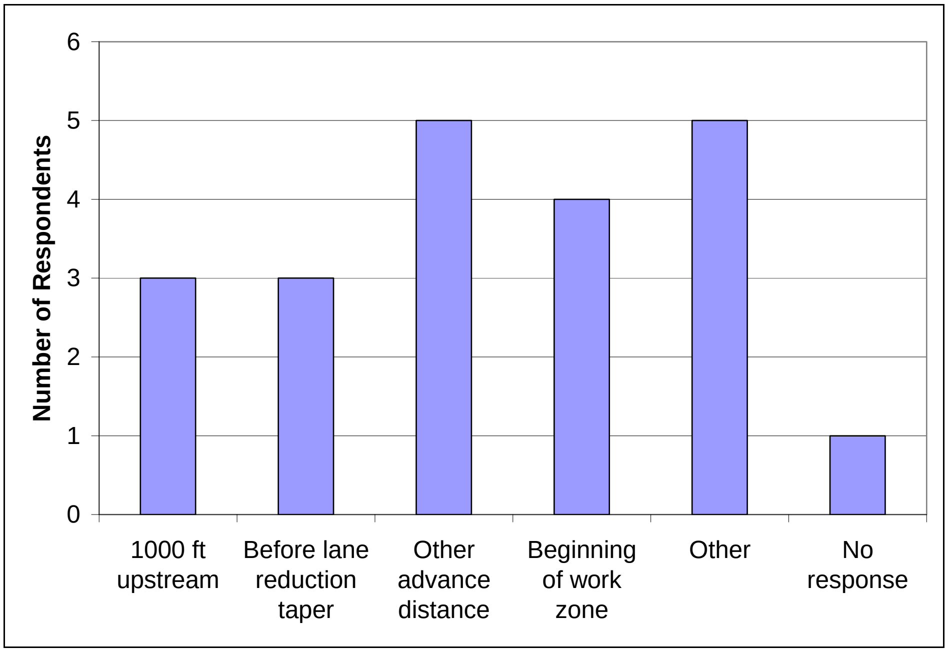


Figure 3-16. Answers to TxDOT Survey Question 4.

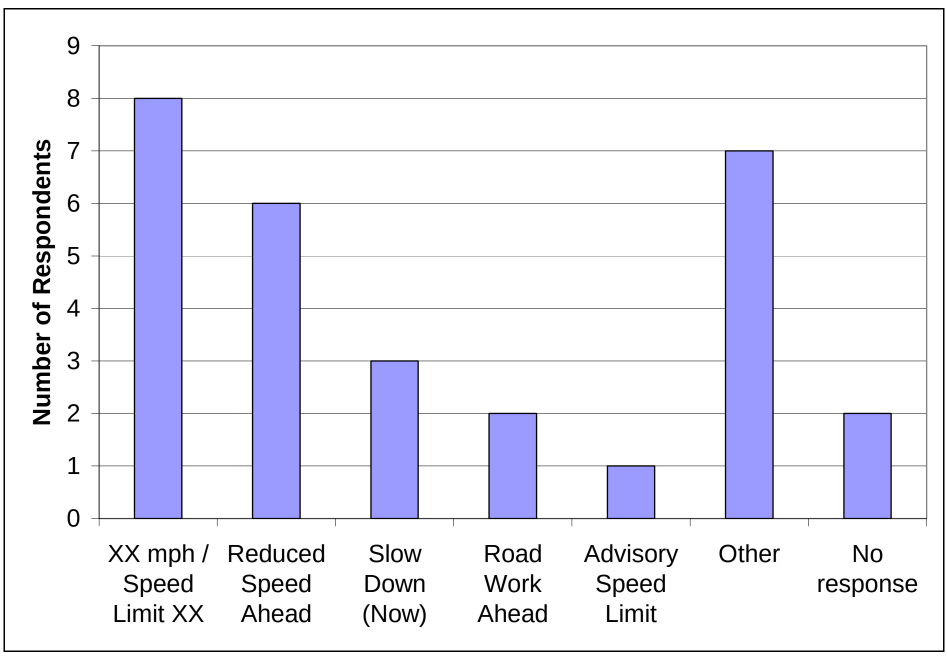


Figure 3-17. Answers to TxDOT Survey Question 5.

Question 6: a) Have you used PCMS with radar/speed display capabilities? b) If so, what messages do you use?

Question 6b applied only to those who answered affirmatively to Question 6a. Of those two respondents, both said that they used a message of “Your Speed” or “Your Speed Is” in a manner similar to a speed display trailer. One of the two respondents also stated that they alternated that message with a message of “Speed Limit XX.” Figure 3-18 shows the distribution of answers to Question 6a.

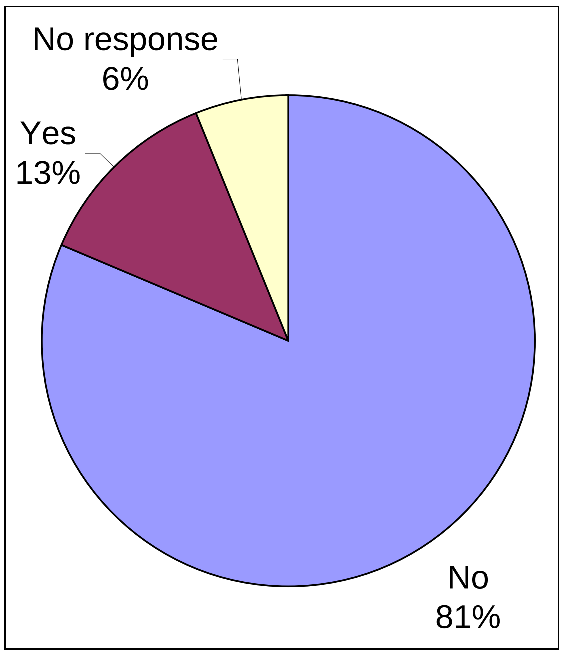


Figure 3-18. Answers to TxDOT Survey Question 6a.

Question 7: a) Have you used static signs with innovative messages (i.e., “Slow Down -- My Daddy Works Here,” etc.)? b) If Yes, what messages have you used?

As shown in Figure 3-19, about half of the respondents (9 of 16) said in Question 7a that they had not used innovative messages on their signs. Just over one-third (6 of 16) have used such signs, and there was no response to the question from the remaining participant. All six who answered affirmatively to Question 7a stated that they used the “Give ‘Em a Brake” message on static signs.

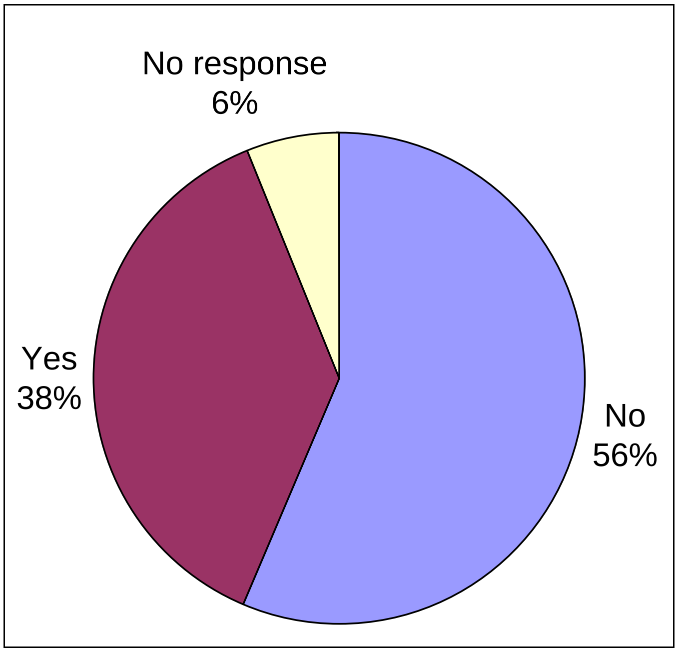


Figure 3-19. Answers to TxDOT Survey Question 7a.

Question 8: Which of the following strategies do you use for speed control and/or improved compliance, and how effective are they?

	Have used this strategy?	*Strategy was effective? (if used)*
Lane Narrowing	☐	⊙ *Yes* ⊙ *Partially* ⊙ *No*
Longer Speed Zone Transitions	☐	⊙ *Yes* ⊙ *Partially* ⊙ *No*
Flagging (as a Speed Control Method)	☐	⊙ *Yes* ⊙ *Partially* ⊙ *No*
PCMS (as a Speed Control Method)	☐	⊙ *Yes* ⊙ *Partially* ⊙ *No*
Rumble Strips	☐	⊙ *Yes* ⊙ *Partially* ⊙ *No*

As in the out-of-state survey, respondents to the first part of Question 8 were able to select as many of the five strategies as they wished. For each strategy used, respondents were then asked to describe how effective they believed the strategy was. Twelve of the 16 respondents selected at least one strategy, while four selected none of them. However, some respondents provided their opinion of the effectiveness of some strategies even if they did not indicate they had used them. Thus, there are two distributions for the second part of Question 8, one for strategy users and one for all responses. Table 3-2 shows the answer distributions for Question 8.

Table 3-2. Answers to TxDOT Survey Question 8.

Question 8a (n = 16)

"Which of the following strategies do you use for speed control and/or improved compliance?"

	Responses	Percent
PCMS	10	63%
Flagging	6	38%
Lane Narrowing	4	25%
Longer Speed Zone Transitions	1	6%
Rumble Strips	1	6%
None of the Above	4	25%

Question 8b — Users Only (n = variable)

"Was the strategy effective?"

		Yes		Partially		No	
	n	Responses	Percent	Responses	Percent	Responses	Percent
PCMS	10	4	40%	5	50%	1	10%
Flagging	6	2	33%	4	67%	0	0%
Lane Narrowing	4	2	50%	2	50%	0	0%
Longer Speed Zone Transitions	1	0	0%	1	100%	0	0%
Rumble Strips	1	0	0%	0	0%	1	100%

Question 8b — All Responses (n = 16)

"Was the strategy effective?"

	Yes		Partially		No	
	Responses	Percent	Responses	Percent	Responses	Percent
PCMS	6	38%	5	31%	1	6%
Flagging	3	19%	4	25%	1	6%
Lane Narrowing	2	13%	3	19%	2	13%
Longer Speed Zone Transitions	1	6%	1	6%	2	13%
Rumble Strips	1	6%	0	0%	3	19%

The following list contains the comments submitted by four of the respondents after answering Question 8, not listed in any particular order.

- "PCMS are normally placed @ 1 mile in advance of the work zone speed reduction area and are very effective, usually the driver has slowed to the work zone speed limit at the PCMS or well in advance of the actual work zone."
- "Our area is rural in nature. Highways such as US 75 carry a lot of traffic and they resist slowing down because it is mostly an open rural highway. It is very difficult to get motorists to adhere to the speed reductions unless there are law enforcement vehicles on project."
- "Different strategies are more effective depending upon local conditions. Engineering judgment needed to select method most effective for conditions."
- "Until traffic became accustomed to the trailers they were effective."

Question 9: What other methods of influencing work zone speeds have you used? Did you find them effective?

Fully half of the respondents (8 of 16) stated that they use enforcement to influence work zone speeds. There were a wide variety of other answers, including radar trailers and media campaigns. Two respondents did not provide answers to this question. The answer distribution is shown graphically in Figure 3-20.

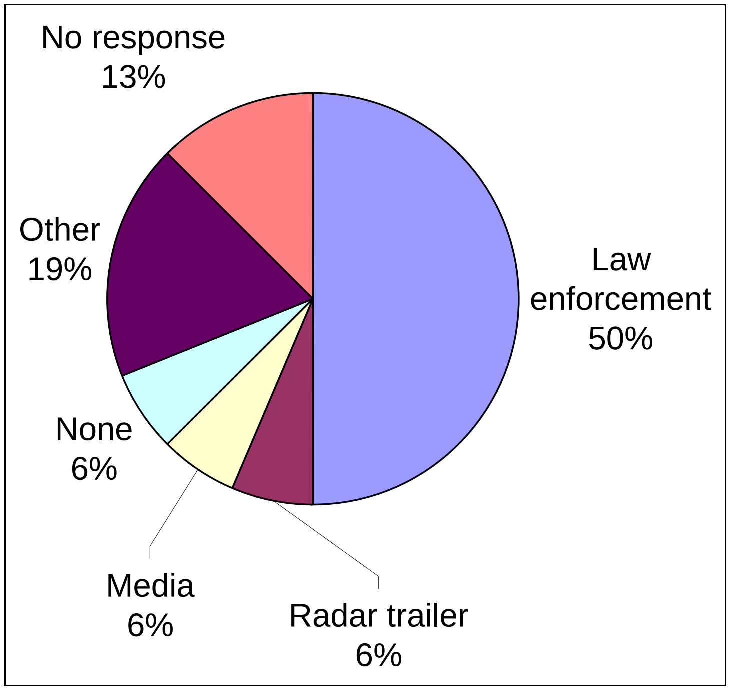


Figure 3-20. Answers to TxDOT Survey Question 9.

Question 10: How do you determine where and when to use enforcement of work zone speed limits?

There appears to be no predominant policy with respect to the use of enforcement in work zones, as shown in the answer distribution in Figure 3-21. The two most common answers, with 25 percent each (4 of 16), were the decision of the area engineer (AE) to implement enforcement and the decision of law enforcement personnel to voluntarily patrol the area.

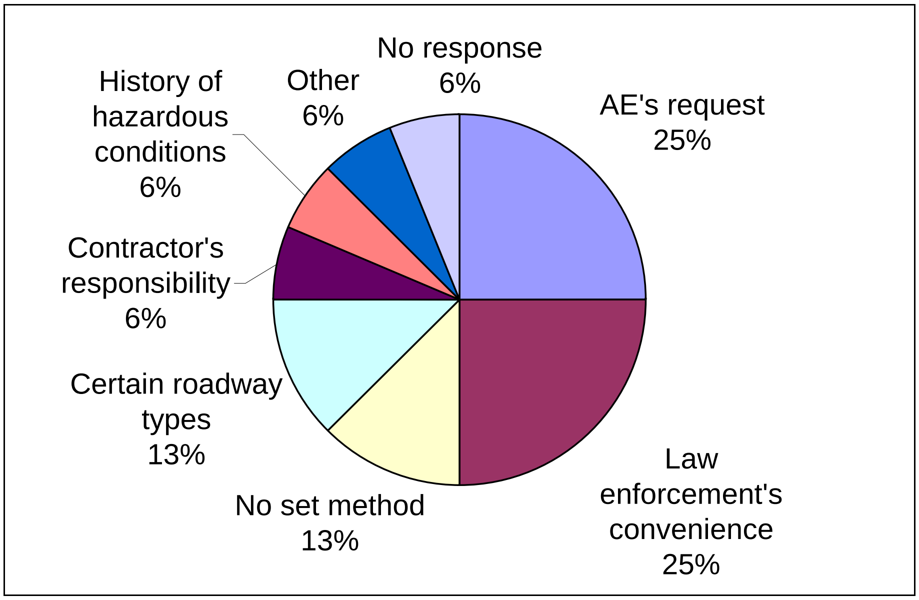


Figure 3-21. Answers to TxDOT Survey Question 10.

Question 11: How are arrangements made to provide for enforcement activities in work zones (i.e., contractor is responsible to schedule enforcement officers and pay for their time; District Office has a contract or joint program with DPS to coordinate and fund work zone enforcement; etc.)?

Figure 3-22 shows approximately one-third (6 of 16) of the respondents stated that the enforcement agencies scheduled and paid for their own activities. Another quarter of the respondents (4 of 16) said that it was usually the contractor's responsibility to provide for enforcement on their projects. Two respondents each said that they either used a program of coordination between TxDOT and enforcement, or they used a STEP (Selective Traffic Enforcement Programs) grant to fund enforcement activities.

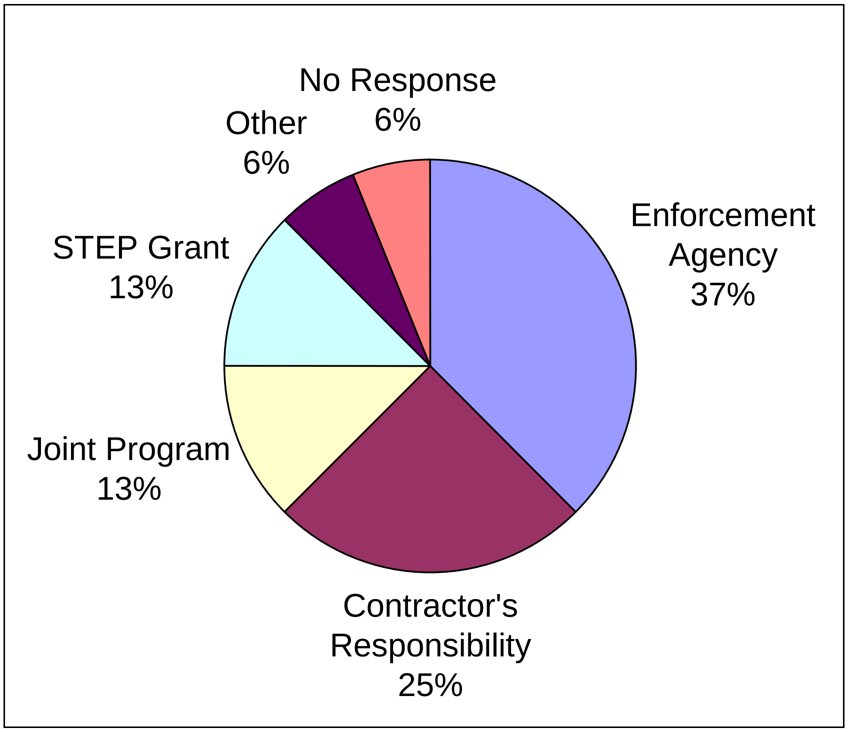


Figure 3-22. Answers to TxDOT Survey Question 11.

Question 12: Who performs the actual enforcement (i.e., local police, DPS officers, etc.)?

Respondents were allowed to name as many agencies as necessary, as Figure 3-23 illustrates. Generally, the agency in charge of enforcement depends on the jurisdiction in which the project is located. Almost half of the respondents named more than one agency, and the explanation was associated with which agency had the jurisdiction in the area of the project. Thus, DPS officers tend to perform enforcement on most state highways in rural areas, local police take charge on projects within city limits, and sheriff's departments take up the remaining cases. One respondent indicated the hiring of off-duty officers from local police departments.

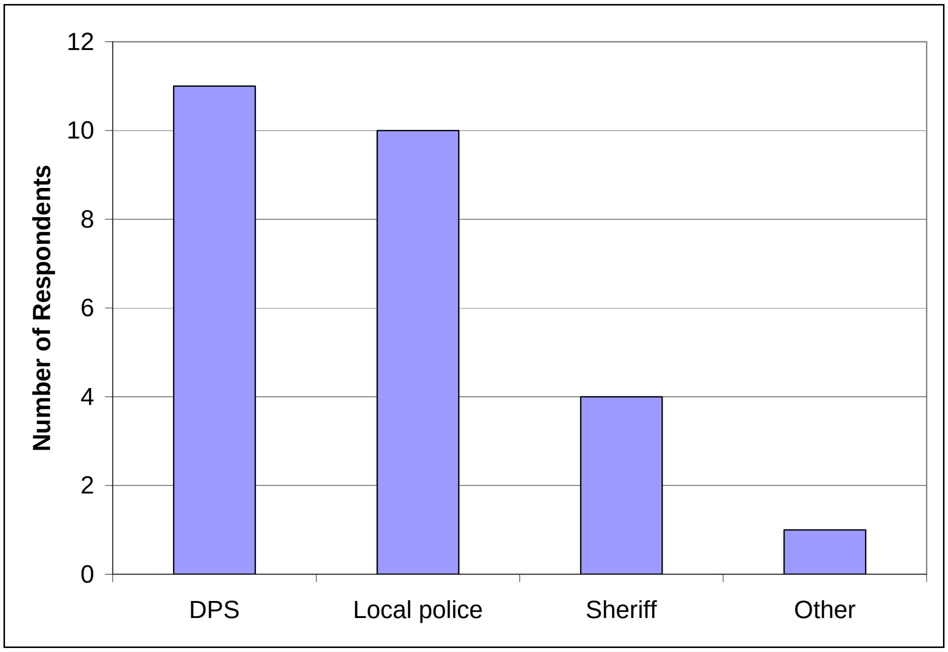


Figure 3-23. Answers to TxDOT Survey Question 12.

CONCLUSIONS

Based on the responses from the out-of-state survey and the TxDOT survey, researchers draw the following conclusions concerning the state-of-the-practice for work zone speed limits:

- Both in Texas and nationwide, the methods for determining the appropriate value for WZSLs vary. Engineering judgment and a simple 10 mph reduction are the most common approaches, but the former can be fairly subjective while the latter may be a "blanket" approach that incorporates little or no consideration of conditions in the work zone.
- TxDOT engineers indicate a preference to post WZSLs in proximity to actual work being performed, but the preference and the practice may be different when it comes to implementation.
- Variable speed limits in work zones are very uncommon in the United States. There are locations where the concept is being studied, but no widespread or consistent use has been reported.
- Agencies use static signs at virtually every work zone, as work zone traffic control standards would support. Portable changeable message signs are also very common, receiving affirmative responses by approximately two-thirds of the respondents in both surveys. Speed trailers are more common in Texas (63 percent) than the rest of

the country (36 percent), while beacons and flags are used more frequently in other states (50 percent) than in Texas (6 percent). Respondents recognized rumble strips as a potential device to use, but they did not use them very often.

- Advance notice of work zone activities through the use of these devices also varies widely. The location at which drivers see one of these devices is more than likely upstream of the work zone, but the exact distance upstream is not a constant.
- The majority of PCMS users display a speed-related message, either paired with work zone information or as a stand-alone message.
- The use of PCMS with radar is increasing in other states, but use in Texas is much less common. Those who do use PCMRs are extremely likely to use them in a manner similar to a speed trailer, often with an alternating message displaying the speed limit in the area. Occasionally, a text message encouraging the driver to reduce his or her speed may supplement or replace the speed display.
- Use of innovative messages on static signs is very common, particularly in other states. However, the innovative message is almost certainly “Give ‘Em a Brake” or some variation thereof.
- Other states frequently use rumble strips and lane narrowing for speed control and/or improved compliance, while Texas commonly uses PCMS. However, the perception among engineers is that none of the devices specified in the survey are particularly effective on a consistent basis.
- Law enforcement was repeatedly identified as a means to encourage compliance and was by far the most effective in the opinion of survey respondents. However, there was no consensus on the circumstances under which law enforcement was utilized. The area engineer or the contractor may request enforcement, or it could be left to the availability and willingness of the enforcement agency itself, or it could depend on the nature of the work being done on the project.
- The method of funding law enforcement was similarly varied. In other states there is often a joint agreement between the DOT and the enforcement agency; otherwise, it is usually the contractor’s responsibility to pay for enforcement activities. In Texas, it is common that the law enforcement agency schedules their own enforcement

activities, so they pay for it as well. Occasionally the contractor will be responsible, or there will be grant funding or a joint agreement between TxDOT and DPS.

- The personnel who actually conduct the enforcement generally are determined by which agency has jurisdiction in the area of the project. This is true both in Texas and nationwide. State highway patrols are most commonly used, although local police or sheriff's departments are utilized inside city limits or other jurisdictions.

CHAPTER 4
SELECTION OF TREATMENTS FOR TESTING

INTRODUCTION

The findings from the DOT surveys and literature review were used to develop a list of treatments with potential for field testing. This list contained descriptions of each suggested treatment, as well as discussion of its deployment in the field and issues or concerns that might be encountered with each treatment. Using this information, the research team and the project advisors selected certain treatments for testing in field studies.

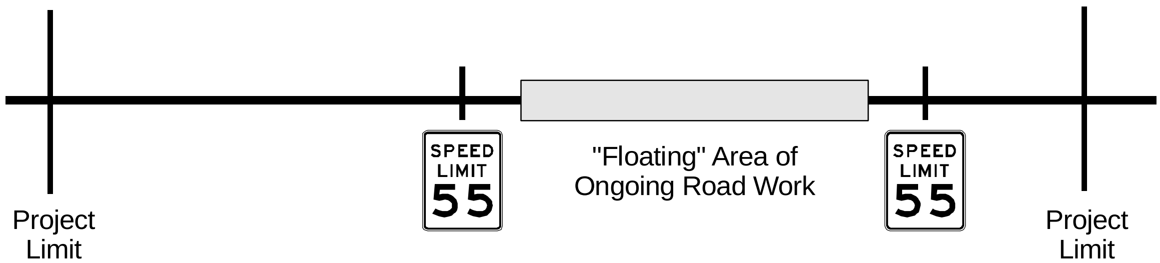
DESCRIPTION OF TREATMENTS

Table 4-1 provides an overview of the various devices and treatments that were suggested for testing in this work plan. The following section describes the treatments in further detail; descriptions include research questions and issues that would need to be addressed to proceed with testing for each treatment. A simplified sketch is also provided for each item to help illustrate the possible layout of proposed devices.

Table 4-1. List of Suggested Treatments for Field Testing.

Item	Treatment	Devices Required	Suggested Roadway
1	"Floating Speed Zone"	Standard static signing, PCMS	Divided multilane
2	Low-Cost Supplemental Devices	Innovative signs, beacons, flags, etc.	Two-lane rural
3	System #1	Standard static signing, light-emitting diode (LED) full-matrix PCMS, speed trailer	Divided multilane
4	System #2	Standard static signing, LED full-matrix PCMS and PCMR	Divided multilane
5	Speed Display Trailer	Standard static signing, speed trailer	Divided multilane
6	PCMR	Standard static signing, PCMR	Divided multilane
7	Supplemental Enforcement	Same as 1-6, but with periodic enforcement	Any
8	Remote enforcement	Standard traffic control, speed & image capture/transfer device	Divided multilane

Item #1: "Floating" (Focused) WZSL



Standard: 55 mph over entire extents of project (limit to limit of work zone) Proposed: 55 mph in applicable locations, perhaps multiple WZSLs within one work zone project (begin with one focused WZSL in project, later perhaps more than one)

Research Question: Will focused WZSL have higher compliance than full-length WZSL?

The objective of Item #1 was to determine the effectiveness of a work zone speed limit that moves, or "floats," with the work being performed. This would help researchers determine if speed zone compliance can be increased with a minimum of extra signs and devices and without significantly changing construction practices or drivers' expectation.

Concept

The conceived advantage to the "floating speed zone" was that drivers may legally drive the normal posted speed limit in areas where no work is being performed, but still reduce speeds in the presence of workers and equipment. This is in contrast to the common practice of posting the WZSL at the beginning of a project and continuing that WZSL for the entire distance and duration of the project, regardless of where work is being performed within the project. Under this practice, a WZSL could be posted over several miles for long periods of time, even though work is actually taking place on a small portion of that distance at any given time. Drivers, particularly commuters who pass through the work zone often, may become apathetic toward such a speed limit as the distance increases. The purpose of testing the "floating speed zone" was to determine if driver compliance increases when the distance under the lower WZSL is reduced and is more strongly perceived to be tied to actual work being performed.

Experimental Plan

The field study for Part 1 would take place on work zones longer than 2 miles, in which work is taking place in segments over time. The duration of the project would have to be long enough that there is time to allow the speed zone to float without having to change the boundaries every one or two days. There would be no additional signing or devices beyond those already required for standard work zone traffic control; however, the standard traffic control would include a portable changeable message sign upstream of the work zone.

The first stage of Part 1 may consist of posting the WZSL over the entire work zone to establish a baseline of driver behavior. Subsequent stages of Part 1 would contain the WZSL posted only around the section of the work zone where work is then occurring. The speed limit signs would then be moved or covered to reflect the boundaries of the "floating speed zone" during each stage of the study. The message on the PCMS would also change to reflect the distance from the PCMS to the WZSL to notify drivers where they would be expected to slow down. Advance warning signs could move with the "floating speed zone" or remain fixed, depending on the nature of the signs.

Specific details of the plan would depend on the nature of the work zone. As an example, Part 1 could take place as follows on a work zone with a length of 8 miles.

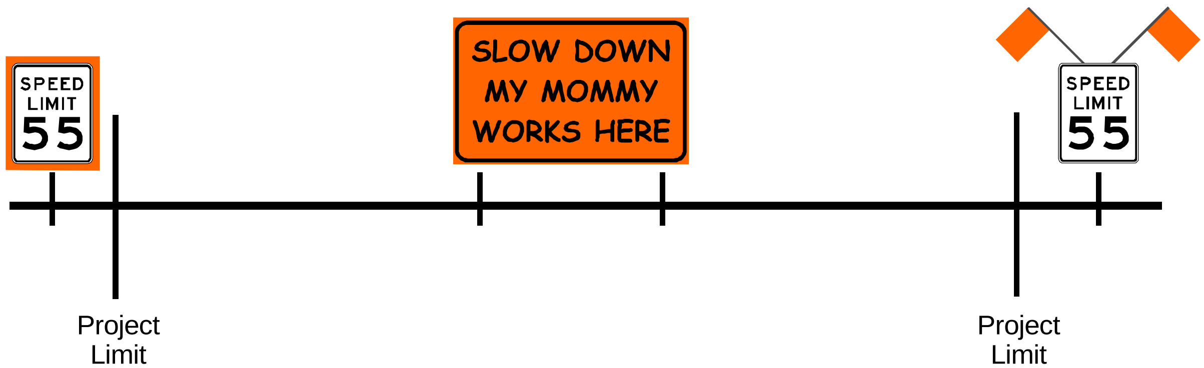
Time Period	Area Where Work Is Being Performed	Area of WZSL Coverage	PCMS: [WORK ZONE AHEAD REDUCED SPEED X MILES]
Weeks 1-2	[Anywhere]	Miles 0.0-8.0	X = 1
Weeks 3-5	Miles 0.0-2.0	Miles 0.0-2.0	X = 1
Weeks 6-8	Miles 2.0-4.0	Miles 2.0-4.0	X = 3
Weeks 9-11	Miles 4.0-6.0	Miles 4.0-6.0	X = 5
Weeks 12-14	Miles 6.0-8.0	Miles 6.0-8.0	X = 7
Weeks 15+	[Anywhere]	Miles 0.0-8.0	X = 1

Speed data will be collected by laser guns and/or counter-classifiers at specified intervals throughout the work zone, and the resulting data from each time period will be compared to determine the level of compliance. If the duration of the project is long enough, a final time period could be used to re-post the WZSL over the entire project, to determine if there are any lingering effects of the "floating speed zone" over the entire work zone.

Some issues that would need to be addressed to implement the "floating speed zone" include the following:

- Can lower (work zone) speed limit be posted for only part of a project?
- What is the minimum acceptable length (i.e., 0.2 mile) for a focused WZSL?
- What is the practical minimum length of a WZSL?
- Is it practical to have more than one focused WZSL within a project? If so, what is the maximum (or minimum) acceptable length between them?
- TxDOT policy says maximum speed limit change must be equal to or less than 15 mph.
- What justifies activities for a focused WZSL? (*Suggestions: Resurfacing a long section of divided highway, reconstruction of a long section of highway, other projects that take place over long sections but work occurs in "pieces" or segments.*)
- What is the minimum duration time (i.e., one week, one month, etc.) for a focused WZSL?
- What is the optimal means (i.e., beacon, reduced speed ahead, increased size of signs) of showing the focused WZSL?
- Where are the best (or necessary) places to collect speed data? (*Suggestions: Upstream of project limits (full WZSL), downstream of initial project limit, at location of focused WZSL signs, downstream of final project limit.*)

Item #2: Low-Cost Supplemental Devices



Standard: Current work zone traffic control standard Proposed: Add-on devices or innovative signs in addition to current standard

Research Question: Will supplemental devices improve WZSL compliance?

The objective of Item #2 was to test the effectiveness of one or more devices to supplement an existing work zone traffic control plan that TxDOT could obtain more easily and at lower costs than other devices suggested here.

Concept

It may be possible to improve drivers' compliance with inexpensive devices that are supplemental to the currently prevalent work zone traffic control plan. If these devices are effective it would expand the options available for future work zones. These devices would be relatively easy to install, minimizing the extra effort needed to incorporate them into an existing work zone traffic control plan. For example, flags, flashing beacons, or orange borders may be installed on any or all of the static WZSL signs in a work zone to improve their visibility. Also, a static sign with an innovative message (i.e., "MY DADDY/MOMMY WORKS HERE" in an approved childlike font) may be posted as part of the advance warning signage or in the work zone near the physical location of the workers and equipment.

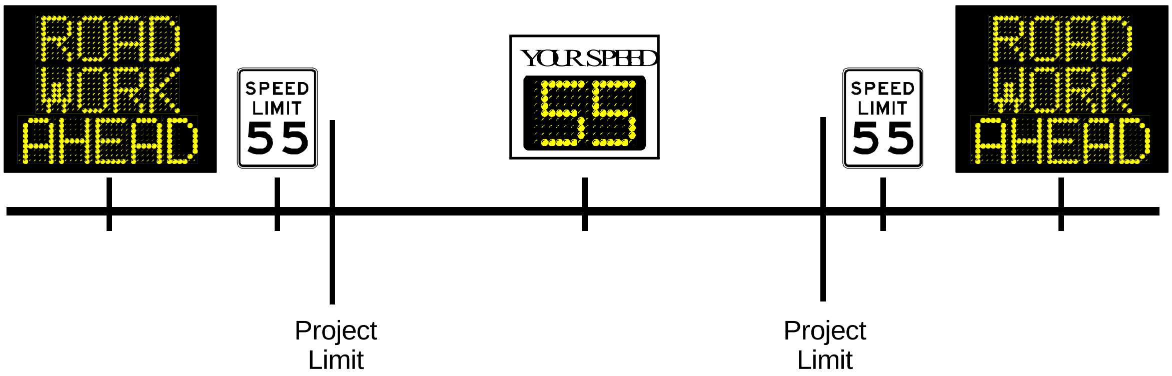
Experimental Plan

The selected devices would be installed at one or more work zones to supplement the existing work zone traffic control plan. The devices would remain in place either until researchers complete the test or until crews complete the road work. Prior to the installation of the devices, researchers would collect speed data at the test site to establish a baseline of driver behavior. Researchers would continue to collect speed data at the test site throughout the test to determine the effectiveness of the devices in increasing compliance with the WZSL.

Some issues that would need to be addressed to implement the low-cost supplemental devices include the following:

- What is the purpose of the devices (i.e., deliver a personalized message, “scare” the driver, increase visibility)?
- What devices should be used? (*Suggestions: Sign-mounted beacons or flags, “My Daddy/Mommy Works Here” signs, police car profile cut-out, orange-bordered speed limit signs.*)
- Where should the devices be placed?
- Do the devices require any waivers or other special permission to be used?
- Where are the best (or necessary) places to collect speed data? (*Suggestions: Upstream of project limits, downstream of initial project limit, at location of devices, downstream of final project limit.*)

Item #3: System #1



Standard: Current work zone traffic control standard Proposed: Defined system of devices in addition to current standard

Research Question: Can previously tested and commonly used devices be brought together in a "packaged set" such that their presence and position as defined in the system's parameters provide higher compliance than the current standard with or without any of the devices alone?

The objective of Item #3 was to test a system of devices to determine its effectiveness in reducing work zone speeds and increasing compliance to work zone speed limits. The most likely environment for this system would be on a freeway or other multilane highway.

Concept

Many types of devices have been used in work zones in an attempt to reduce speeds and increase compliance to the posted WZSL. Most of these devices have been tested and their individual effectiveness quantified and documented. However, these same devices may have a greater impact on compliance if they are used in conjunction with each other. Traditional static signs, speed display trailers, and changeable message signs all play a role in work zone traffic control; perhaps a defined system made up of these components can have a more positive effect than any of the components individually. It was anticipated that the particular devices selected for System #1 would increase driver awareness and improve compliance.

Experimental Plan

The basis of System #1 was traditional advance signing and WZSL static signing, as defined on a traffic control plan sheet. In addition to the traditional signing scheme, two devices would be added: a LED full-matrix PCMS in advance of the work zone and a speed display trailer within the work zone. The PCMS would be placed 1 mile upstream of the work zone, and would advise drivers of the upcoming road work. The speed display trailer would be placed at approximately the midpoint of the work zone (space permitting) and serve as a reminder to drivers of the reduced WZSL.

The advantage of using a full-matrix PCMS over a three-line PCMS is that graphics may be used in conjunction with the text. Thus, the "Workers" symbol on a traditional W21-1a diamond sign may be placed on the message board with the message "WORK ZONE AHEAD" as the first phase of the message. Phase two of the message could read "REDUCED SPEED AHEAD / XX MPH."

Speed data would be collected at specified locations upstream, within, and downstream of the work zone to determine drivers' compliance with the WZSL. Researchers would select a reference (control/comparison) site to determine the increased effectiveness of System #1 over traditional signing.

Some issues that would need to be addressed to implement System #1 include:

- What devices should be used? (*Suggestion: LED full-matrix PCMS in advance of the work zone, speed display trailer within the work zone.*)
- Where should they be located, as defined in relation to current work zone traffic control, and in relation to each other? (*Suggestion: PCMS 1 mile upstream of the work zone, speed display trailer at approximate midpoint of the work zone.*)
- What kind of work zones or roadways should be tested with this system? (*Suggestion: Any type of roadway is a potential candidate, although very high-volume roads may be too heavily traveled for the speed trailer to be effective. The type of work should be something of a longer duration to justify the use of PCMS.*)
- Does the PCMS require any waivers or other special permission to be used?
- What message(s) should be displayed on the PCMS? (*Suggestion: Standard messages should be appropriate (i.e., ROAD WORK AHEAD, REDUCED SPEED XX MPH).*)
- Where are the best (or necessary) places to collect speed data? (*Suggestions: Upstream of PCMS, upstream of project limits, downstream of initial project limit, at speed trailer, downstream of final project limit.*)

Item #4: System #2

Standard: Current work zone traffic control standard Proposed: Identical to System #1 with exception of PCMR replacing speed display trailer

Research Question: Can an innovative device be used in a "packaged set" such that its presence and position as defined in the system's parameters provide higher compliance than the current standard with or without any of the devices alone?

The objective of Item #4 was to test a system of devices to determine its effectiveness in reducing work zone speeds and increasing compliance to work zone speed limits. The most likely environment for this system would be on a freeway or other multilane highway.

Concept

System #2 was very similar to System #1 in that its basis was traditional advance signing and WZSL static signing, as defined on a traffic control plan sheet. Two additional devices would also be added for System #2: a LED full-matrix PCMS in advance of the work zone and a LED full-matrix PCMS with radar capability within the work zone.

The PCMS with radar capability (PCMR) replaces the speed display trailer in System #1. The advantage to the PCMR is that it can display messages and graphics in addition to drivers' speeds, and it can also display different messages to drivers who are traveling above a predetermined threshold. Thus, the PCMR is intended to more aggressively capture the speeding driver's attention than a traditional speed display trailer. Researchers anticipated that the particular devices selected for System #2 would increase driver awareness and improve compliance, perhaps more effectively than System #1.

Experimental Plan

The PCMS will be placed 1 mile upstream of the work zone, just as in System #1. The PCMR will be placed at approximately the midpoint of the work zone (space permitting) to serve as a reminder to drivers that they are in a work zone with a reduced speed limit. The PCMR would have a one-phase default message as follows: “SPEED LIMIT XX / YOUR SPEED XX.” However, if the radar unit detects a vehicle traveling above a specified threshold (i.e., 5 mph above the WZSL), the message would change to the following two-phase message: “YOUR SPEED XX / YOU ARE SPEEDING” – “YOUR SPEED XX / SLOW DOWN.” This two-phase message would be shown until the speeding vehicle passes out of the range of the radar unit, when the one-phase default message would be displayed again. The actual speed being displayed would have a maximum value (i.e., 15 mph above the WZSL) to prevent aggressive drivers from “racing up” the displayed speed.

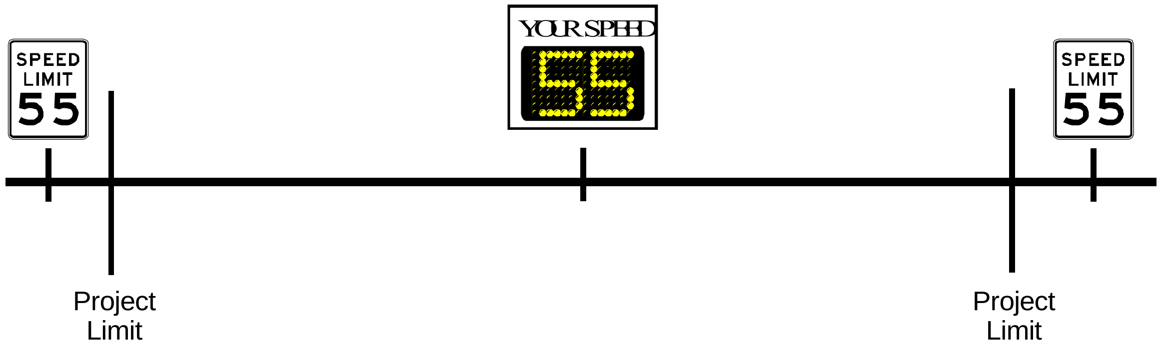
Speed data will be collected at specified locations upstream, within, and downstream of the work zone to determine drivers’ compliance with the WZSL. A reference (control/comparison) site will be selected to determine the increased effectiveness of System #2 over traditional signing.

Some issues that would need to be addressed to implement System #2 include the following:

- What devices should be used? (*Suggestion: LED full-matrix PCMS in advance of the work zone, LED full-matrix PCMS with radar capability within the work zone.*)
- Where should they be located, as defined in relation to current work zone traffic control, and in relation to each other? (*Suggestion: PCMS 1 mile upstream of the work zone, PCMR at approximate midpoint of the work zone.*)
- What kind of work zones or roadways should be tested with this system? (*Suggestion: Any type of roadway is a potential candidate, although very high-volume roads may be too heavily traveled for the speed trailer to be effective. The type of work should be something of a longer duration to justify the use of PCMS.*)
- Does the PCMR require any waivers or other special permission to be used?

- What message(s) should be displayed on the PCMS? (*Suggestion: Standard messages should be appropriate (i.e., ROAD WORK AHEAD, REDUCED SPEED XX MPH).*)
- What message(s) should be displayed on the PCMR? (*Suggestion: Default message for normal conditions (i.e., SPEED LIMIT XX / YOUR SPEED XX). Different set of messages for speeding vehicles (i.e., YOUR SPEED XX / YOU ARE SPEEDING, YOUR SPEED XX / SLOW DOWN).*)
- Where are the best (or necessary) places to collect speed data? (*Suggestions: Upstream of PCMS, upstream of project limits, downstream of initial project limit, at PCMR, downstream of final project limit.*)

Item #5: Speed Display Trailer



Standard: Current work zone traffic control standard Proposed: Identical to System #1 with exception of PCMS removed

Research Question: How does the use of a speed display trailer improve WZSL compliance over current work zone traffic control? That is, what are the speed reductions, and how long do they last?

The objective of Item #5 was to determine the effectiveness of a traditional speed display trailer in reducing speeds within a work zone.

Concept

Speed display trailers can be a useful tool in increasing drivers' awareness of their speed relative to the posted WZSL.

Experimental Plan

In addition to normal work zone traffic control signing, one or more speed display trailers would be placed at strategic points within a work zone to remind drivers of the reduced WZSL and their own speed. Researchers would collect speed data at specified locations upstream, within, and downstream of the work zone to determine drivers' compliance. A reference site would be used to determine the relative effectiveness of the trailer.

Some issues that would need to be addressed to implement the speed display trailer include the following:

- Where should the speed trailer be located, as defined in relation to current work zone traffic control? (*Suggestion: At approximate midpoint of the work zone.*)

- What kind of work zones or roadways should be tested with this system? (*Suggestion: Any type of roadway is a potential candidate, although very high-volume roads may be too heavily traveled for the speed trailer to be effective.*)
- What benefits are obtained from this test? (*Suggestions: Quantify numerical reduction in speed and duration of said reduction. Provide baseline for comparison in Item #6 (see below).*)
- Where are the best (or necessary) places to collect speed data? (*Suggestions: Upstream of project limits, downstream of initial project limit, at speed trailer, downstream of final project limit.*)

Item #6: PCMR

Standard: Current work zone traffic control standard Proposed: Identical to System #2 with exception of PCMS removed

Research Question: How does the use of a PCMR improve WZSL compliance compared to current work zone traffic control with and without a speed display trailer? That is, what are the speed reductions, and how long do they last?

The objective of Item #6 was to determine the effectiveness of a PCMR in reducing speeds within a work zone.

Concept

If speed display trailers are effective at increasing compliance, displays capable of messages and graphics may be more effective. Replacing a speed display trailer with a PCMR would help researchers determine the effectiveness of this device.

Experimental Plan

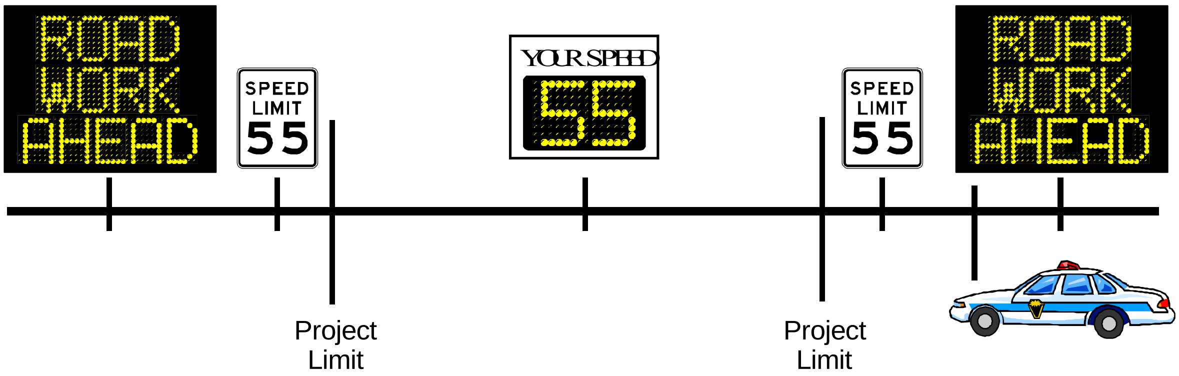
In addition to normal work zone traffic control signing, one or more PCMRs would be placed at strategic points within a work zone to remind drivers of the reduced WZSL and their own speed. The messages and thresholds programmed into the PCMR would be the same as those described in Item #4. Speed data would be collected at specified locations upstream, within, and downstream of the work zone to determine drivers' compliance. A reference site would be used to determine the relative effectiveness of the PCMR.

While a full-matrix full-size PCMR may be appropriate for freeways and other multilane highways, a PCMR with a smaller display may be more appropriate for work zones on two-lane highways. The experimental plan would be the same, but the message would be reduced to one line per phase.

Some issues that would need to be addressed to implement the PCMR include the following:

- Where should the PCMR be located, as defined in relation to current work zone traffic control? (*Suggestion: At approximate midpoint of the work zone.*)
- What kind of work zones or roadways should be tested with this system? (*Suggestion: Any type of roadway is a potential candidate, although very high-volume roads may be too heavily traveled for the PCMR to be effective.*)
- What benefits are obtained from this test? (*Suggestion: Quantify numerical reduction in speed and duration of said reduction.*)
- Where are the best (or necessary) places to collect speed data? (*Suggestions: Upstream of project limits, downstream of initial project limit, at PCMR, downstream of final project limit.*)

Item #7: Supplemental Enforcement



Standard: Little to no scheduled enforcement activity Proposed: Periodic enforcement coinciding with installation of other systems

Research Question: What added benefit results from one or more of the aforementioned systems when enforcement is conducted in conjunction with that system?

The objective of Item #7 was to compare the effectiveness of the previously mentioned systems with the effectiveness of enforcement to supplement those systems.

Concept

It is widely accepted that enforcement is the most effective means of obtaining compliance in work zones. To gain a better appreciation for the effectiveness of other means, they should be tested in conjunction with enforcement.

Experimental Plan

One or more of the previously mentioned systems in Items #1-#6 would be installed as outlined above. To supplement the effects of those systems, upstream or downstream enforcement would be added at the test site for two hours each day for a period of one week. Enforcement would then be removed for at least one week before being added for another one-week period. During the period of active enforcement, the daily two-hour interval would occur at different times each day (i.e., Monday—morning peak, Tuesday—evening peak, Wednesday—noon peak, etc.).

Some issues that would need to be addressed to implement the systems with supplemental enforcement include the following:

- Which systems should be enforced? (*Suggestion: All systems are candidates, although the floating WZSL should probably be excluded, since that method explicitly tests drivers' behavior in reaction to maintaining the standard speed limit outside of the working environment. Otherwise, this item will be limited by the number of sites being tested and the available budget.*)
- On what schedule would enforcement be implemented? (*Suggestion: At each site, the system under investigation will be in place for at least two weeks without enforcement to establish a baseline of behavior. Then, upstream or downstream enforcement will be added for two hours each day for a period of one week (Monday-Friday). Enforcement will then be removed for at least one week before being added for another one-week period. During the enforcement periods, the daily two-hour interval will occur at different times of day (morning peak, evening peak, midday, etc.).*)
- How will enforcement efforts be paid for? (*Suggestion: Some enforcement efforts could be paid out of research project funds if the panel approves. On certain work projects enforcement could be added as a bid item.*)
- Where are the best (or necessary) places to collect speed data? (*Suggestions: Upstream of project limits, downstream of initial project limit, at device(s), downstream of final project limit.*)
- Previously listed issues related to each individual system.

Item #8: Remote Enforcement

Standard:	Officer must personally view and record speeds of offending vehicles to enforce a WZSL
Proposed:	Officer may use video/radar system to monitor conditions within the work zone and conduct enforcement downstream

Research Question: Does the use of a remote enforcement system improve compliance with WZSL?

The objective of Item #8 was to determine the feasibility and effectiveness of a remote enforcement system to improve compliance with work zone speed limits.

Concept

Because enforcement is generally regarded as the most effective means of improving compliance, a system that would make enforcement more efficient and/or cost-effective would improve the benefits of enforcement. A device that could record drivers' speeds within the work zone, match those speeds to the appropriate vehicles, and notify an enforcement officer located downstream of the work zone would eliminate a large portion of the safety concerns associated with issuing speeding citations in work zones. The officer would receive speed and vehicle information from the remote device in the work zone and then issue the citation downstream of the work zone where making a traffic stop is much safer.

Researchers in previous projects have field tested a prototype system on a limited basis; however, much more testing is needed to draw meaningful conclusions on the effectiveness and feasibility of this system (*16*).

Experimental Plan

The experimental device would be placed at a specified location within the downstream half of the work zone. The device, through the use of radar, would monitor drivers' speeds as they travel through the work zone. When the device detects a vehicle traveling above a specified threshold (i.e., 5 mph above the WZSL), the device would capture an image of the offending vehicle, showing the model and license plate of the vehicle. Superimposed on the image would be (at a minimum) the date, time, and speed of the offending vehicle. This image would be sent via radio signal (or similar medium) to an enforcement officer stationed downstream of the work zone. The officer could then identify the offending vehicle as it passed his position and execute a traffic stop to issue a warning or citation.

The monitor/capture device within the work zone could conceivably be integrated with a traditional speed display trailer or PCMR so that the driver could receive an immediate display of the recorded speed. Thus, the system would notify a driver of an offending vehicle that it recorded an illegal speed before the driver is stopped by an officer.

Speed data would also be collected at specified locations within the work zone to determine the effectiveness of increasing compliance relative to a reference site and/or other devices described in Items #1-#6.

Some issues that would need to be addressed to implement the systems with supplemental enforcement include the following:

- Does TxDOT want to research this system? (If not, remaining issues are moot.)
- How do you observe offending vehicles and record their speed? (*Suggestion: Utilizing a principle similar to that researched by Fontaine, Schrock, and Ullman, an "off the shelf" system is reportedly available to record video images and coordinated speed data and transmit them to a receiver in the officer's downstream patrol vehicle (16). Another possibility is to build a system; this could involve the use of a speed trailer or PCMR, which would be connected to a video capture system to transmit the images downstream.*)
- Is it legal? (*Uncertain; some say yes, but the method has not been tested in court to establish the precedent. There is reluctance to field test the method for fear of losing a court challenge and establishing a negative precedent. (Related to Issue #1.)*)

- Should drivers be notified that remote enforcement is active? If yes, how? (*Suggestion: This is related to Issue #3, in that any legal challenges may be more easily withstood if drivers have notification that the system is active. One means is through advance notification, either through static signing or PCMS. (The advance notification itself may, at least initially, be a useful compliance tool.) If a speed trailer or PCMR is used to record speeds, the speed/message displayed to drivers would also serve as notification that they have been recorded at an offending speed.*)
- How will enforcement efforts be paid for? (*Suggestion: Similar to Item #7, project funds or contract funds could be used for a certain level of effort; however, it is anticipated that certain jurisdictions could be persuaded to include this as part of normal activities if they are convinced the new system is a useful tool worth developing.*)
- Would it be necessary to obtain waivers or special permission to field test this system? (*Suggestion: Uncertain, but likely. Ultimately influenced by answers to Issues #1, #3, and #4.*)

SELECTION OF TREATMENTS

The research team met with the project management committee to present the descriptions of the proposed treatments for discussion and feedback, with the intent of selecting the treatments for testing during field studies. During the meeting, researchers and project advisors discussed the relative merits of each treatment, such as its perceived effectiveness, cost of implementation, and ability to properly test the treatment in a timely manner. In particular, the benefits of enforcement were generally agreed upon, but the method of paying for supplemental enforcement was an issue that was not easily resolved. Also, project advisors determined that the concept of remote or automated enforcement was one that should be addressed in a different project at a later date.

The remaining discussion centered on the prioritization of the suggested devices and systems. It was determined that priority should be given to those devices that were lower in cost and easier to obtain; project advisors reasoned that these devices would be more likely to be implemented by project managers and contractors than devices that were more costly or more complicated. Thus, the priority for treatments to be tested was established as follows:

- supplemental devices, specifically orange-border speed limit signs,
- speed display trailers,
- PCMS,
- System #1,
- floating speed zone,
- PCMR/System #2,
- supplemental enforcement, and
- remote enforcement.

Given the limitations of the project's timeline and budget, researchers concentrated their efforts on the three treatments with highest priority: orange-border speed limit signs, speed display trailers, and PCMS. Chapter 5 provides more detailed descriptions of these treatments.

CHAPTER 5
FIELD STUDIES

This chapter contains descriptions of the treatments tested in this project, as well as explanation of the site selection and data collection processes used to conduct field testing.

DESCRIPTION OF TREATMENTS

Three treatments were tested in this project:

- speed display trailer,
- changeable message sign with radar, and
- orange-border speed limit sign.

The following section provides a description of each device and its observed or expected effectiveness in improving work zone speed limit compliance.

Speed Display Trailer

Speed display trailers are used to notify drivers of their current speed as they approach the location of the unit, and to motivate speeding drivers to slow down to a compliant speed. While there are different options available for these units, the basic components are the same:

- a radar emitter/receiver,
- a microcomputer to process the reflected radar waves, and
- a readout panel to display the corresponding speeds to approaching drivers.

Speed display units may be used in any type of work zone, but because of cost and installation they are most appropriate on roadways with higher volumes or speeds.

The most common speed display units are trailer-mounted, though there are some mounted on sign posts as temporary or permanent installations. Trailer-mounted units can be towed to the location to be monitored and moved within the extents of a work zone to pinpoint the location where violations are most likely to occur. Trailer units may be fully enclosed in a trailer box or they may be more compact with a single integrated emitter and readout panel; an example of the latter, which was used in field testing on this project, is shown in Figure 5-1.

Speed display trailers are most often white or orange in color. Usually they have a placard above the readout panel that reads “YOUR SPEED” or “YOUR SPEED IS,” and many trailers have hardware to mount a speed limit sign above or next to the readout to remind drivers of the posted speed limit. Many trailer units, such as the one shown in Figure 5-1, are solar-powered with a battery backup; other trailers are powered by a generator. Their portability and self-contained power source make installing speed display trailers very simple. The only requirements necessary are that the site has sufficient line of sight to track approaching vehicles and it has adequate shoulder or clear zone width to position the trailer away from the travel lanes.

Figure 5-1. Compact Speed Display Trailer.

Speed display trailers, in addition to making drivers aware of their current speed, commonly have a psychological effect on drivers, who may think that there is active enforcement nearby and improve their compliance. Even regular drivers tend to adjust their speed, unsure if enforcement is present. Periodic supplemental enforcement helps to reinforce this concept and improve the effectiveness of the speed display unit between periods of active enforcement. Therefore, speed display trailers can have a substantial effect on WZSL compliance even in the absence of enforcement, and the long-term effects do not dissipate as quickly as with other treatments. Chapter 2 describes the effects of speed display trailers in previous studies.

Changeable Message Sign with Radar

Portable changeable message signs are often used in work zones for a variety of purposes; one common purpose is to motivate drivers to comply with a work zone speed limit. Section 6F.52 of the 2003 *Texas Manual on Uniform Traffic Control Devices* (TMUTCD) states that the primary purpose of PCMS in work zones is to advise the road user of unexpected situations, including where the speed of motor vehicle traffic is expected to drop substantially.

The TMUTCD also gives standards for the design and installation of PCMSs. Portable changeable message signs shall be temporary traffic control devices with the flexibility to display a variety of messages. Each message shall consist of either one or two phases. Typically, a phase shall consist of up to three lines of eight characters per line. Portable changeable message signs should subscribe to the principles established in the TMUTCD and, to the extent practical, with the design (that is, color, letter size and shape, and borders) and applications prescribed in the TMUTCD, except that the reverse colors for the letters and the background are considered acceptable. The front face of the sign should be covered with a protective material. The color of the elements should be yellow or orange on a black background.

PCMS displays often consist of up to three fixed-height rows of mini-bulbs or LEDs. More recent PCMSs, such as that shown in Figure 5-2, have a full matrix of LEDs or bulbs to permit text of different sizes or even graphics. Figure 5-2 shows a PCMS used in this project displaying the default message shown in field studies.

Figure 5-2. Full-Matrix PCMS with Default Message.

Portable changeable message signs should be used as a supplement to and not as a substitute for conventional signs and pavement markings. The PCMS should be visible from 0.5 mile under both day and night conditions. The message should be legible from a minimum distance of 650 ft. The message panel should have adjustable display rates, so that drivers can read the entire message at least twice at the posted speed, the off-peak 85th percentile speed prior to work starting, or the anticipated operating speed.

Standard messages shown on PCMS include "REDUCED SPEED AHEAD" or "SPEED LIMIT XX" to indicate to drivers that they are either approaching or within a work zone speed limit. These messages serve as clear reminders of the need for slower speeds. Other, non-traditional messages may be used to further motivate drivers to comply; these messages, like static signs with innovative text in Section X.4.1 of Appendix B, have inconsistent results. Some messages may be very effective, while other messages may actually result in the opposite response, so engineers should exercise great care and closely monitor conditions when using a non-traditional message on a PCMS.

An increasing number of PCMS models, such as the ones used in the field studies for this project, have the capability of speed detection using a radar emitter similar to a speed display trailer. PCMS with radar may be used to send specific messages to speeding drivers, similar to that shown in Figure 5-3. When the radar unit detects a vehicle traveling at a speed above a preset threshold, the display changes from the default message to a message urging the driver to slow down to a compliant speed. Once the vehicle either sufficiently slows or passes the PCMR, the display reverts to its default message.

This method has an advantage over basic PCMS operation because the change in message helps to catch a driver's attention, especially when the new message is targeted to that driver. It also signals to noncompliant drivers that they are being "watched" by the sign, and may create a concern that there is active enforcement nearby, which further motivates them to slow down. Figure 5-3 shows the sequence of message phases shown to violators for the PCMS used in this project.

Orange-Border Speed Limit Sign

Speed zones on the TxDOT highway system, such as those approaching work zones, often begin at locations that are unexpected by drivers. In many of these cases, the initial reduction in posted speed limit is unexpected because it occurs prior to any physical indication of a need to slow down, such as a change in cross-section or the presence of workers or equipment. In addition, work zone speed limit signs are often posted in close proximity to other signs, most of which are orange, and have a light-blue or white sky as a background. These conditions serve to reduce the visibility and conspicuity of many of the speed limit signs used to notify drivers of an upcoming reduced speed limit. Unexpected changes in speed limit may result in unfavorable traffic operational characteristics such as high speeds, high speed variances, and erratic decelerations, each of which may be associated with more frequent crashes. Improving the visibility and conspicuity of the speed limit signs in these situations can improve motorists' early response to them.

(a) First phase in sequence to violators

(b) Second phase in sequence to violators

(c) Final phase in sequence to violators

Figure 5-3. Specific Message to Violators on PCMS with Radar.

Recent TxDOT-sponsored studies have explored the effectiveness of conspicuity treatments on non-work zone speed limit signs *(31,32)*. These studies tested the use of a 3-inch red microprismatic border to the speed limit sign at the entry to speed zones approaching five towns in central Texas. Figure 5-4 shows an example of the typical 24×30 inch speed limit sign (R2-1) with the extended 3-inch red border used in those studies.

Figure 5-4. Speed Limit Sign (R2-1) with 3-inch Red Border.

The purpose of the 3-inch red microprismatic border around the perimeter of the initial speed limit sign (R2-1) was to increase the conspicuity of the sign, with the intention that it would improve the percentage of drivers complying with the posted speed limit and other speed-related measures. Selection of red for the border color in those projects was based on recommendations of the TTI/TxDOT project team members and the results of two focus groups, which found little potential for driver confusion with the red speed limit border. Results from those projects showed significant speed reductions in the vicinity of the treated signs.

In those projects, researchers discussed the use of other colors, including orange. However, because orange is reserved for use in temporary traffic control applications, using it with a standard speed limit sign in a non-work zone application could mislead a road user. Therefore, orange was not considered for field evaluation as part of those projects, and the concept was referred to researchers and project advisors for testing on this project.

Researchers anticipated that using orange borders on regulatory signs would attract motorists' attention and reinforce the message that there is an active work zone. Borders of any color are not currently a treatment identified by the TMUTCD; researchers on previous projects were required to obtain permission from FHWA to test the red-border signs as experimental devices. However, if the borders are applied properly they may be used without altering the basic design of the sign, as shown in Figure 5-5. This was the approach used in this project, and special permission was not necessary to test the signs.

In order to prevent altering the basic design of the speed limit sign, the orange border could not obscure the face of the sign, including the black border around the sign's legend. The orange sheeting met the standard of "work zone orange" sheeting (fluorescent, microprismatic). A border thickness of 3 inches on all sides was used for non-freeway signs and 6 inches on all sides for freeway-size signs. For example, in Figure 5-5, a freeway speed limit sign with a size of 36×48 inches with a 6-inch orange border on all sides will result in a composite sign with an overall size of 48×60 inches. Figure 5-6 illustrates the relative sizes of the freeway and non-freeway signs by comparing a 36×48 inch sign with a 6-inch orange border and a 24×30 inch sign with a 3-inch orange border.

Figure 5-5. Freeway-Size Speed Limit Sign (R2-1) with 6-inch Orange Border.

Figure 5-6. Relative Sizes of Freeway and Non-Freeway Orange-Border Speed Limit Signs.

SITE SELECTION

The following section describes the process used to select study sites for the field testing conducted in this project.

Required and Preferred Conditions for Study Sites

Researchers established a set of criteria to determine the suitability of a work zone to be used as a study site. There were four required conditions and four preferred conditions, described as follows:

- duration at least 6 months (required);
- length at least 2 miles (required);
- reduction in speed limit for the work zone (required);
- project of significant impact on traffic (not simple maintenance, landscaping, striping, etc.) (required);
- maximum two lanes in each direction of travel (preferred);
- variety of functional classes and roadway conditions (preferred);

- minimal turning movements to restrict free-flow through traffic (preferred); and
- located in Bryan, Austin, or Houston Districts (preferred).

Researchers required the minimum duration in order to have a study site that would be active for the entire duration of field testing. The length requirement was necessary to have a work zone long enough that the work zone conditions would affect drivers; in short-distance work zones, especially at high posted speeds, drivers often pass through the work zone without changing speeds because there is not sufficient distance to slow down before leaving the work zone. The reduction in speed limit was required so that drivers would be forced to make a conscious decision whether to adjust their speeds and comply with the reduced speed limit. The nature of the work project was necessary to show drivers that active work was taking place and there was a visible risk to workers and equipment.

Researchers established the preferred criteria to improve the data collection process. Collecting speed data on more than two lanes in a single direction is difficult, particularly when trying to keep the lanes separate for data analysis. The variety of locations was desired to gain an appreciation for how the devices perform under different conditions. Minimizing turning movements is important to maintaining free-flow speeds, which give the truest representation of the behavior of drivers. The preference of sites within the Bryan, Austin, or Houston Districts was based on the ability of researchers to transport equipment and travel to the study sites more efficiently at those locations.

Sources of Information

Researchers consulted several sources to obtain information on candidate study sites. Members of the Project Monitoring Committee offered suggestions, and researchers listed other sites based on their personal knowledge of active work zones. Finally, researchers consulted extensively the TxDOT online database of ongoing projects to gain more information on the sites suggested and look for other sites with potential for testing.

Verification of Site Characteristics

After listing approximately 20 candidate sites, researchers visited the sites to verify the site characteristics found in the TxDOT database or mentioned by others. Researchers discovered that, since the TxDOT database is only updated monthly, conditions at work zones could vary significantly from what is listed. A project that is listed as only partially complete at the beginning of the month could be concluded by the end of the month if weather and other conditions allow the contractor to proceed faster than anticipated. Also, the characteristics of some work zones and the nature of work being performed as described in the database did not always match what researchers found in visiting the site.

Upon visiting each site, researchers noted the progress of the work and compared it to the anticipated completion in the TxDOT database. They then evaluated the site with respect to the required and preferred conditions specified above, and made a determination whether the site was suitable for further consideration. Sites with great potential were documented with a video taken while driving through the work zone and comments made on a site characteristics worksheet.

Identification of Study Sites

After completing visits to all the preliminary sites, researchers decided that five work zones had potential for testing and were worthy of further consideration. Two of those sites, I-20 west of Weatherford and US-59 in Shepherd, were ultimately used as study sites and are described in detail in the following sections. The remaining three sites, listed as follows, were eventually removed from consideration:

- SH 103 west of Lufkin – A three-phase resurfacing project on a two-lane alignment. This site was not used because the construction schedule was delayed and testing could not be completed during this research project.
- US-59 north of Splendora – A construction project to build freeway alignment in the median of existing expressway lanes, which would be converted to one-way frontage roads. This site was not used because arranging for appropriate traffic control to install devices was problematic and the construction schedule was accelerated so that the work was completed before testing could begin.
- US-79 in Hutto – A widening project on a four-lane alignment to resurface existing lanes and add shoulders and a two-way left-turn lane. This site was not used because excessive turning movements made acquiring accurate free-flow speed data difficult, if not impossible, and the presence of local constables for traffic control made it appear that active enforcement was taking place, which affected speeds.

I-20 West of Weatherford

I-20 travels east to west from the Texas-Louisiana border to the junction with I-10 in western Reeves County. With help from the TxDOT database, a work zone was identified on I-20 near the city of Weatherford. Weatherford is part of the Fort Worth District and is located approximately 20 miles west of Fort Worth. The area around I-20 in Weatherford is rural farmland with some trees. The construction activity during the study period included the reconstruction of the eastbound lanes of I-20. This work zone met the requirements for:

- duration and the significance of work for the project,
- length of the construction zone,
- reduction in the speed limit for the work zone, and
- three other preferable criteria.

The only criterion that was not met with this study site was the preferred criterion that it is not located in the Bryan, Austin, or Houston Districts. After several months of effort locating potential study sites, researchers determined that not meeting this final criterion was not detrimental to the selection of this site.

Experimental Design for the Data Collection

The construction activity was located on the eastbound side of I-20. To accommodate the eastbound traffic, eastbound lanes were merged and redirected onto the existing westbound side of I-20. During the testing period, two-way traffic was carried on the two reconstructed westbound lanes while the two existing eastbound lanes were removed and rebuilt. This plan resulted in one eastbound lane with a shoulder and one westbound lane with a shoulder. The test considered only the traffic traveling in the westbound lane. The speed limit was 70 mph upstream of the work zone and 60 mph in the work zone.

Speed Collection Setup

The total length of the construction work zone was 10 miles. To accurately quantify the speeds of the vehicles traveling through the work zone, there were six data collection sites:

- approximately 1 mile upstream of the work zone,
- at the first advance warning sign,
- at the completion of the merge taper from two westbound lanes to one lane,

- at the approximate midpoint of work zone,
- at the beginning of the diverge taper from one westbound lane to two lanes, and
- approximately 1 mile downstream of the work zone.

Figure 5-7 shows the layout of the data collection for I-20. The direction of traffic was westbound, shown as right to left. Points A-F represent the approximate location of the data collection instruments. A changeable message sign was located at Point B as part of the existing traffic control plan and was present for all tests. The first orange-border sign (OBSLS1) was approximately 0.5 mile downstream of Point B. The first changeable message sign with radar (CMR1) was located near the end of the merge taper. The second orange-border sign (OBSLS2) was located between Points C and D, and the second changeable message sign with radar (CMR2) was located at data collection Point D. There were three on/off ramps in the area of the data collection site: US-281, FM 4, and a local road (LR).

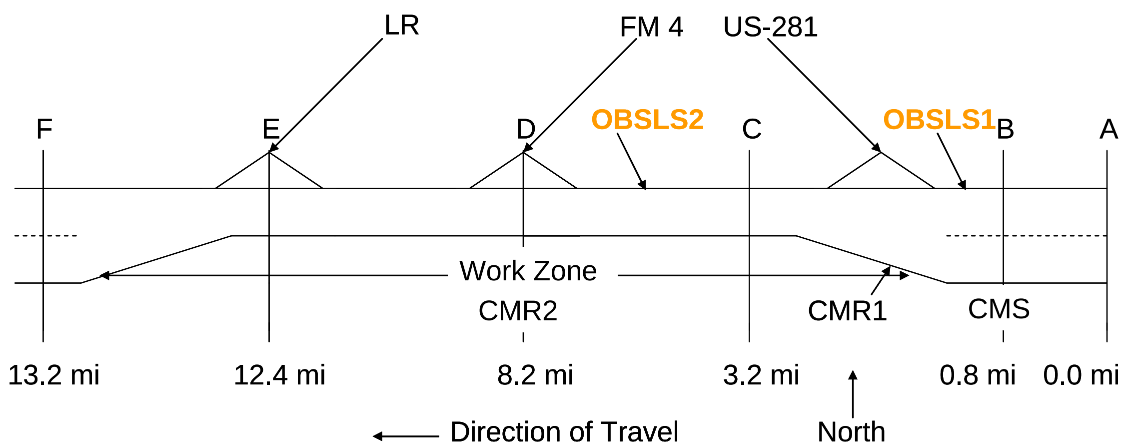


Figure 5-7. I-20 Study Site Layout.

Point A is the beginning, or the zero, mile point for the data collection section on I-20. Figure 5-8 shows the placement of the pneumatic tubes at Point A. All eastbound and westbound lanes are open and there is no evidence of the upcoming work zone; traffic is traveling under free-flow conditions with a 70 mph posted speed limit.


Figure 5-8. I-20 Point A.

Point B is 0.8 mile from Point A. Figure 5-9 shows the changeable message sign that is located on the left side of the road. This CMS provides the first traveler information about the work zone. This point is considered the beginning of the work zone with a work zone speed limit posted at 60 mph. Although Point B is considered the beginning of the work zone there is no work-related activity here.


Figure 5-9. I-20 Point B.

The first orange-border sign is located after Point B. As shown in Figure 5-10, the orange-border sign was placed on the right side of I-20. Downstream of the orange-border sign there are more construction signs for the work zone. At this point, the grass median separates the eastbound and westbound traffic and the merge of the westbound traffic has not started.

Figure 5-10. I-20 First Orange-Border Sign (OBSLS1).

The first speed trailer is located at the merge of the westbound traffic on I-20. Figure 5-11 shows the location of the speed trailer with respect to the channelization barrels and the concrete median barrier. The speed trailer is approximately 20 ft to the left of the westbound traffic.

Figure 5-11. I-20 PCMR #1.

Point C is located at mile marker 386 on I-20 and approximately 3.2 miles from Point A. As shown in Figure 5-12, there is one lane of traffic in each direction with 4-ft shoulders and an additional 5-ft asphalt sloped shoulder. There is a concrete median barrier between the opposing traffic and the driver maintains a clear line of sight. Also shown in Figure 5-12, there is a classifier chained to the mile post and two piezometric sensors placed approximately 10 ft apart over the pavement. The sensors run perpendicular to the westbound traffic and extend over the entire shoulder and lane.

Figure 5-12. I-20 Point C.

Figure 5-13 shows the second orange-border sign. The orange-border sign was placed on the right side of the travel lanes with a clear view for the westbound traffic. The geometric and pavement characteristics remain the same as Point C.

Figure 5-13. I-20 Second Orange-Border Sign (OBSLS2).

The fourth data collection site, Point D, is located 8.2 miles from Point A. Figure 5-14 shows Point D and the overpass of FM 4. The second PCMR is located on the right side of the westbound lane approximately 15 ft from the traffic lane. The classifiers and the pneumatic tubes were placed under the overpass within 50 ft of the speed trailer. With the exception of the overpass, the geometric and surface characteristics remain the same as the other locations within the work zone.

Figure 5-14. I-20 Point D and PCMR #2.

Point E was located under the overpass of a local road approximately 12.4 miles from the beginning of the data collection and near the end of the work zone. The conditions at this point are the same as the conditions throughout the work zone.

Point F, shown in Figure 5-15, is located 13.2 miles from the beginning of the data collection from Point A. This site is the final data collection site for I-20. Shown in this figure, the number of lanes is restored for both the eastbound and westbound directions. The classifier is shown at the base of the I-20 sign, and the piezometric sensors extend across the right shoulder and the two lanes of westbound traffic. Similar to the other data collection sites, the pavement is in excellent condition. The shoulder at this site changes from the 4-ft concrete shoulder with an additional 5-ft sloped asphalt shoulders in the work zone to one 12-ft concrete shoulder.

Figure 5-15. I-20 Point F.

US-59 in Shepherd

US-59 is a four-lane divided highway that travels in a north/south direction from Texarkana through Houston to Victoria, where it changes to an undivided highway for the rest of its route to Laredo. The study site was located near the town of Shepherd approximately 17 miles south of Livingston. The area around the study site was urban with fueling stations and restaurants. The scope of work was the construction of the US-59 overpass through the city of Shepherd. The work zone was located in the median between the northbound and southbound traffic and the length of the work zone was approximately 6.1 miles. Unlike the first study site, all the lanes of traffic remained open through the work zone. The speed limit was 70 mph upstream of the work zone and 55 mph in the work zone. Because the work zone was located within the city limits the exit speed limit remained 55 mph.

The scope of work and the layout of the work zone met the criteria for site selection. After initial observation of the work zone the researchers felt that five data collection locations were capable of providing sufficient information on the speeds throughout the work zone. The five data collection locations were:

- approximately 1 mile upstream of the work zone,
- at the beginning of the work zone and near the reduced speed limit,
- at the approximate midpoint of the work zone,
- approximately 0.5 mile upstream of the end of the work zone, and
- approximately 1 mile downstream of the work zone.

Figure 5-16 illustrates the layout of the work zone and the locations of the data collection points. The locations of all the data collection spots were referenced to the San Jacinto County line (CL). Point A was located 2.5 miles south of the county line; with Points B, C, D, and E located at 4.3, 4.8, 5.8, and 6.8 miles south of the county line, respectively. At this study site, orange-border signs 1 and 2 (OBSLS1 and OBSLS2) and the speed display trailer (SDT) were located slightly past Point B. There were stop signs (SS) located on the minor streets at intersections with Loop 424, SH 150, and two local roads (LR). The local road near Point C had an overhead flashing beacon (Bea) with stop control on the minor street.

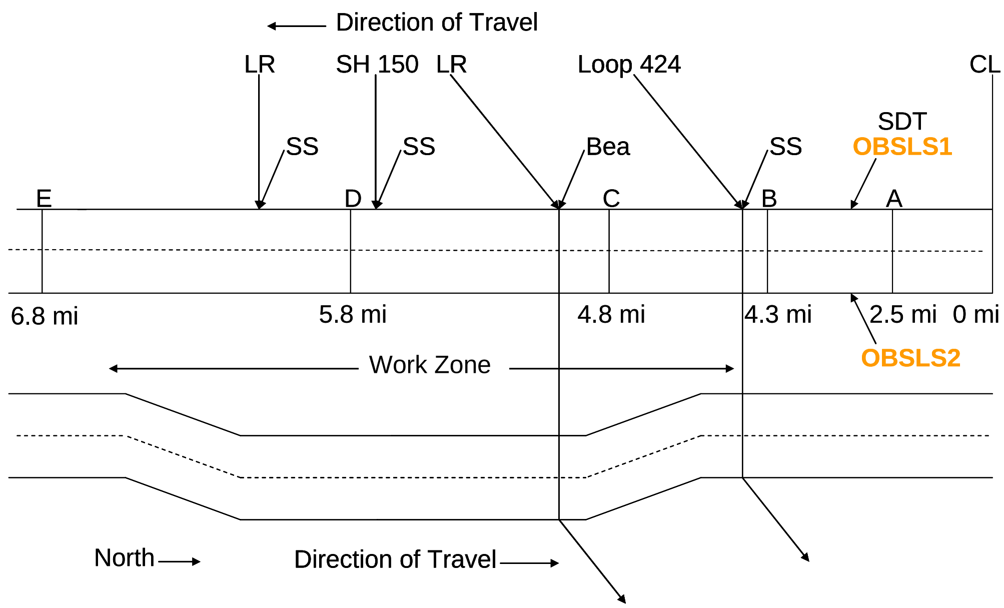


Figure 5-16. US-59 Study Site Layout.

Point A is located upstream of the work zone and is shown in Figure 5-17. In this figure, there are no signs of the upcoming work zone. Vehicles are able to travel freely at the 70-mph posted speed. The lane widths are 12 ft with an 11-ft shoulder.

Figure 5-17. US-59 Point A.

The second data collection location was Point B, 4.3 miles south of the county line and 1.8 miles south of Point A. This is considered the beginning of the work zone. In Figure 5-18, the two orange-border signs are located on both sides of the highway. In addition to the signs, there are orange barrels that alert drivers to the work zone and prevent access to a left-turn/U-turn lane. Point B is also the location of the speed trailer.

Figure 5-18. US-59 Point B.

The third data collection location was Point C. Point C is located 4.8 miles from the county line and 2.3 miles from Point A. Point C, shown in Figure 5-19, is located in the work zone near the construction activity. The left side of the figure shows the construction of the overpass. The work zone is between the existing southbound lanes and the modified northbound alignment. The surface condition is considered excellent near Point C. The lane widths and the right shoulder width are consistent with Points A and B. Shown in the figure, there is no left shoulder and a concrete median barrier separates the traffic from the construction. The figure also shows the configuration of the pneumatic tubes that were placed 16 ft apart and are located across both lanes. (The tubes are located under the van.)

The fourth data collection location, Point D, is 3.3 miles from Point A and is shown in Figure 5-20. This location is just downstream of the intersection with SH 150 and the merge point with the future overpass. At this point, the driver is able to see the end of the work zone.

In this figure, the lane widths and right shoulder widths are consistent with the rest of the work zone, and there remains a concrete median barrier on the left side of the highway. This figure also shows the configuration of the piezometric sensors that were located across the right shoulder and the two lanes.

Figure 5-19. US-59 Point C.

Figure 5-20. US-59 Point D.

The final data collection location, Point E shown in Figure 5-21, is downstream of the work zone and there is no construction activity present at this data collection location. At this location the speed remains 55 mph because US-59 is inside the city limits. This figure shows that the left shoulder has been restored and there is a grass median that separates the north and southbound traffic.

Figure 5-21. US-59 Point E.

DATA COLLECTION

Duration of Data Collection

Field testing was based on a sequential before-and-after study. Data were initially collected for three days under existing conditions, and then a device was installed at the site. After a period of at least one week to allow drivers to become accustomed to seeing the device, data were collected for at least three days with the treatment in place. The treatment was then removed and, after another adjustment period, a different treatment was installed and the process repeated. For one device at each site, data were collected after removing the device to determine if there were any residual effects from the device's presence. The specific sequence of testing and data collection at Site 1 is as follows:

- Collect "Before" data.
- Install PCMR at merge taper and collect data.
- Remove PCMR and collect "After" data.
- Re-install PCMR at merge taper, install PCMR near midpoint of work zone, and collect data.
- Remove PCMRs, install orange-border speed limit signs (OBSLS) upstream of merge taper and near midpoint of work zone, and collect data.

Description of Data Collection Instruments

There were three primary data collection devices used in this study: classifiers, piezometric sensors, and pneumatic tubes. Electronic classifiers were used to store and bin the data from the vehicles traveling on the highway. The data from the classifiers were downloaded onto TTI computers and used in the speed analysis. Piezometric sensors were placed perpendicular to the traffic and extended across the travel lanes and the shoulder. These sensors were placed 10 ft apart and provided information back to the classifier, which included speed and axle configuration that would be used to classify the type of vehicle traveling over the sensor. Pneumatic tubes were set up similar to piezometric sensors and recorded the same type of information. Both pneumatic tubes and piezometric sensors were used interchangeably throughout both study sites.

CHAPTER 6
DATA ANALYSIS

AVAILABLE DATA

The data available from the speed data collection at the two study sites included two numerical and three categorical variables, as described below.

Numerical variables were Speed and Headway. Speed (mph) and time headway (seconds) data were collected for each vehicle traveling through the work zone sites during the study periods.

Categorical variables were Vehicle, Location, and Treatment. The variable "Vehicle" included integer values in the range of 1 through 12 indicating the types of vehicles. Vehicles were classified based on their measured length into 12 categories according to the FHWA vehicle classification scheme. The variable "Location" included integer values from 1 through 6 for I-20, and 1 through 5 for US-59. Speed data were collected at six locations on I-20, and five locations on US-59. (A counter malfunction prevented researchers from obtaining data at Location 3 during the OBSLS test at US-59.) The variable "Treatment" corresponded to the time period when the speed data were collected. It was a character variable with the following values:

BEF: data collection before any of the traffic control devices were deployed.

SD1: data collection during the operation of one speed display.

AFT: data collection after removal of the first speed display.

SD2: data collection during the operation of two speed displays.

OB1: data collection when speed limit signs with orange borders were installed.

DATA PRE-PROCESSING FOR STATISTICAL ANALYSIS

Raw data from the counters were downloaded into spreadsheet files and formatted for data analysis and review. The files were reviewed for errors in recording or downloading, such as vehicles with zero speed or zero headway. Vehicle data with errors were removed from the data set and a corrected data file was created for each treatment at each location. These files were then combined into two aggregate data files, one for I-20 and another for US-59, using a computer program coded in C++. The program performed the following three major tasks:

- arranged the data into a single data file in a format that was appropriate for statistical data analysis,
- reclassified vehicles by aggregating the original 12 categories into two main vehicle types, passenger cars and trucks, and
- extracted the data of vehicles with time headways greater than or equal to 5 seconds.

Class 1 in the new classification scheme represents passenger cars, and class 2 represents trucks. The rule for aggregation was:

- if (FHWA vehicle class ≤ 5), then new vehicle class = 1;
- if (FHWA vehicle class > 5), then new vehicle class = 2.

The time headway threshold was established to separate free-flowing vehicles from the rest of the traffic stream. Vehicles with time headway shorter than 5 seconds were considered to be affected by other vehicles in front of them and were excluded from the analysis.

MEASURES OF EFFECTIVENESS

The measures of effectiveness (MOE) used in the evaluation of the speed control devices included four speed parameters:

- mean speed,
- standard deviation of speed,
- 85th percentile speed, and
- percentage of vehicles complying with the speed limit.

The traffic control devices were evaluated based on the differences in these MOE between the time periods before and during the operation of the devices. The differences in MOE were tested for statistical significance at the 95 percent confidence level.

STATISTICAL ANALYSIS

Multifactor ANOVA

First a multifactor analysis of variance (ANOVA) was performed to determine which factors (categorical variables) have statistically significant effects on vehicle speed. The dependent variable was *speed*, and the factors were *vehicle* (vehicle type), *location* (location of data collection point), and *treatment*. There were a total of 271,204 speed data points from I-20 and 202,469 from US-59. Table 6-1 summarizes results of the multifactor ANOVA for US-59.

Table 6-1. Results of Multifactor Analysis of Variance for US-59.

Analysis of Variance for speed - Type III Sum of Squares					
Source	**Sum of Squares**	**Degrees of Freedom**	**Mean Square**	**F-Ratio**	**P-Value**
MAIN EFFECTS					
Vehicle	1.6886E5	1	168865.0	3423.73	0.0000
Location	3.3103E6	4	827582.0	16779.21	0.0000
Treatment	3.9355E4	3	13118.4	265.97	0.0000
RESIDUAL	9.9857E6	202460	49.3		
TOTAL (CORRECTED)	1.3487E7	202468			

All p-values are less than 0.05, indicating that all three factors have a statistically significant effect on speed at the 95 percent confidence level.

Significance Tests

The subsequent results of the statistical analyses indicate whether a difference in a certain MOE is statistically significant. All significance tests were conducted at the 95 percent confidence level. The statistical significance of the differences in the mean speeds was determined using T-tests. The differences in 85th percentile speeds were tested for statistical significance using a post-hoc quantile test using nonparametric bootstrapping procedure *(33)*. Binomial proportion tests were used to evaluate the statistical significance of differences in the percentages of vehicles complying with the speed limit. F-tests were used to check for statistically significant differences in the standard deviations of the speeds.

RESULTS

The MOE were calculated for each treatment type in all measurement points at the two sites. The ANOVA results indicated that vehicle type had a statistically significant effect on speeds. Thus, the remaining analyses were performed on all both passenger cars and trucks.

Mean Speed

The mean speed profiles in Figure 6-1 and Figure 6-2 show the spatial variation of mean speeds of passenger cars and trucks at the study sites on I-20 and US-59, respectively. Each graph in the two figures corresponds to a certain treatment. The speed limits are indicated with dashed lines in the figures, and the positions of the devices are noted by SDT (speed display trailer), PCMR (portable changeable message sign with radar), and OBSLS (orange-border speed limit sign).

As expected, the mean speeds of passenger cars are 1 to 4 mph higher than the mean speeds of trucks. It is true for the entire freeway sections at both sites. However, the difference in mean speeds of the two vehicle types on I-20 is less uniform than on US-59. At the I-20 site, the mean speed differences between cars and trucks are consistently greater in advance of the work zone (i.e., at Locations 1 and 2) than within the work zone (i.e., at Locations 3, 4, and 5). At the US-59 site, the mean speed differences between the two vehicle types are about the same within and in advance of the work zone. These patterns may be explained by the differences in work zone geometry at the two sites. The road work on I-20 required the closure of one of the two lanes, while the road work on US-59 did not require any lane closure. Passenger cars traveling in the two-lane sections could pass slower trucks, while they were not able to do so in the one-lane sections. Therefore, at the I-20 site, passenger cars could easier maintain their desired speed at Locations 1 and 2 (two-lane sections) than at Locations 3, 4, and 5 (one-lane sections), where they were often forced to stay behind slower vehicles.

In Figure 6-1 and Figure 6-2, the first graphs at the top show the mean speed profiles before the deployment of any traffic control device. Comparing them to the other speed profiles in Figure 6-1 and Figure 6-2 may be used to evaluate the effectiveness of each treatment option (speed control strategy) in terms of its impact on mean speeds. Locations where mean speed was reduced in response to a speed control device are indicated by shaded ellipses. More significant improvements are indicated by darker shading. Findings based on inspections of the speed profiles for the two study sites are discussed separately.

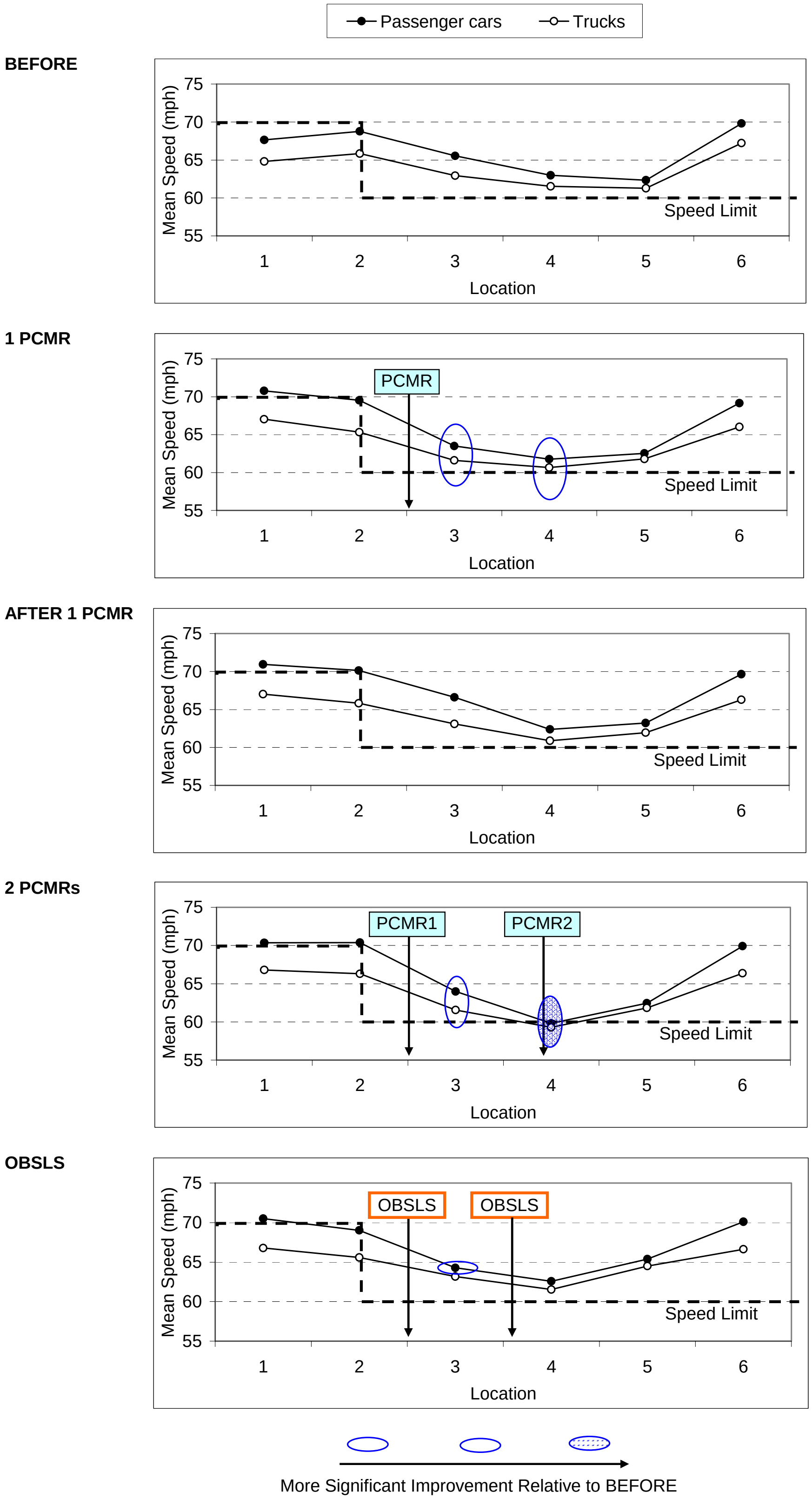


Figure 6-1. Mean Speed Profiles for Trucks and Passenger Cars on I-20.

The speed profiles on the second graph in Figure 6-1 correspond to the time period when a PCMR was deployed at the lane closure taper at the beginning of the work zone and had been operated for at least a week. Results from Figure 6-1 show that the PCMR reduced mean speeds for both passenger cars and trucks at the two nearest measurement locations downstream. The most significant reduction in mean speed was 2.1 mph for passenger cars and 1.3 mph for trucks at Location 3. The reduction at Location 4 was 1.2 mph for cars and 0.9 mph for trucks. All of these improvements (reduction in mean speed) were found statistically significant at the 95 percent confidence level. At other locations, the PCMR either did not reduce mean speeds or the reduction was not statistically significant.

The third graph in Figure 6-1 shows mean speed profiles determined from speed data collected after the removal of the first PCMR. During this time the mean speed at Location 3 (the first measurement point downstream of the PCMR location) increased to a level higher than during the Before period. Although the mean speed remained relatively low at Location 4, it can be concluded that the PCMR did not have a significant residual effect on mean speeds on I-20.

The speed profiles plotted in the fourth graph in Figure 6-1 correspond to the time period when the first PCMR was reinstalled at its original location at the lane closure taper and a second PCMR was deployed near the midpoint of the work zone. The mean speed at Location 3 was reduced by 1.6 mph for passenger cars and 1.4 mph for trucks. Even more significant mean speed reductions of 3.2 mph for passenger cars and 2.3 mph for trucks were observed at Location 4. All of these reductions were found to be statistically significant at the 95 percent confidence level.

The fifth graph in Figure 6-1 shows mean speed profiles when OBSLS were deployed in the work zone. Although OBSLS reduced the mean speed of passenger cars by 1.3 mph at Location 3 and by 0.4 mph at Location 4, and these reductions were found to be statistically significant, they were less effective than either the single or dual PCMRs.

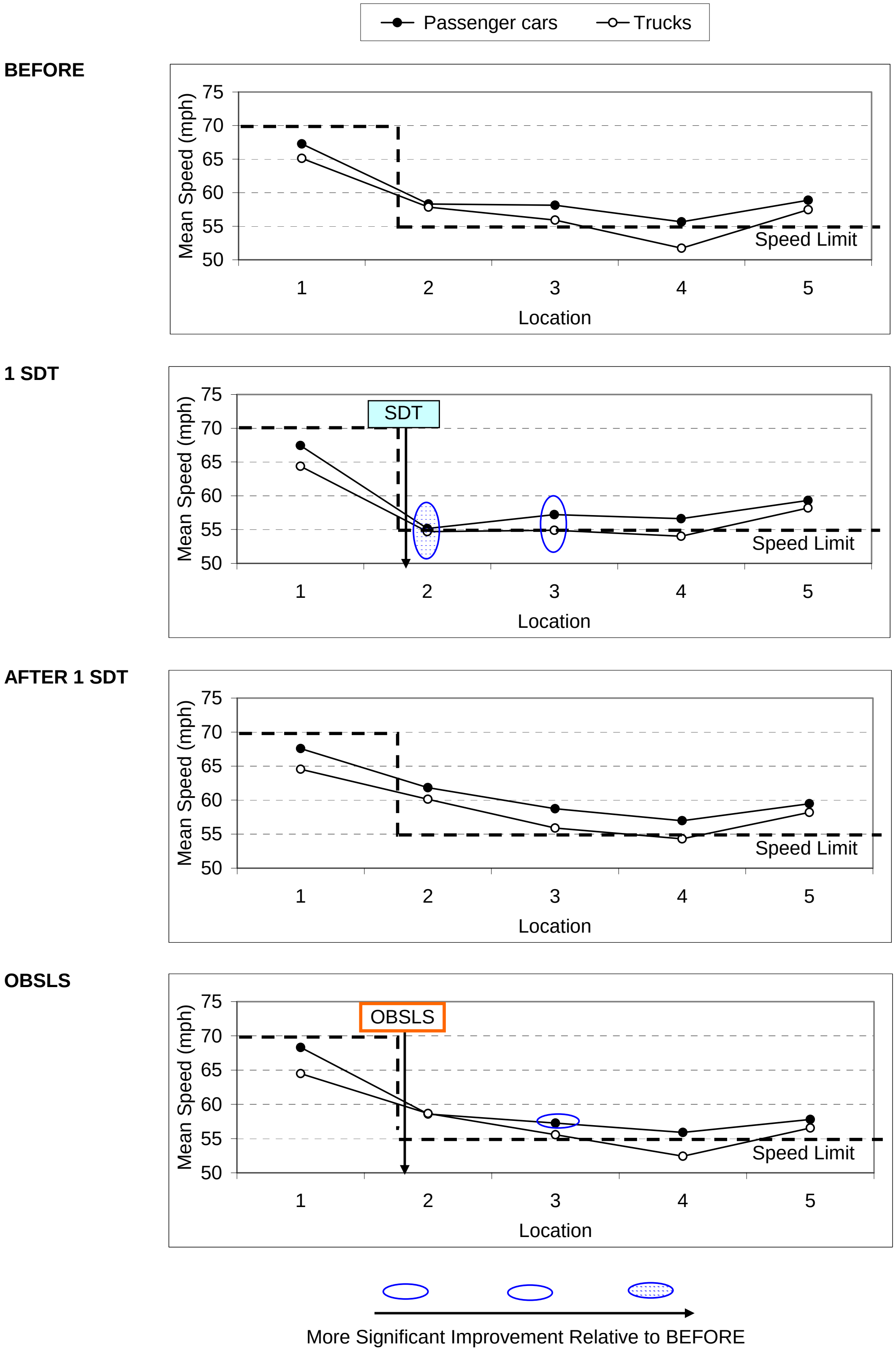


Figure 6-2. Mean Speed Profiles for Trucks and Passenger Cars on US-59.

The speed profiles on the second graph of Figure 6-2 show that the speed display trailers reduced mean speeds for both passenger cars and trucks at the two nearest measurement locations downstream of the device. The most significant reduction in mean speed was 3.1 mph for both passenger cars and trucks at Location 3. The reduction at Location 4 was 0.9 mph for cars and 1.0 mph for trucks. These reductions were statistically significant at the 95 percent confidence level.

The third graph in Figure 6-2 shows mean speed profiles determined from speed data collected after the removal of the speed display trailer. After removing the trailer the mean speeds increased to the same or higher levels than during the Before period at all measurement locations downstream of the device. It can be concluded that, similar to I-20, the speed display trailer did not have a significant residual effect on mean speeds on US-59.

The fourth graph in Figure 6-2 shows mean speed profiles when OBSLS were deployed in the work zone on US-59. OBSLS reduced the mean speed of passenger cars by 0.9 mph and the mean speed of trucks by 0.4 mph at Location 3. Although these reductions were statistically significant, the OBSLS was less effective than either the PCMRs, similar to the findings on I-20.

To evaluate the effectiveness of the speed control devices on the mean speed of the entire traffic stream, mean speed profiles were determined considering all vehicles. The mean speed profiles in Figure 6-3 and Figure 6-4 show the spatial variation of mean speeds for all vehicles for each device along the highway on I-20 and US-59, respectively. Each profile corresponds to a certain treatment. The speed limits are indicated with dashed lines in the figures.

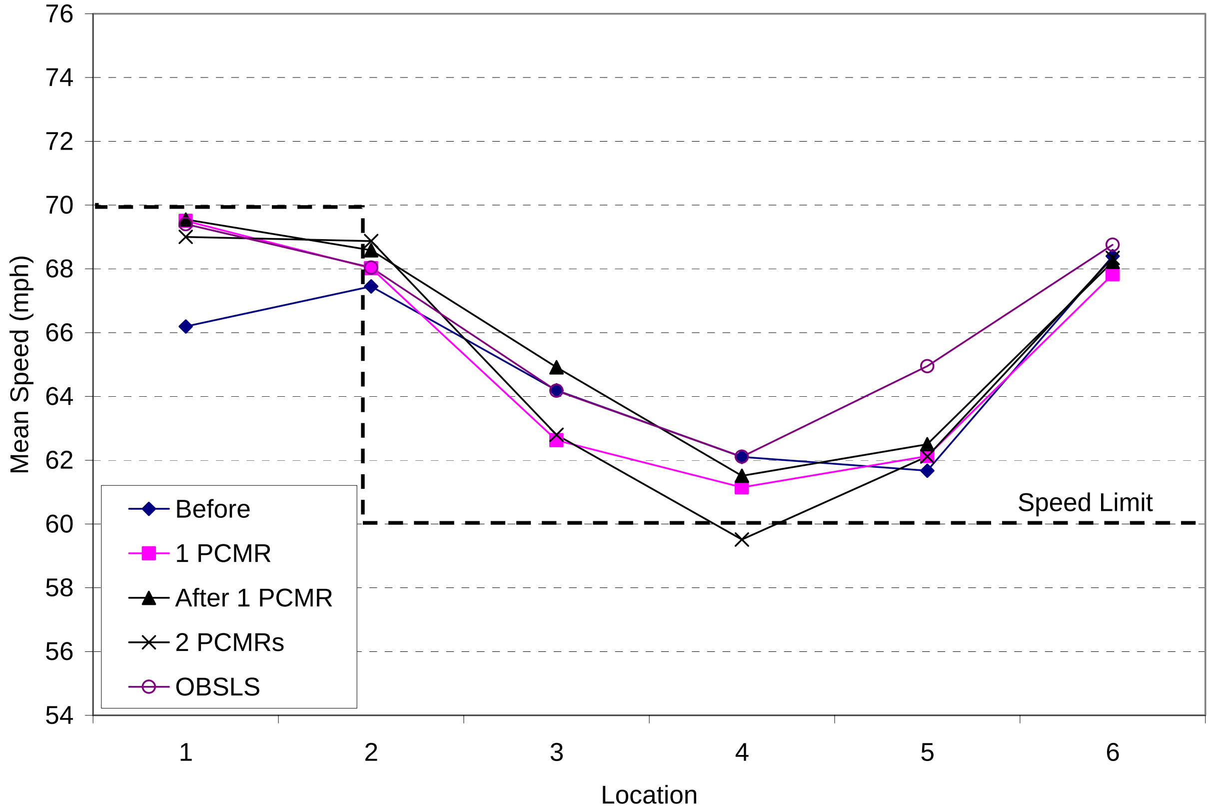


Figure 6-3. Mean Speed Profiles for of All Vehicles for Each Device on I-20.

Inspection of Figure 6-3 shows that the mean speed at the first measurement point, 1 mile upstream of the lane closure taper, was always below the posted speed limit, regardless of the device installed. However, the mean speed exceeded the speed limit everywhere within and downstream of the work zone, with the exception of Location 4 when two PCMRs were installed. Addition of a second PCMR reduced the mean speed just below the speed limit (59.5 mph) near the midpoint of the work zone. In terms of mean speed, the PCMRs were more effective than the OBSLS and existing conditions with no treatment. Orange-border speed limit signs appeared to have little or no effect on mean speed. Most of the differences, relative to the mean speeds observed before the deployment of the devices, were statistically significant at the 95 percent confidence level.

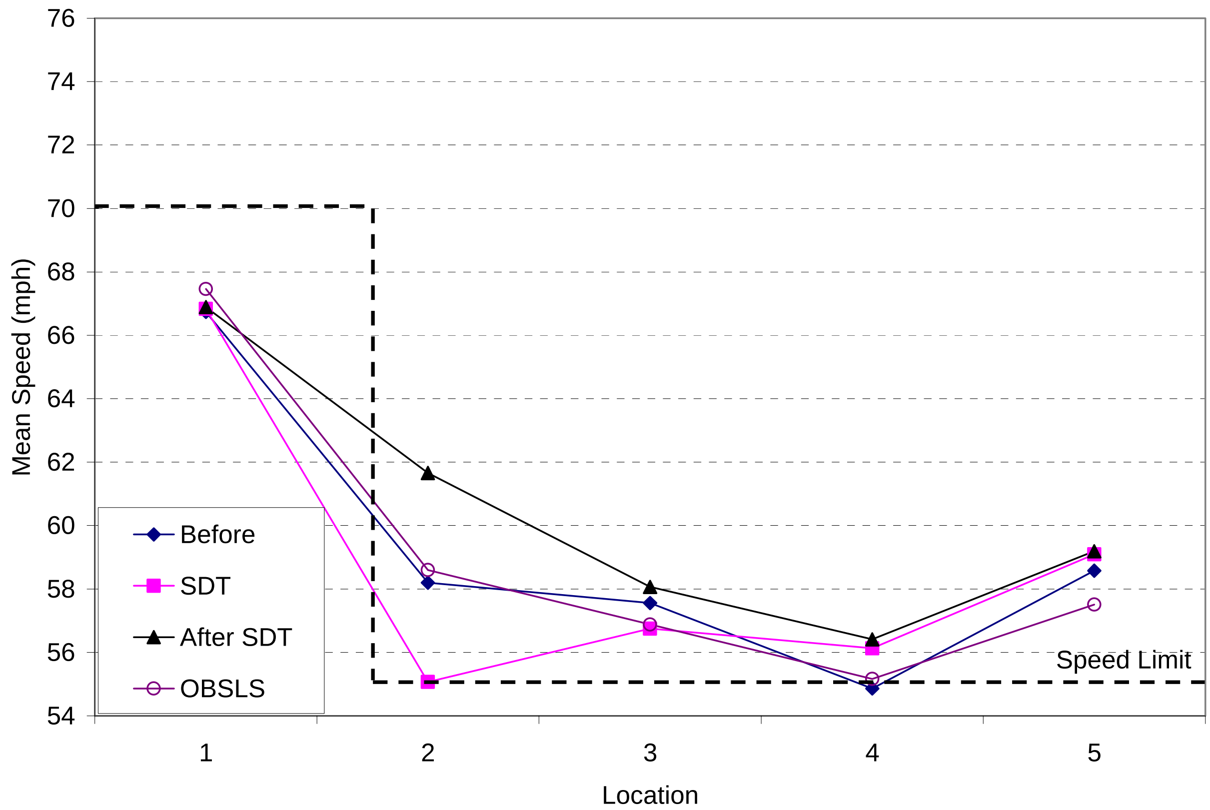


Figure 6-4. Mean Speed Profiles of All Vehicles for Each Device on US-59.

Figure 6-4 shows results similar to Figure 6-3. Mean speeds on US-59 upstream of the work zone were always below the posted speed limit, regardless of treatment. Within and downstream of the work zone, mean speeds were always equal to or higher than the speed limit. The speed display trailer showed the most noticeable effect, as vehicles slowed much more dramatically entering the work zone, resulting in a mean speed of 55.1 mph at Location 2. As traffic progressed through the work zone, however, the relative effectiveness of all treatments was much more similar, with a difference of only 1.6 mph between the highest and lowest values at Location 4.

85^{th} Percentile Speed

The speed profiles in Figure 6-5 and Figure 6-6 show the spatial variation of 85^{th} percentile speeds of passenger cars and trucks through the study sites. Figure 6-5 and Figure 6-6 are formatted in the same way as Figure 6-1 and Figure 6-2. The first graph at the top shows the 85^{th} percentile speed profiles under existing conditions (i.e., before deployment of any traffic control device). Comparing these speed profiles to the others in Figure 6-5 and Figure 6-6 may be used to evaluate the effectiveness of each treatment option in terms of its effect on 85th percentile speeds. Locations where 85th percentile speeds were reduced in response to a speed control device are indicated by shaded ellipses; more significant reductions are indicated by darker shading. Each graph in the two figures corresponds to a certain treatment. The speed limits are indicated with dashed lines in the figures, and the positions of the devices are noted. Similar to the mean speed profiles in Figure 6-1 and Figure 6-2, the 85th percentile speeds of passenger cars are 1 to 5 mph higher than the 85th percentile speeds of trucks. Findings for the two study sites are discussed separately.

The second graph in Figure 6-5 indicates that the PCMR reduced 85th percentile speeds for both passenger cars and trucks at the two nearest measurement locations downstream of the device. The most significant reduction was 2 mph for passenger cars and 1 mph for trucks at Location 3. The reduction at Location 4 was 1 mph for both cars and trucks. These speed reductions were statistically significant at the 95 percent confidence level.

The third graph in Figure 6-5 indicates that the PCMR did not have a significant residual effect on 85th percentile speeds at the study site on I-20. After removing the PCMR, the 85th percentile speed returned to the same or increased to a higher level than before deployment of the device.

The speed profiles in the fourth graph of Figure 6-5 correspond to the time period when the first PCMR was reinstalled at the lane closure taper and a second PCMR was deployed near the midpoint of the work zone. The 85th percentile speed at Location 3 was reduced by 2 mph for passenger cars and by 1 mph for trucks. At Location 4, the speed reductions were more significant, with values of 3 mph for passenger cars and 2 mph for trucks. All of these reductions in 85th percentile speeds were statistically significant at the 95 percent confidence level.

The fifth graph in Figure 6-5 shows 85th percentile speed profiles when OBSLS were deployed in the work zone. The OBSLS reduced the 85th percentile speed of passenger cars by 1 mph at Location 3, which was statistically significant. However, the signs did not have a significant effect on the 85th percentile speed of trucks. Similar to mean speeds, the OBSLS were less effective than the PCMR in reducing the 85th percentile speed.

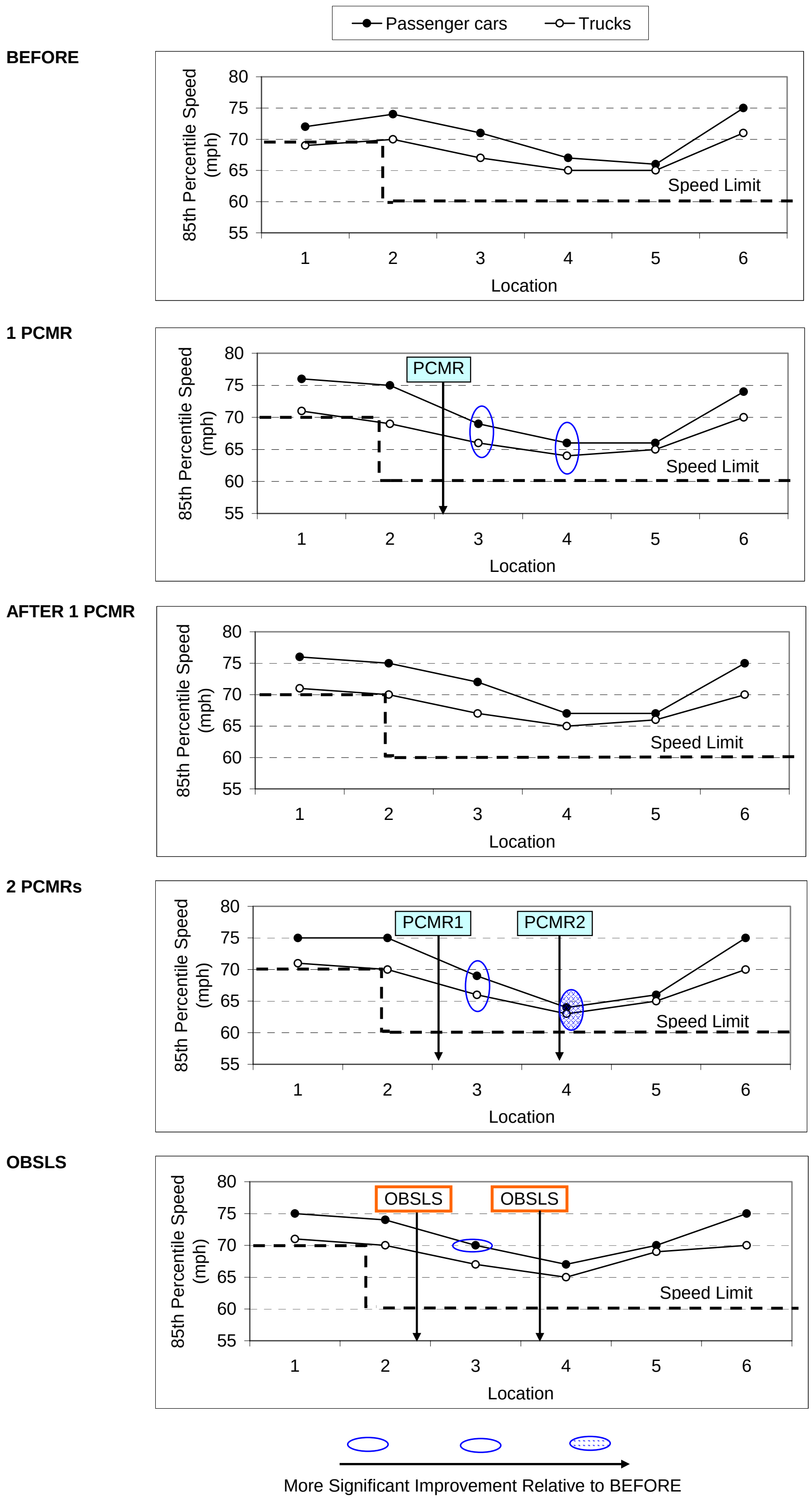


Figure 6-5. 85th Percentile Speed Profiles for Trucks and Passenger Cars on I-20.

The speed profiles on the second graph of Figure 6-6 show that the speed display trailer reduced 85th percentile speeds on US-59 for both passenger cars and trucks at the two nearest measurement locations downstream of the device. The most significant reduction in mean speed was 4 mph for both passenger cars and trucks at Location 3. The reduction at Location 4 was 2 mph for cars as well as for trucks. These reductions were statistically significant at the 95 percent confidence level.

The speed profiles in the third graph in Figure 6-6 show that the SDT did not have a significant residual effect on US-59 speeds after it was removed. After its removal, the 85th percentile speed returned to the same or increased to higher levels than before deployment of the trailer.

The fourth graph in Figure 6-6 shows that OBSLS reduced the 85th percentile speed of passenger cars by 1 mph at Location 3, and this reduction was statistically significant. However, it did not have a significant effect on the 85th percentile speed of trucks. As with I-20, the OBSLS was less effective than the speed display trailer in reducing the 85th percentile speed on US-59.

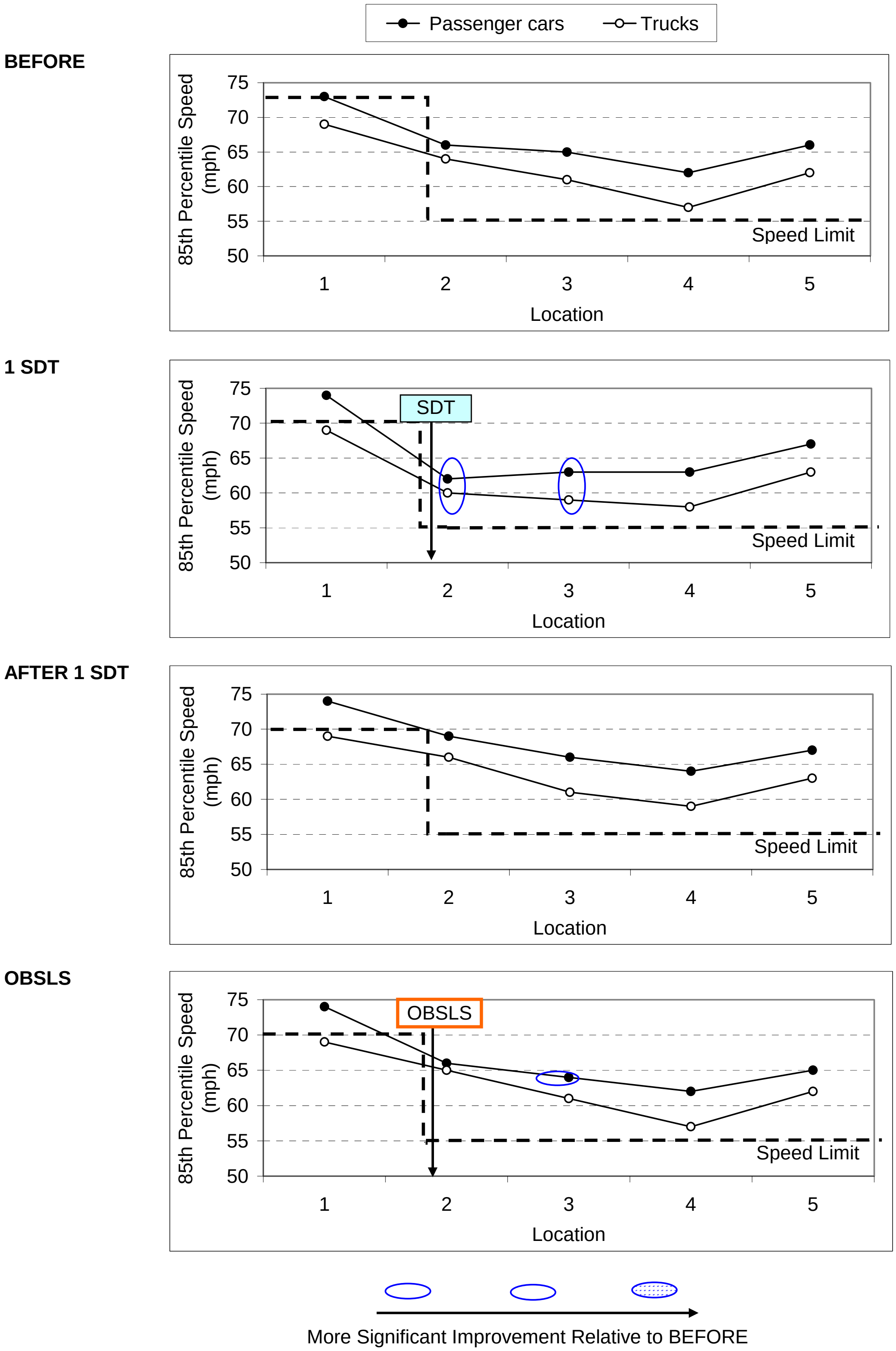


Figure 6-6. 85th Percentile Speed Profiles for Trucks and Passenger Cars on US-59.

To assess the effectiveness of the speed control devices on the 85th percentile speed of all vehicles in the traffic stream, 85th percentile profiles were determined by considering all vehicle types. Figure 6-7 and Figure 6-8 show the 85th percentile speeds of all vehicles for each device at I-20 and US-59, respectively. Inspection of Figure 6-7 reveals that the 85th percentile speed of traffic on I-20 was never below the posted speed limit, regardless of the device installed. However, a look at the profile of each device shows that the PCMRs had better effectiveness relative to OBSLS and existing conditions with no treatment. Also, as with mean speeds, the addition of a second PCMR had an improved effect on 85th percentile speeds at the midpoint of the work zone, compared to a single PCMR at the beginning of the work zone.

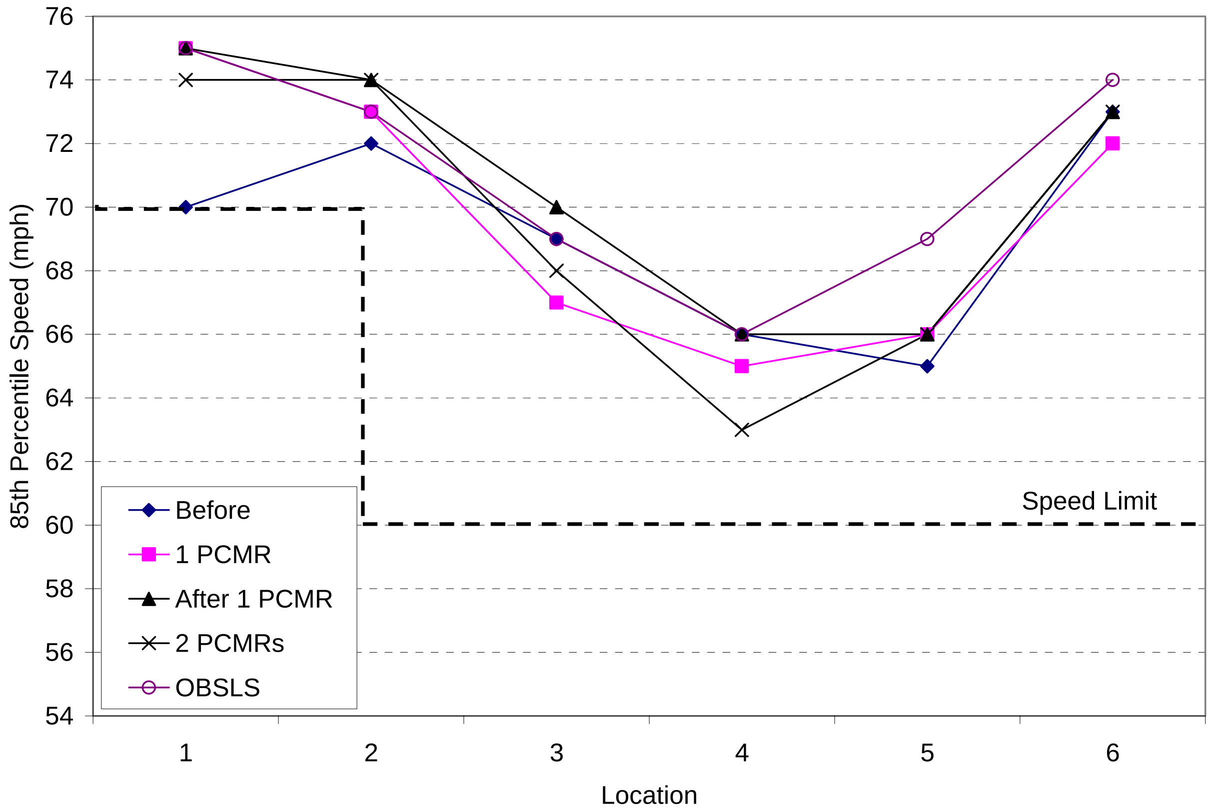


Figure 6-7. 85th Percentile Speed Profiles of All Vehicles for Each Device on I-20.

Figure 6-8 shows results similar to Figure 6-7. The speed display trailer had the best effectiveness in reducing speeds, some 4 mph below the 85th percentile speed at Location 2 for OBSLS or previous conditions. Informal discussions with some drivers in the area indicated that they thought the presence of the SDT meant that enforcement was active nearby, even though this study employed no enforcement. The display of drivers' speeds has an influential effect, sending a message that they are being "watched" and compliance is especially important at that location. While the overall speed trend declined as distance into the work zone increased, the speed display had the most effect early in the work zone.

Figure 6-8 also shows that conditions after removing the SDT were actually worse than they were before installing it, with 85th percentile speeds about 1 to 2 mph higher throughout the work zone. Similar to the mean speed profiles, most differences were found to be statistically significant at the 95 percent confidence level.

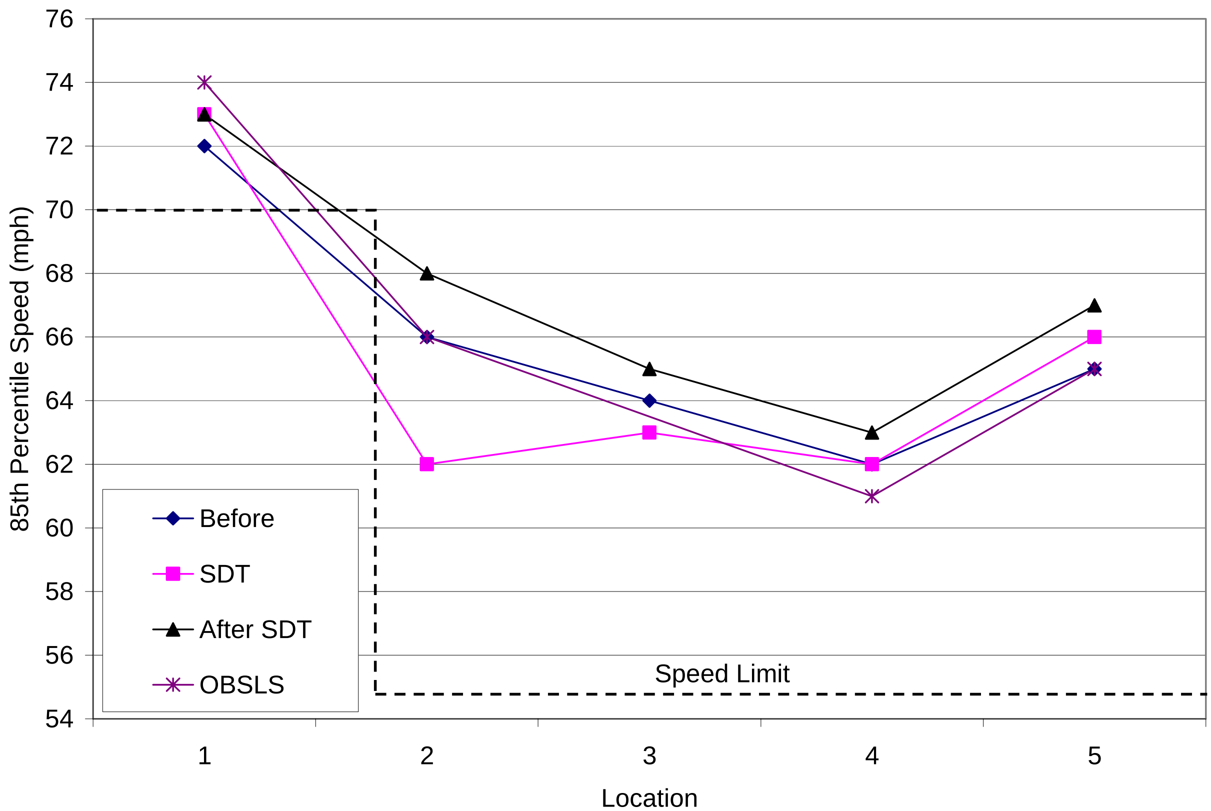


Figure 6-8. 85th Percentile Speed Profiles of All Vehicles for Each Device on US-59.

Speed Limit Compliance

Table 6-2 and Table 6-3 list the speed limit compliance rates on I-20 and US-59, respectively. Table 6-2 underscores the findings from the speed profiles. Compliance with the posted speed limit improved with the presence of two PCMRs, rising as high as 61 percent at Location 4, and the presence of a PCMR at Location 3 resulted in an increase in compliance of approximately 10 percent over OBSLS or no treatment. The OBSLS treatment showed a small increase in compliance at Location 4, near where the midpoint OBSLS was installed, but results were similar to those with existing conditions before testing. In general, the findings from OBSLS testing indicate that it performs similar to other low-cost supplemental devices such as flags and beacons, in that it attracts attention to the sign by increasing its visibility, and discussions with TxDOT workers at the work zones were very favorable regarding their continued use. However, their effects on compliance are minimal unless used in conjunction with other devices.

Another finding from Table 6-2 is that compliance rates were extremely low immediately after entering the work zone and just prior to exiting the work zone. Locations 2 and 6 were near the extents of the reduced speed limit, and the data from those locations represent drivers' behavior in those transitional areas. Both of those locations had two full-width lanes and shoulders in each direction of travel and little or no indication that work was taking place at those locations. The lack of compliance at Location 2 indicates that drivers did not feel a need to slow down to 60 mph prior to the merge taper area to maintain their level of comfort. Similarly, once the cross-section was restored to two lanes in each direction at Location 6, drivers were motivated to speed up, anticipating the restoration of the regulatory 70 mph speed limit downstream.

Table 6-2. Speed Limit Compliance Rates on I-20.

Location	Speed Limit (mph)	Before	1 PCMR	After 1 PCMR	2 PCMR	OBSLS
1	70	85	60	59	64	60
2	60	6	6	5	4	6
3	60	21	32	18	31	23
4	60	34	44	40	61	31
5	60	37	32	29	30	13
6	60	3	5	4	5	4

NOTE: Shaded cells indicate statistically significant ($\alpha = 0.05$) differences relative to "Before" values.

The poor compliance rates at either end of the work zone reinforce findings from previous studies that, absent the threat of enforcement, drivers will drive as fast as they feel comfortable. Even though a reduced speed limit is posted and they are notified that they are within the limits of a work zone, drivers still maintain speeds at or near those outside the work zone because the cross-section is that of a road under normal conditions and there are no workers or equipment that might pose an added risk to the driver.

The compliance rates in Table 6-3 show greater improvement on US-59 than on I-20, but they are still below 60 percent for any device inside the work zone. The removal of the SDT shows a marked reduction in compliance compared to having the SDT in place, and rates after removing the SDT are 3 to 15 percent lower than conditions before testing began. As with I-20, the OBSLS at US-59 showed little to no improvement in compliance for the locations where data were available. Finally, compliance rates decreased downstream of the work zone for all treatments. Location 5 had no sign of active road work and the entire four-lane divided cross section was in place there, which resulted in conditions very similar to those upstream of the work zone that had a posted speed limit of 70 mph. Even though the posted speed limit was still reduced at Location 5, the risk to drivers had greatly diminished and the resulting speeds increased accordingly.

Table 6-3. Speed Limit Compliance Rates on US-59.

Location	Speed Limit (mph)	Before	SDT	After SDT	OBSLS
1	70	78	73	73	68
2	55	31	54	16	32
3	55	41	45	38	--
4	55	58	50	47	55
5	55	27	22	23	30
NOTE: Shaded cells indicate statistically significant ($\alpha = 0.05$) differences relative to "Before" values.					

Standard Deviation of Speed

Table 6-4 and Table 6-5 summarize the standard deviation of speeds on I-20 and US-59, respectively. The standard deviation on I-20 slightly increased within the work zone in the case of all traffic control devices, except at the lane closure taper when the first PCMR was deployed. Although the changes were small they were found statistically significant at the 95 percent confidence level. Therefore, researchers can conclude that, with the exception of the first PCMR, the traffic control devices did not improve the uniformity of speed in the work zone.

Table 6-4. Standard Deviation of Speeds on I-20.

Location	Speed Limit (mph)	Before	1 PCMR	After 1 PCMR	2 PCMR	OBSLS
1	70	4.66	5.23	5.38	4.96	5.25
2	60	4.73	5.13	5.26	5.21	5.23
3	60	4.63	4.51	5.02	5.08	5.26
4	60	3.81	3.82	4.19	4.16	4.05
5	60	3.61	3.66	3.88	3.82	4.46
6	60	4.65	4.75	4.88	5.08	5.01

NOTE: Shaded cells indicate statistically significant (α = 0.05) differences relative to "Before" values.

The standard deviation on US-59 decreased within the work zone in the case of both traffic control devices, indicating that they improved the uniformity of speeds. The improvement was more significant for the speed display than the speed limit sign with orange border.

Table 6-5. Standard Deviation of Speeds on US-59.

Location	Speed Limit (mph)	Before	SDT	After SDT	OBSLS
1	70	5.38	6.13	5.96	6.43
2	55	7.82	7.00	6.85	7.67
3	55	6.24	5.80	6.32	--
4	55	6.67	6.23	6.58	6.28
5	55	7.82	8.81	8.64	8.69

NOTE: Shaded cells indicate statistically significant (α = 0.05) differences relative to "Before" values.

CHAPTER 7
CONCLUSIONS

Based on the findings from the literature review and survey of DOT personnel, researchers make the following conclusions:

- Both in Texas and nationwide, the methods for determining the appropriate value for WZSLs vary. Engineering judgment and a simple 10-mph reduction are the most common approaches, but the former can be fairly subjective and the latter may be a "blanket" approach that incorporates little or no consideration of conditions in the work zone.
- TxDOT engineers indicate a preference to post WZSLs in proximity to actual work being performed, but the preference and the practice may be different when it comes to implementation.
- Variable speed limits in work zones are very uncommon in the United States. There are locations where the concept is being studied, but no widespread or consistent use has been reported.
- Static signs are used at virtually every work zone, as work zone traffic control standards would support. Portable changeable message signs are also very common, receiving affirmative responses by approximately two-thirds of the respondents in both surveys. Speed trailers are more common in Texas (63 percent) than the rest of the country (36 percent), while other states use beacons and flags more frequently (50 percent) than in Texas (6 percent). Rumble strips are recognized as a potential device to use, but they are not used very often.
- Advance notice of work zone activities through the use of these devices also varies widely. The location at which drivers see one of these devices is more than likely upstream of the work zone, but the exact distance upstream is not a constant.
- The majority of PCMS users display a speed-related message, either paired with work zone information or as a stand-alone message.
- The use of PCMS with radar is increasing in other states, but use in Texas is much less common. Those who do use PCMRs are extremely likely to use them in a manner similar to a speed trailer, often with an alternating message displaying the

speed limit in the area. Occasionally, the speed display may be supplemented by or replaced with a text message encouraging the driver to reduce his or her speed. These devices have shown effectiveness in improving WZSL compliance.

- Use of innovative messages on static signs is very common, particularly in other states. However, the innovative message is almost certainly "Give 'Em a Brake" or some variation thereof.
- In other states, rumble strips and lane narrowing are frequently used for speed control and/or improved compliance, while Texas commonly uses PCMS. However, the perception among engineers is that none of the devices specified in the survey are particularly effective on a consistent basis.
- Law enforcement was repeatedly identified as a means to encourage compliance and is widely regarded as the most effective. However, there was no consensus of survey respondents on the circumstances under which to utilize law enforcement. The area engineer or the contractor may request enforcement, or it could be left to the availability and willingness of the enforcement agency itself, or it could depend on the nature of the work being done on the project.
- Methods of funding law enforcement are similarly varied. In other states there is often a joint agreement between the DOT and the enforcement agency; otherwise, it is usually the contractor's responsibility to pay for enforcement activities. In Texas, it is common for the law enforcement agency to schedule their own enforcement activities, so they pay for it as well. Occasionally the contractor will be responsible, or there will be grant funding or a joint agreement between TxDOT and DPS.
- The agency having jurisdiction in the area of the project generally determines the personnel who actually conduct the enforcement. This is true both in Texas and nationwide. State highway patrols are most commonly used, although local police or sheriff's departments are utilized inside city limits or other jurisdictions.

Based on the findings from analysis of field data, researchers made the following conclusions:

- Devices that display an approaching driver's speed are effective at reducing speeds and improving work zone speed limit compliance.

- Orange borders are a low-cost method of substantially improving the visibility and conspicuity of speed limit signs and they are well-received by workers, but they do not show a consistent measurable effect on improving compliance. They should be used in conjunction with other devices to obtain the greatest benefit.
- Drivers tend to travel as fast as they feel comfortable, absent the threat of enforcement. Even in areas posted as work zones with reduced speed limits, if there are no indications that active work is taking place and the road maintains a normal cross-section, drivers generally maintain the speed they were traveling before entering the work zone, regardless of the posted work zone speed limit.
- To avoid work zone speed limits that drivers ignore or widely disobey, officials should post them at realistic values and the speed limits should be confined as much as possible to the specific areas where active work is taking place.

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APPENDIX A
TEXT OF SURVEY QUESTIONS

This appendix contains the full text of each survey in its entirety, as presented to the survey participants on the survey web site.

Out-of-State Survey

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1. How do you determine the appropriate work zone speed limits on your projects?

2. Have you used variable speed limits (i.e., speed limit varying over time in response to changes in traffic conditions)? ⊚Yes ⊚No
If so, please explain the procedure used to determine how the speed limit is changed.

3. What devices do you use to notify the driver of a lower work zone speed limit? (These devices may include, but are not limited to: post-mounted static signs, portable changeable message signs, speed display trailers, flashing beacons, and other devices.)

4. For the devices used in Question 3 above, at what locations relative to the work zone are these devices located (i.e., 1000 ft upstream of work zone, start of lane reduction taper, beginning of work zone, etc.)? For multiple devices, what spacing interval is used between devices?

5. If you use Portable Changeable Message Signs (PCMS) for driver notification, what are your typical messages?

6. Have you used PCMS with radar/speed display capabilities? ⊚Yes ⊚No
If so, what messages do you use?

7. Have you used static signs with innovative messages (i.e., “Give ‘Em a Brake,” “Slow Down – My Daddy Works Here,” etc.)? ⊚Yes ⊚No
If Yes, what messages have you used?

8. Which of the following strategies do you use for speed control and/or improved compliance, and how effective are they?

	Have used this strategy?	*Strategy was effective? (if used)*
Lane Narrowing	☐	⊚ *Yes* ⊚ *Partially* ⊚ *No*
Longer Speed Zone Transitions	☐	⊚ *Yes* ⊚ *Partially* ⊚ *No*
Flagging (as a Speed Control Method)	☐	⊚ *Yes* ⊚ *Partially* ⊚ *No*
PCMS (as a Speed Control Method)	☐	⊚ *Yes* ⊚ *Partially* ⊚ *No*
Rumble Strips	☐	⊚ *Yes* ⊚ *Partially* ⊚ *No*

Comments:

9. What other methods of influencing work zone speeds have you used? Did you find them effective?

10. How do you determine where and when to use enforcement of work zone speed limits?

11. How are arrangements made to provide for enforcement activities in work zones (i.e., contractor is responsible to schedule enforcement officers and pay for their time; DOT has a contract or joint program with Highway Patrol to coordinate and fund work zone enforcement; etc.)?

12. Who performs the actual enforcement (i.e., local police, state highway patrol, etc.)?

Name:
Title:
Agency:
Street Address/P.O. Box:
City:
State:
Zip Code:
Telephone:
Fax:
E-Mail:

TxDOT Survey

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1. How do you determine the appropriate work zone speed limits on your projects?

2. Do you post and remove the work zone speed limit according to the status of the actual work being performed? (For example, on a work zone 10 miles in length, do you post the work zone speed limit for all 10 miles for the entire duration of the project, or do you move the extents of the speed limit to cover the portion of the work zone where work is taking place?)

3. What devices do you use to notify the driver of a lower work zone speed limit? (These devices may include, but are not limited to: post-mounted static signs, portable changeable message signs, speed display trailers, flashing beacons, and other devices.)

4. For the devices used in Question 3 above, at what locations relative to the work zone are these devices located (i.e., 1000 ft upstream of work zone, start of lane reduction taper, beginning of work zone, etc.)? For multiple devices, what spacing interval is used between devices?

5. If you use Portable Changeable Message Signs (PCMS) for driver notification, what are your typical messages?

6. Have you used PCMS with radar/speed display capabilities? ⊚Yes ⊚No
If so, what messages do you use?

7. Have you used static signs with innovative messages (i.e., "Give 'Em a Brake," "Slow Down -- My Daddy Works Here," etc.)? ⊚Yes ⊚No
If Yes, what messages have you used?

8. Which of the following strategies do you use for speed control and/or improved compliance, and how effective are they?

	Have used this strategy?	*Strategy was effective? (if used)*
Lane Narrowing	☐	⊚ *Yes* ⊚ *Partially* ⊚ *No*
Longer Speed Zone Transitions	☐	⊚ *Yes* ⊚ *Partially* ⊚ *No*
Flagging (as a Speed Control Method)	☐	⊚ *Yes* ⊚ *Partially* ⊚ *No*
PCMS (as a Speed Control Method)	☐	⊚ *Yes* ⊚ *Partially* ⊚ *No*
Rumble Strips	☐	⊚ *Yes* ⊚ *Partially* ⊚ *No*

Comments:

9. What other methods of influencing work zone speeds have you used? Did you find them effective?

10. How do you determine where and when to use enforcement of work zone speed limits?

11. How are arrangements made to provide for enforcement activities in work zones (i.e., contractor is responsible to schedule enforcement officers and pay for their time; DOT has a contract or joint program with Highway Patrol to coordinate and fund work zone enforcement; etc.)?

12. Who performs the actual enforcement (i.e., local police, state highway patrol, etc.)?

Name:
Position/Title:
TxDOT District/Area:
Telephone:
E-Mail:

APPENDIX B
PROPOSED MATERIAL FOR INCLUSION IN THE TXDOT WORK ZONE SAFETY AND MOBILITY MANUAL

This appendix contains the text proposed as a chapter of the forthcoming manual containing TxDOT's state-level work zone safety and mobility policy.

WORK ZONE SPEED LIMIT COMPLIANCE

CHAPTER X

SECTION X.1 – INTRODUCTION

Motivating drivers to comply with traffic regulations is an extremely important yet challenging task. Further, motivating drivers to comply with regulations within work zones is critical to the safety of both motorists and workers approaching and within the work zones.

One of the regulations with which drivers most obviously need to comply is the work zone speed limit (WZSL). While it is one of the most important regulations, it is often also the most frequently violated. Work zone speed limit violations reduce a driver's reaction time and margin for error and erode the safety of workers as well as other drivers. According to the Texas Department of Public Safety, 9523 crashes occurred in work zones on the state highway system in 2000, resulting in 143 fatalities and 9899 incapacitating, non-incapacitating, and possible injuries. Speed was cited as a contributing factor in approximately 42 percent of these crashes; therefore, motivating drivers to comply with speed limits in work zones will help to reduce the risk of crashes approaching and within work zones.

This chapter contains descriptions of a variety of treatments and methods for improving WZSL compliance, as well as recommendations on their use. These treatments have been divided into three main categories:

- "awareness" treatments, which are used to attract a driver's attention to the presence of a WZSL and motivate compliance;
- "design" treatments, which are used to encourage compliance by modifying a driver's behavior; and
- "enforcement" treatments, which are used to improve compliance through the threat and/or issuance of traffic citations.

Along with the descriptions of these treatments, their use and anticipated benefits will also be discussed.

In addition to this introductory section, this chapter contains five other sections. Section X.2 contains a generalized decision-making flowchart outlining the process an engineer may take in deciding what compliance treatment(s) to use in a work zone. Section X.3 discusses characteristics of and guidelines for different types of roadways and road work projects. Section X.4 describes a selection of "awareness" treatments, Section X.5 identifies "design" treatments, and Section X.6 discusses "enforcement" treatments.

SECTION X.2 – DECISION PROCESS

Using the information presented in the following sections of this chapter, this section contains a generalized flowchart (see Figure X-1) describing the decision-making process an engineer might use when deciding what treatment(s) to use at a particular work zone to improve work zone speed limit compliance. Two example flowcharts, Figure X-2 and Figure X-3, follow the generalized flowchart; they include conditions an engineer might encounter and show possible treatments that the engineer may use under those conditions.

The questions raised in this decision-making process are described in Section X.3, and more information about each category of conditions is contained therein. Treatments are discussed in Sections X.4 through X.6. Standards and specifications on the installation and usage of many treatments described in this chapter can be found in other TxDOT reference documents, such as the *Texas Manual on Uniform Traffic Control Devices* (TMUTCD), *Roadway Design Manual*, *Procedures for Establishing Speed Zones*, and *Standard Highway Sign Designs for Texas*.

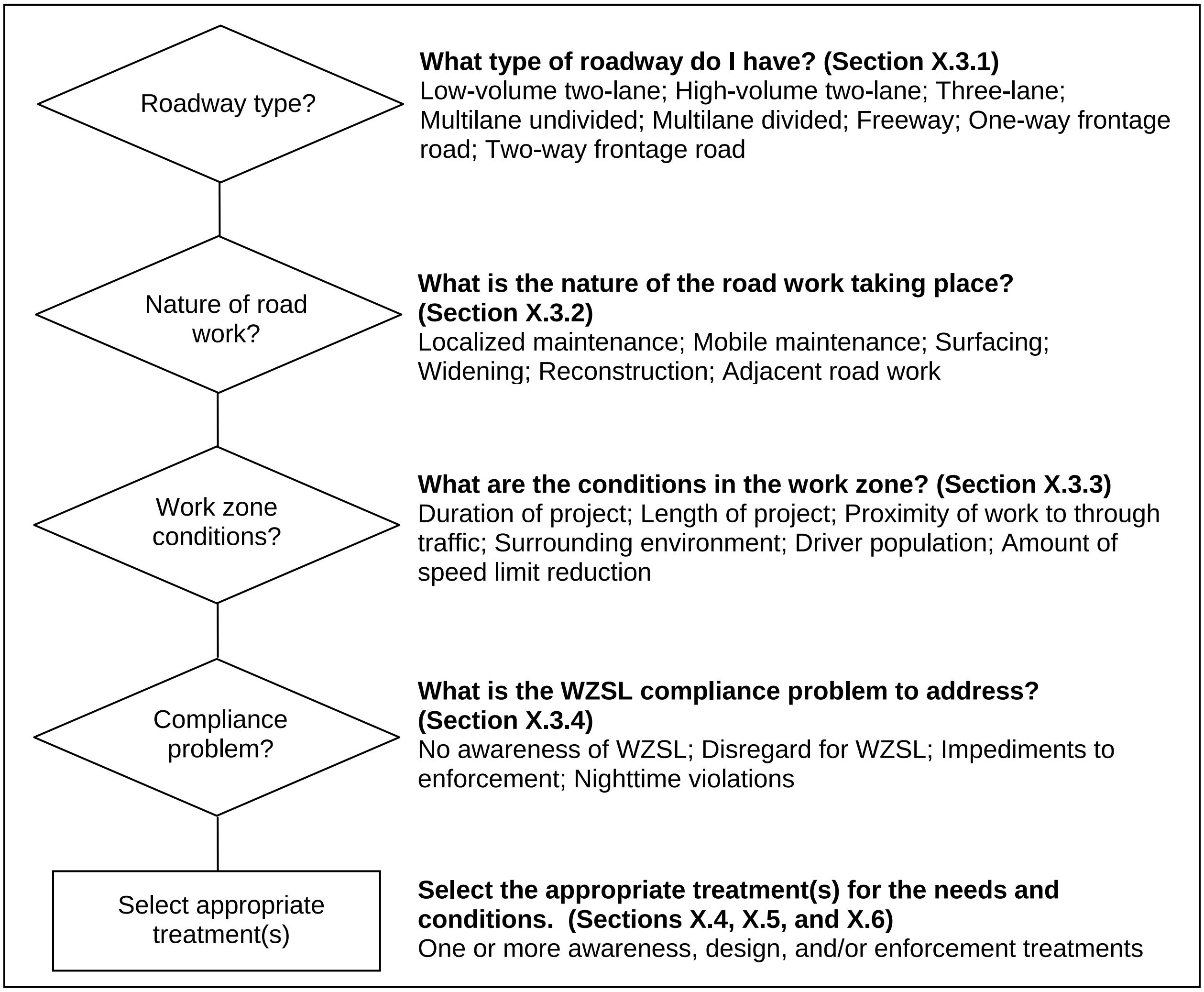
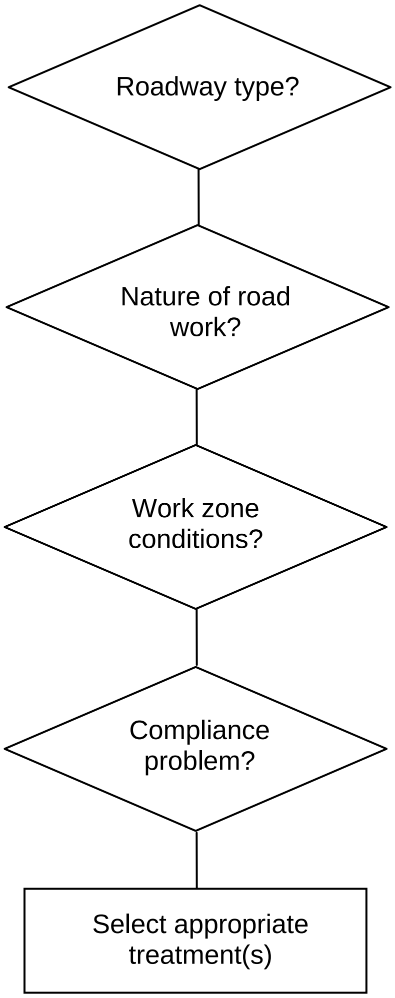


Figure X-1. Generalized Decision-Making Process.

Example 1: A project is initiated to replace and upgrade guardrails and end terminals on an 8-mile segment of a rural, two-lane Farm-to-Market (FM) roadway. Traffic volumes are estimated at 4000 vehicles per day, with mostly local traffic. The roadway has 11-ft lanes and 11-ft shoulders, and there will be no work zone speed limit posted.



What type of roadway do I have?
Low-volume two-lane

What is the nature of the road work taking place?
Mobile maintenance

What are the conditions in the work zone?
Duration of project: short (days to weeks)
Length of project: spot locations over 8 miles
Proximity of work to through traffic: on shoulder
Surrounding environment: rural, predominantly trees and fields
Driver population: familiar
Amount of speed limit reduction: none

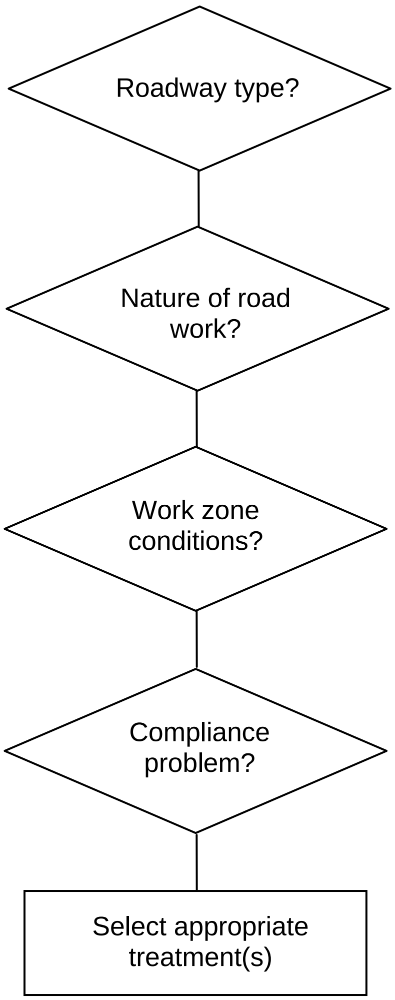
What is the WZSL compliance problem to address?
No awareness of WZSL (unexpected presence of workers)

Select the appropriate treatment(s) for the needs and conditions.
Awareness treatments: advance warning signs, speed limit signs, low-cost supplemental devices, flagging (when encroaching into travel lanes)

Figure X-2. Decision-Making Flowchart for Example 1.

This project does not justify the expense or labor of more complex treatments because of the short duration and mobile nature of the work being performed. Most important is to notify drivers that there are workers in close proximity to the travel lanes, requiring drivers to take extra caution while passing through the area. Advance signing, additional speed limit signs, flags, beacons, and supplemental plaques are all treatments that will accomplish this. In addition, if it becomes necessary to encroach into the travel lanes, temporary flagging may be needed to control the flow of traffic.

Example 2: A two-year project is initiated to reconstruct a 20-mile segment of four-lane Interstate highway, partially located in a small urbanized area. Traffic volumes are estimated to be 25,000 vehicles per day, predominantly unfamiliar drivers passing through the area. Traffic will be shifted to one lane in each direction, and the speed limit will be lowered from 70 mph to 60 mph.



What type of roadway do I have?
Freeway

What is the nature of the road work taking place?
Reconstruction

What are the conditions in the work zone?
Duration of project: very long (approximately two years)
Length of project: 20 miles
Proximity of work to through traffic: separated by Interstate median
Surrounding environment: mostly rural, partially urban
Driver population: mostly unfamiliar
Amount of speed limit reduction: 10 mph (70 to 60)

What is the WZSL compliance problem to address?
Disregard for WZSL (long distance erodes compliance);
Impediments to enforcement (narrower lanes and shoulders)

Select the appropriate treatment(s) for the needs and conditions.
Awareness treatments: multiple signing treatments, beacons, supplemental WORK ZONE plaques, orange sign borders, PCMS, periodic use of speed display trailer and/or PCMR, others as necessary

Design treatments: drums and barriers, possibly enforcement shoulders

Enforcement treatments: routine and/or periodic supplemental enforcement, regular supplemental enforcement if necessary, team or remote enforcement

Figure X-3. Decision-Making Flowchart for Example 2.

The long duration and distance of the work justify the use of more treatments and more complex treatments. Standard advance warning and regulatory signs are necessary as a basic part of the traffic control plan; however, adding orange-border speed limit signs at regular intervals will remind drivers of the lower work zone speed limit and beacons will help identify signs and channelizing devices. If a significant compliance problem is anticipated, engineers should consider enforcement shoulders in the design of the work zone area. After the project begins, the project engineer should monitor conditions at the work zone to determine if there is a developing compliance problem that should be addressed. If so, the use of speed display trailers, routine or supplemental enforcement, and eventually team or remote enforcement should be considered in order of increasing complexity and cost.

SECTION X.3 – WORK ZONE CHARACTERISTICS

This section discusses various characteristics of work zones related to the roadway type, the nature of the road work and work zone conditions, and the types of problems that can be encountered that affect work zone speed limit compliance. Each of these characteristics presents unique aspects to be considered in developing an appropriate response to noncompliance, and different combinations of characteristics will produce different challenges to address the problem. Chapters 6G and 6H of the 2003 TMUTCD contain definitions and descriptions of various types of work zone conditions, and Chapter 1 of the TxDOT manual *Procedures for Establishing Speed Zones* discusses the concept of factors that affect safe speed, but more information will be provided on roadway and work zone characteristics in this section. In conjunction with the information presented in this section and relevant sections of other TxDOT manuals, engineers are encouraged to use the flowchart in Section X.2 or a similar method to assess all of the factors that are represented in a particular work zone in order to generate options for improving WZSL compliance.

Section X.3.1 – Roadway Type

There are numerous roadway configurations; however, for the purposes of work zone speed limit compliance, the vast majority of them can be grouped into eight main categories:

- low-volume two-lane,
- high-volume two-lane,
- three-lane,
- multilane undivided,
- multilane divided (non-freeway),
- freeway,
- one-way frontage road, and
- two-way frontage road.

Each of these categories has unique aspects that help define appropriate speed limit compliance strategies, and they will be discussed in turn in the following paragraphs. Further descriptions of similar categories and typical work zone applications can be found in the 2003 TMUTCD, Section 6G and 6H.

Low-Volume Two-Lane

This roadway type applies primarily to rural FM roadways, county roads, and some state highways. Traffic on these roadways is predominantly local in nature, with either an origin or destination located on that roadway. Traffic volumes in this category are generally below 5000 vehicles per day and often below 2000. Cross-sections on these roadways are usually very narrow, with lane widths of 9 to 12 ft and shoulders of 3 ft or less, as shown in Figure X-4.

Because of the simpler cross-sections and traffic patterns, work zone traffic control often involves completely closing a lane for a specified distance during the road work project and using a pilot car and/or flagger(s) to direct traffic through the work zone. The project engineer may also decide to completely close the road and establish a detour route until the road work is completed. In either case, work zone speed limit compliance is a minor issue because speeds are extremely limited by the nature of the work being performed. Advance warning is provided through static or changeable message signs and optional supplemental low-cost devices.

Figure X-4. Low-Volume Two-Lane Rural Roadway.

In other conditions, a project engineer may elect to allow traffic through while the work is being performed, closing portions of the road only at very specific points in the progress of the project. For the project shown in Figure X-5, the roadway is open to traffic while being resurfaced. In these situations, WZSL compliance may be more of an issue as workers and/or equipment are in close proximity to traffic and road conditions may be more hazardous to drivers. Worker safety, nighttime visibility,

Figure X-5. Resurfacing Project with Traffic Permitted on Low-Volume Two-Lane Road.

and wet road conditions should all be considered. Signage (warning signs and/or speed limit signs) at regular intervals, lighting, and supplemental low-cost devices are all potential countermeasures at these locations. Because of the low volumes and narrow cross-section, enforcement is generally not cost-effective unless a pattern of behavior is observed and an area is available for officers to execute traffic stops.

High-Volume Two-Lane

This roadway type primarily applies to many state highways, some FM roadways, and some U.S. highways. These roadways are generally rural or suburban collectors or arterials, with some local traffic as well. Traffic volumes in this category are typically between 5000 and 20,000 vehicles per day. Cross-sections on these roadways may be somewhat narrow, but will often have wider shoulders than those in the low-volume category, as shown in Figure X-6.

Work zone traffic control on two-lane high-volume roadways is more complicated than on their low-volume counterparts. Lane closures have a larger impact on traffic operations because of the higher volumes. Flaggers and pilot vehicles serve a greater role in lane closures, and temporary traffic signals may be appropriate if conditions warrant, particularly if the road work takes place over a longer distance. Other types of road work will be served by shifting traffic onto the shoulder or narrowing the driving lane if the cross-section has adequate width.

Figure X-6. High-Volume Two-Lane Roadway.

Because of the increased delay associated with higher volumes, drivers may become more impatient in such work zones and attempt to travel at higher speeds to make up for the delay. WZSL compliance becomes important in these situations. A full detour may be a viable option if a roadway with similar capacity exists in the area to carry the traffic; however, there are several options if traffic must be carried through the work zone.

Narrow lanes can be used to present the image of a constricted driving area where drivers feel uncomfortable at high speeds; and barriers, barrels, cones, and/or delineators can be added to supplement the image. Changeable message signs or static warning signs provide information in the work zone and in advance of the work zone. In addition to standard speed limit signs, speed display trailers and/or supplemental enforcement may be used if space is available.

Three-Lane

Three-lane roadways are two-lane roadways with either a center two-way left-turn lane (TWLTL) or occasionally a second travel lane in one direction. These roadways are usually in the high-volume category and in suburban settings and they provide more flexibility in work zone traffic control than two-lane roadways. With the extra flexibility, however, comes an extra level of complexity in WZSL compliance. The third lane almost always allows for carrying traffic through the work zone, but in a configuration unfamiliar and potentially confusing to motorists. In addition, the presence of a third lane implies the presence of substantial turning movements, which may help to calm traffic or may increase the risk of collision with speeding vehicles.

If the road work takes place at an intersection, then speed limit compliance is usually achieved by the traffic signal or STOP signs posted to control traffic on the various legs of the intersection. If the road work is on a three-lane corridor, then compliance must be encouraged through other means. Channelization is very important, which can be achieved by barrels, barricades, delineators, cones, and/or barriers. Along with the speed limit and standard warning signs, restrictions in turning movements must also be adequately signed. Enforcement can be easily facilitated if there are multiple driveways in a three-lane segment, providing areas off of the roadway for surveillance and for executing traffic stops.

Multilane Undivided

Multilane undivided roadways may be rural, suburban, or urban; U.S. and state highways make up the majority of these roadways, though some FM roads may also fit in this category. In rural settings they will be high-speed arterials serving traffic that is regional in nature, with a small percentage of local traffic. As shown in Figure X-7, rural multilane roadways

Figure X-7. Multilane Undivided Highway.

generally have 11- or 12-ft lanes and may have shoulders up to 12 ft, although “Poor-Boy” designs have little or no paved shoulders. Suburban and urban roadways will also be arterials, though speeds will be lower in urban settings. Suburban roadways may have shoulders or curb and gutter; urban roadways will be curbed.

Because of the higher volumes and the more generous cross-section, traffic will almost always be carried through the work zone. Depending on the nature of the work being done, there may be more than one lane of traffic open in one or both directions of traffic, which underscores the importance of WZSL compliance. If multiple lanes are open, drivers are more likely to drive as they would under normal operating conditions.

For urban and suburban work zones, channelizing traffic with barrels, barriers, and/or cones is a viable design-related option; in rural settings, delineators or barricades may be more desirable if speeds are high. In addition to standard advance warning treatments, low-cost supplemental devices such as flags or beacons added to warning signs can be beneficial in capturing the driver’s attention.

If multiple lanes are open, more involved treatments such as changeable message signs, speed display trailers, and/or supplemental enforcement may be appropriate to influence drivers to comply with the speed limit. If only one lane is open in each direction, the higher volumes may slow down the traffic stream such that drivers self-enforce the speed limit. Speed display trailers and/or enforcement may be used if necessary.

Multilane Divided (non-freeway)

Multilane divided roadways are like the undivided roadways described above in that they have driveways and intersections, but they have a median (raised, depressed, TWLTL, etc.) to divide the two directions of traffic, as shown in Figure X-8. Rural expressways will have shoulders, while suburban roadways may have curb and gutter instead of shoulders.

Figure X-8. Multilane Divided Highway.

Multilane divided roadways generally have high volumes and high speeds, especially in rural settings. Because of this, motivating drivers to comply with the work zone speed limit becomes more difficult. If multiple lanes are open in a given direction of travel, and if a platoon or a substantial volume of traffic is traveling at high speeds, individual drivers are more prone to “go with the flow,” which may violate the reduced speed limit in the work zone. Potential conflicts with traffic entering or leaving the roadway at driveways and intersections compound the safety risk to drivers and workers.

Besides confirming that the WZSL is properly and realistically set, enforcement is the surest method to encourage compliance. However, when enforcement is not feasible, other methods provide a degree of assistance. Awareness treatments such as changeable message signs (perhaps with innovative messages) and low-cost supplemental devices (i.e., flags, beacons, orange-border signs) help to capture the driver’s attention. Speed display trailers or changeable message signs (CMS) with radar capabilities offer a surrogate for enforcement.

Freeway

Freeways have similar characteristics to multilane divided roadways, with the exceptions that freeways have full access control and are always designed for high volumes and high speeds whether urban or rural (see Figure X-9). Strategies for work zone traffic control are also similar except that in rural settings, traffic may be detoured to the frontage road for certain types of road work. Otherwise, traffic is always allowed through the work zone and must be accommodated.

Figure X-9. Freeway Section.

The “go with the flow” attitude is also present in high-volume urban settings and it becomes a greater temptation in rural settings with work zones of longer distances. Drivers will resist traveling at lower speeds on freeways, especially if they are driving on a section where improvements appear to be complete or where road work has not yet begun.

For long-distance work zones, it is important to set the work zone speed limit to apply only within the boundaries of where the road work is actually taking place. This will encourage WZSL compliance because drivers are not being compelled to slow down in an area that has no active work.

As with multilane divided roadways, besides confirming that the WZSL is properly and realistically set, enforcement is the surest method to encourage compliance. However, when enforcement is not feasible, other methods provide a degree of assistance. In merge and crossover areas, barriers and delineators provide design treatments that encourage drivers to slow down. Awareness treatments such as changeable message signs (perhaps with innovative messages) and low-cost supplemental devices (i.e., flags, beacons, orange-border signs) help to capture the driver's attention. Speed display trailers or CMS with radar capabilities offer a surrogate for enforcement.

One-Way Frontage Road

One-way frontage roads (see Figure X-10) are unique in that, depending on the surrounding environment, they can have a mixture of higher-speed freeway-related traffic with lower-speed local traffic turning into and out of driveways and intersections. This mixture of turning and merging traffic creates a unique set of traffic conditions that must be accounted for in work zone traffic control. Detours may be used to completely avoid these conflicts, but accommodating local businesses and residences may require carrying traffic through the work zone.

Figure X-10. One-Way Frontage Road.

For safety as well as for WZSL compliance, awareness and design treatments are very important to inform both local drivers and freeway drivers of the work being done and the expected behavior in the work zone. Channelization and signage are the two primary tools to use. Channelization through the use of barrels and delineators guides drivers to the proper lanes. Signage (static and changeable) will assign right-of-way, notify drivers of the work being done, and declare the appropriate speed limit. In many cases, the combination of unfamiliar driving conditions and high volumes keeps speeds low; however, if volumes are lighter and channelization improves the efficiency of traffic flow, enforcement measures may be needed to motivate compliance with the work zone speed limit.

Two-Way Frontage Road

Two-way frontage roads (see Figure X-11) have many similarities to low- or high-volume two-lane roadways, with the added characteristic of being in close proximity to a freeway. Detours may be used to route traffic through the work zone if freeway exits and/or intersections are within a reasonable distance. Otherwise, part or all of a lane may be closed to allow the road work to take place. Treatments for these work zones will be similar to those used on other two-lane roadways, with an emphasis on signing, supplemental devices, and perhaps flagging or lighting.

Figure X-11. Two-Way Frontage Road.

Section X.3.2 – Nature of Road Work

The nature of the road work being performed also has an influence on the appropriateness of various treatments. For example, short-term projects or work that does not expose workers to traffic do not require treatments as complex or costly as projects that are of longer duration or higher risk. This section discusses six types of road work that encompass the majority of projects completed:

- localized maintenance,
- mobile maintenance,
- surfacing,
- widening,
- reconstruction, and
- adjacent road work.

Each has characteristics that can be evaluated in conjunction with the roadway type to develop appropriate treatments for work zone speed limit compliance. Brief descriptions of these types of road work are provided below; however, they are discussed within the context of work zone speed limit compliance. Thorough explanations of the various types of road work projects and their requirements are found in the *Roadway Design Manual* and other reference documents. Further descriptions of similar types of road work projects and typical work zone applications can be found in the 2003 TMUTCD, Sections 6G and 6H.

Localized Maintenance

Figure X-12. Localized Maintenance (Sign Replacement).

Localized maintenance includes tasks such as surface spot-patching, mowing, guardrail repair, and other short-term low-exposure activities. As shown in Figure X-12, work in this category is confined to the roadside or a small area on the roadway and lasts for a short time. Because of the small area and short duration, speed limits are not changed from normal conditions. Much of the signing for these tasks is often temporary in nature and is usually minimal. For surface patching, workers close a lane for a short period of time, and traffic must be routed around it until the repaired surface is ready for use; otherwise, impact on traffic is nominal. As such, WZSL compliance is not a significant issue for localized maintenance projects. The greater concern is the safety of workers and, when necessary, accommodation of traffic.

Mobile Maintenance

Tasks in the mobile maintenance category are also short-term but are not confined to a specific location. Rather, they take place in a longer segment of roadway and may involve a moving, or rolling, operation. This category includes road work such as striping (see Figure X-13), seal coating, guardrail construction, and rumble strip installation. Work zone speed limits may be posted for projects in this category, but more often there is simply a well-defined work zone with the same speed limit. When there is no speed limit reduction, workers and equipment operators must take extra care when in close proximity to traffic. In locations where lanes or shoulders are temporarily closed, drivers may slow down somewhat as they pass through the modified travel lanes in the work zone. Otherwise, given the short-term nature of the project, supplemental enforcement would be the best method to improve compliance during the project; the expense of obtaining and installing other signs and devices are often prohibitive for short-term projects.

Figure X-13. Mobile Maintenance (Striping).

Surfacing

This category consists of projects longer in duration than maintenance and other short-term projects, such as 2R and some 3R projects, which involve closing one or more lanes for an extended period of time and over a considerable distance. Milling, overlay, and bridge deck repair are some examples of road work in this category. On freeways and multilane divided roads, one side may carry all traffic and the other side may be completely closed. For other roadway types, traffic must be detoured or otherwise routed through the work zone. In these situations, WZSL enforcement can be encouraged primarily through awareness and enforcement treatments. Advance warning, static signing, delineation, and supplemental enforcement are all useful countermeasures.

Widening

This category contains projects that are intended to widen the existing road surface by adding or widening lanes or shoulders, as shown in Figure X-14. This category of projects does not include adding lanes that are separated by a median (i.e., converting a two-lane roadway into a four-lane divided roadway), which the Adjacent Road Work section addresses below. Widening involves a significant amount of equipment and a large number of workers in close proximity to the travel lanes for an extended amount of time; thus, the control of speeds through these work zones is very important to the safety of workers and drivers.

A common design treatment that affects speeds is narrowing the lane(s) adjoining the area to be widened. Depending on the length of the project, WZSL signs at regular intervals are appropriate to remind drivers of the lower limit. Low-cost supplemental devices are also appropriate to capture drivers' attention. If a compliance problem develops, the use of supplemental enforcement should be investigated, keeping in mind that there may be limited space available for officers to execute a traffic stop within the work zone.

Figure X-14. Roadway Widening.

Reconstruction

These 4R projects completely rebuild, and perhaps realign, existing roadways. This means closing part or all of the roadway for a considerable length of time and possibly a long distance. When traffic is allowed through the work zone, one or more lanes must be diverted from their normal alignment, as illustrated in Figure X-15. Lane or shoulder widths are often reduced and driveways, intersections, or ramps may be temporarily closed.

These unfamiliar conditions justify a reduced speed limit in the work zone; however, several factors contribute to noncompliance. The greater the length or duration of the work zone, the more drivers will tend to exceed the speed limit, particularly for regular drivers of that roadway (see Section X.3.3). In addition, noncompliance also tends to increase with the distance between the operating travel lanes and the workers and equipment in the lanes under reconstruction. Narrow lanes and shoulders may help encourage reduced speeds, and appropriate signing should be posted, with speed limit signs at regular intervals. Speed display trailers and/or changeable message signs are useful if there is sufficient room in the roadside area. However, the threat of enforcement is the most effective treatment for increasing compliance. The primary obstacle to supplemental enforcement is often the lack of space for officers to execute a traffic stop within the work zone. Design treatments such as enforcement shoulders will improve the effectiveness of enforcement. Other possible enforcement strategies include team enforcement and remote or automated enforcement.

Figure X-15. Traffic Diverted to One Lane on a Reconstruction Project.

Adjacent Road Work

Like widening projects, adjacent road work projects are often 4R projects; however, the majority of the work takes place on right-of-way that is not physically connected to the existing travel lanes. Examples include converting a two-lane roadway into a four-lane divided roadway, or constructing new expressway cross-section between existing frontage lanes. Much of the work does not directly affect traffic in the area in that the work is not occurring on the travel lanes (see Figure X-16); however, there are still work crews and large equipment that are active nearby.

Compliance strategies for adjacent road work are similar to those used for reconstruction projects. One significant difference, however, is that adjacent road work projects are more likely to have ample shoulder width to facilitate enforcement activities.

Figure X-16. Construction of Overpass Adjacent to Active Travel Lanes.

Section X.3.3 – Nature of Work Zone Conditions

Just as the type of road work can have an effect on drivers' speeds, so can the conditions present in a particular work zone. Six factors that contribute to establishing the work zone environment are discussed in this section:

- project duration,
- project length,
- proximity of work to through traffic,
- surrounding environment,
- driver population, and
- amount of speed limit reduction.

Each of these factors plays a part in the driver's decision to travel at a given speed and should be used when developing strategies to encourage WZSL compliance.

Project Duration

Figure X-17. Duration of Project.

The duration of a project (as shown in Figure X-17) can influence considerably the appropriate treatments to improve speed limit compliance. Short-term projects do not justify the expense and labor of elaborate combinations of treatments. As projects become longer, the need and the justification for more complex treatments both increase. Not only is the cost of obtaining and installing treatments more appropriate with long-term projects, but driver behavior also validates their use. Drivers who have become accustomed to the conditions in a particular work zone will gradually become more complacent in their compliance with the speed limit and require greater measures to counteract that complacency. In general, the longer a project lasts, the more justification there is to utilize a particular treatment.

Project Length

The length, or distance, of a project (see Figure X-18) affects driver behavior in a manner similar to project duration. Drivers are much more likely to comply with a reduced speed limit over a shorter distance than a longer one. The longer the distance, the more likely a driver will begin to speed up in a work zone, assuming that there are no other factors such as traffic congestion or traffic control devices to help regulate the speed. Thus, a variety of treatments may be justified on a long-distance project that would be unnecessary at shorter distances. In addition, projects of longer distance also tend to be larger projects that warrant higher levels of treatment, so there often is added justification for using additional treatments on projects that extend over long distances.

Figure X-18. Length of Project.

Proximity of Work to Through Traffic

Related to the discussion on Adjacent Road Work in Section X.3.2, the proximity of work to through traffic has an effect on the speed of the traffic stream. Drivers feel more uncomfortable when workers, equipment, or separation devices are near the travel lanes; Figure X-19 shows a vehicle on the shoulder in an attempt to increase the distance between the vehicle and separation barrels. Conversely, drivers may become complacent in a work zone where the actual road work is distinctly separated from the traffic stream and, indeed, the risk of collision or injury is less in these conditions. The WZSL should be set appropriately for the level of exposure to workers and equipment, and then awareness and/or design treatments installed correspondingly. An example from TxDOT *Procedures for Establishing Speed Zones* states that a construction speed zone may not be desirable when using concrete traffic barriers in traffic control, since these barriers normally provide sufficient protection for motorists and workers.

Figure X-19. Road Work in Close Proximity to Through Traffic.

In addition, if there appears to be no work taking place or if work appears to be complete, drivers tend to drive at normal speeds, even if they are still within a posted work zone area. If an area does not have the appearance of a work zone, drivers have minimal motivation to comply with a work zone speed limit. Thus, it is important that work zone speed limit signs be properly posted in the correct location at the correct time. For example, if the extents of a project cover 10 miles, but work is only taking place on 2 miles at any given time, the WZSL should be posted for only those 2 miles and moved whenever the active work area moves. The TxDOT manual *Procedures for Establishing Speed Zones* states that "reduced speeds should only be posted in the vicinity of work being performed and not throughout the entire project."

Surrounding Environment

This characteristic describes the milieu in which a work zone is located, including:

- whether the area is rural, suburban, or urban;
- if the adjacent development is residential, commercial, or undeveloped;
- whether the roadway is level or rolling; and
- whether the roadside is free of obstructions or distractions.

For a given highway with a four-lane undivided cross-section, drivers are much more prone to travel faster in rural, undeveloped settings than in urban, commercialized locations with many billboards and driveways because distractions and potential obstructions are much fewer in the former than the latter. There are some exceptions, such as in some urban locations where the tendency is to "go with the flow," even if the prevailing speed is above the speed limit. However, the alignment of the roadway and the development of its surroundings affect the speed a driver will choose, and compliance treatments should be selected with this in mind.

Driver Population

The term “driver population” here refers to the types of drivers that populate the traffic stream at a given location and can be described by how often a driver passes through that location (familiar/unfamiliar) or by the purpose of the trip (business/errand/casual).

Familiar, or commuter, drivers travel through a location regularly and are well acquainted with the alignment and traffic control devices there; these drivers adapt to become more comfortable in work zone conditions with the passage of time. Unfamiliar, or visitor, drivers rarely travel through a location; any irregularities in traffic control or alignment are compounded for these drivers in work zone conditions. Regardless of the predominant type of driver, driver information is important; however, the means of informing the driver is different. Unfamiliar drivers tend to look more closely for advance warning and instructional signs, while familiar drivers may become oblivious to the same signs because they see them regularly. For unfamiliar drivers, signing needs to be conspicuous so that they can make their decisions on speed and lane choice well in advance. For familiar drivers, additional awareness devices (and perhaps enforcement methods) will be necessary to remind them of the extra caution they need to take in the work zone by traveling at lower speeds. Also, when traffic conditions change for different phases of a project, notifying familiar drivers (through changeable message signs or other means) of the changes is very important.

The purpose of trips through the work zone affects drivers’ behavior. Drivers on business trips are often more aggressive, as they are trying to get to or from work on time. Drivers on errand trips are somewhat more relaxed, but they still have a motivation to get from place to place efficiently. Casual trips are often taken by “Sunday drivers” and vacationers who are just passing through a location on the way to their ultimate destination; a few minutes’ delay is not as important to these drivers as it is to business or errand drivers. If there is a prevalent type of driver in a work zone, awareness treatments can be optimized for that. For example, during a morning rush hour on a freeway, business drivers are interested in travel times from point to point, errand drivers want to know alternate routes, and casual drivers might look to exit until peak traffic subsides. A changeable message sign can be used for any of these purposes, but the message should be tailored to target the type of driver that most needs the message. This practice gives the driver a better idea of what to expect and improves the likelihood of compliance.

Amount of Speed Limit Reduction

The difference in value between the regular speed limit and the work zone speed limit affects drivers’ compliance. By definition, drivers should travel no faster than the posted speed limit, no matter what the value of that limit is; however, drivers are resistant to reductions that they perceive to be excessive or unnecessary. The TxDOT manual *Procedures for Establishing Speed Zones* states that "traffic control in work sites should be designed on the assumption that drivers will only reduce their speeds if they clearly perceive a need to do so; therefore, reduced speed zoning should be avoided as much as practicable." If a work zone speed limit is posted prohibitively lower than the regular speed limit, drivers are likely to ignore the WZSL without significant enforcement.

According to TxDOT *Procedures for Establishing Speed Zones*, regulatory construction speed limits (see Figure X-20) should be used only for sections of construction projects where speed control is of major importance and enforcement is available. Traffic control plans should, as much as possible, accommodate the speeds existing prior to construction. These decisions, however, require engineering judgment depending on the nature of the project and other factors that affect the safety of motorists and workers. Studies normally made in determining regulatory posted speed limits are not required on sections of highway under construction. In selecting the speeds to be posted, however, the engineer should give consideration to safe stopping sight distances, construction equipment crossings, the nature of the construction project, and any other factors that affect the safety of workers and motorists.

Figure X-20. Reduced Speed Limit.

According to Section 6C.01 of the TMUTCD, reduced speed limits should be used only in the specific portion of the temporary traffic control zone where conditions or restrictive features are present. However, frequent changes in the speed limit should be avoided. A temporary traffic control plan should be designed so that vehicles can safely travel through the temporary traffic control zone with a speed limit reduction of no more than 10 mph. A reduction of more than 10 mph in the speed limit should be used only when required by restrictive features in the temporary traffic control zone. Where restrictive features justify a speed reduction of more than 10 mph, additional driver notification should be provided. The speed limit should be stepped down in advance of the location requiring the lowest speed and additional temporary traffic control warning devices should be used.

Engineers must ensure that their recommended value for the WZSL for a given project is realistic and appropriate for the work that is taking place. This practice will prevent a situation that makes illegal the normal driving behavior of prudent drivers.

Section X.3.4 – Type of Noncompliance Problem to Address

There are multiple causes for work zone speed limit violations. If engineers determine that one cause is predominant at a site, they can tailor treatments and countermeasures to address that cause. Four types of noncompliance problems are discussed in this section:

- no awareness of the WZSL,
- disregard for the WZSL,
- impediments to enforcement, and
- nighttime violations.

No Awareness of WZSL

Drivers may not comply with the work zone speed limit because they are unaware that the speed limit has changed in the work zone. This may happen with familiar drivers that do not notice the speed limit signs as they enter the work zone. It may also happen in built-up urban and commercialized areas where work zone signage is not conspicuous in the background clutter of billboards, other signs, and adjacent traffic. Awareness treatments such as those mentioned in Section X.4 should be reviewed for these conditions to increase the visibility of work zone signage.

Disregard for WZSL

Perhaps the most commonly discussed type of violator is the driver who simply disregards the work zone speed limit. Natural driving behavior is to resist reductions in speed unless there is a corresponding increase in risk, either of enforcement or of collision. Section 6A of the TMUTCD states that "the primary function of temporary traffic control is to provide for the safe and efficient movement of vehicles, bicyclists, and pedestrians through or around temporary traffic control zones while reasonably protecting workers and equipment." Section 6C adds that "reduced speed zoning (lowering the regulatory speed limit) should be avoided as much as practical because drivers will reduce their speeds only if they clearly perceive a need to do so." Assuming that the WZSL is properly set for conditions, the appropriate countermeasure is supplemental enforcement. If there is a predominant pattern of willful violation at a work zone, it may be necessary to schedule officers to patrol the work zone on a regular basis. The enforcement treatments in Section X.6 offer suggestions on implementing enforcement activities.

Impediments to Enforcement

Due to the nature of the road work taking place many work zones have characteristics that make conducting enforcement difficult, if not impossible, within the limits of the work zone itself. Narrow lanes, reduced or eliminated shoulders, high traffic volumes, and limited sight distance are all possible impediments to enforcement. Often the only method available in these work zones is for an officer to follow a violator and make the traffic stop downstream of the work zone. This method requires taking additional measures to accommodate enforcement efforts. Traditional measures include design treatments such as enforcement turnouts or shoulders at regular intervals. More recent concepts include enforcement treatments such as team enforcement or remote/automated enforcement. Engineers should examine the specific characteristics of the work zone to determine which treatment(s) is(are) appropriate.

Nighttime Violations

If violations increase during nighttime hours, there may be a visibility problem that needs to be addressed. Additional lighting near WZSL signs and potential points of conflict (lane shifts, temporary exits, etc.) is necessary in this situation. Other treatments may also be beneficial; flashing beacons, flags, and other supplemental awareness treatments improve the visibility of WZSL signs and other traffic control devices.

SECTION X.4 – AWARENESS TREATMENTS

Awareness treatments are used to attract a driver's attention to the presence of a work zone speed limit and motivate compliance. Many of these devices are easy to obtain and install, while others are more expensive and complex. All of these devices are intended to notify a driver of existing work zone conditions and the corresponding work zone speed limit, which will give the driver the information necessary to make a decision to comply with the WZSL.

Five categories of treatments are discussed in this section:
- static signs,
- low-cost supplemental devices,
- changeable message signs,
- speed display trailers, and
- other awareness treatments.

A number of these treatments are discussed in Chapter 6F of the 2003 *Texas Manual on Uniform Traffic Control Devices*, which engineers should consult for the proper design and installation of the treatments. In addition, TxDOT Standard Plan Sheets have guidance specific to work zones for selected treatments; engineers should review the Plan Sheets prior to installing the treatments listed here.

Section X.4.1 – Static Signs

Traditional static signs are the basis for providing messages to drivers in work zones. Speed limit signs, other regulatory signs, and warning signs are all vital parts of a work zone traffic control plan, and most of these signs have standardized designs and requirements for installation as described in the TMUTCD. Other warning signs and signs with innovative text have potential for positively affecting compliance and are also discussed in this section. All of these signs are appropriate, and some are required, to install at all types of work zones.

Speed Limit Signs

According to the 2003 TMUTCD, Section 6F.05, "Regulatory signs inform road users of traffic laws or regulations and indicate the applicability of legal requirements that would not otherwise be apparent." Speed limit signs are the regulatory signs that provide official notification to drivers of the maximum speed in the work zone. They are designed and installed to conform to the standards presented in Part 2 of the TMUTCD and in the *Standard Highway Sign Designs for Texas*, as shown in Figure X-21.

Figure X-21. Speed Limit Sign (R2-1).

In addition to design and installation requirements, work zone speed limit signs should be posted at appropriate intervals to remind the driver of continuing work zone conditions. The specific intervals will vary based on the conditions present at each work zone, but TxDOT's *Procedures for Establishing Speed Zones* suggests a typical interval is 0.2-0.5 mile.

Other Regulatory Signs

"If a temporary traffic control zone requires regulatory measures different from those existing, the existing permanent regulatory devices shall temporarily be removed or covered and superseded by the appropriate temporary regulatory signs. This change shall be made in conformance with applicable ordinances or statutes of the jurisdiction as well as comply with the *Standard Highway Sign Designs for Texas*." (2003 TMUTCD Section 6F.07)

In addition to speed limit signs, other regulatory signs are often necessary to inform drivers of turning restrictions, road closures, increased fines for violations, and other changes in normal driving conditions. Figure X-22 through Figure X-24 show examples of these signs.

Figure X-22. Road Closed Sign (R11-2).

Figure X-23. One Way Sign (R6-2).

Figure X-24. No Right Turns Sign (R3-1).

Advance Warning Signs

When the work space is within the traveled way, except for short-duration and mobile operations, advance warning should:

- provide a general message that work is taking place,
- supply information about highway conditions, and
- indicate how motor vehicles can move through the temporary traffic control zone.

The advance warning area is the section of highway where road users are informed about the upcoming work zone or incident area. Advance warning signs provide additional information to drivers so that they can anticipate changing conditions and the reduced work zone speed limit, if present. An example of an advance warning sign is shown in Figure X-25.

The typical distances for placement of advance warning signs on expressways and freeways should be longer because drivers are conditioned to uninterrupted flow. Therefore, the TMUTCD states that advance warning sign placement should extend on these facilities as far as 0.5 mile or more. On urban streets, the effective placement of the first warning sign in feet should range from 4 to 8 times the speed limit in mph, using the high end of the range for relatively high speeds. When a single advance warning sign is used (in cases such as low-speed residential streets), the advance warning area can be as short as 100 ft if assuming a posted speed of 25 mph. When two or more advance warning signs are used on higher-speed streets, such as major arterials, the advance warning area should extend a greater distance (see Table X-1).

Figure X-25. Advance Warning Sign (CW20-5).

Since rural highways are normally characterized by higher speeds, the effective placement of the first warning sign in feet should be substantially longer – from 8 to 12 times the speed limit in mph. Since two or more advance warning signs are normally used for these conditions, the advance warning area should extend 1500 ft or more for open highway conditions (see Table X-1).

Table X-1. Suggested Advance Warning Sign Spacing (adapted from TMUTCD).

Road Classification	Posted Speed (mph)	Sign Spacing (ft)
Conventional Highways	30	120
	35	160
	40	240
	45	320
	50	400
	55*	500
	60*	600
	65*	700
	70*	800
	75*	900
Expressways or Freeways	All Speeds	See Typical Applications**

Notes:
*Distance between signs should be increased to have 1500 ft advance warning.
**Distance between signs should be increased to have 0.5 mile or more advance warning.

Other Warning Signs

Warning signs are also used within work zones to notify road users of specific situations or conditions on or adjacent to a roadway that might not otherwise be apparent. These signs are useful for WZSL compliance because they remind the driver of the added risk to the safety of motorists or workers that exists within the work zone.

According to the 2003 TMUTCD, warning signs in work zones shall have a black legend on an orange background, except for the Railroad Advance Warning (W10-1) sign which shall have a black message and border on a yellow background, and except for signs that are permitted in Part 2 to have yellow or fluorescent yellow-green backgrounds. Existing warning signs that are still applicable may remain in place. All signs used at night shall be either retroreflective with a material that has a smooth, sealed outer surface or illuminated to show the same shape and similar color both day and night.

Where special emphasis is needed, signs may be placed on both the left and right sides of the roadway. Signs mounted on portable supports may be placed within the roadway itself. Neither portable nor permanent sign supports should be located on sidewalks, bicycle lanes, or areas designated for pedestrian or bicycle traffic. For mobile operations, a sign may be mounted on a work vehicle, a shadow vehicle, or a trailer stationed in advance of the work zone or moving along with it. The work vehicle, and/or the shadow vehicle may have an impact attenuator. A sign display may be mounted on a trailer.

Warning signs shall conform to the standards for warning signs presented in the TMUTCD and in the *Standard Highway Sign Designs for Texas* book. Some warning signs are shown in Figure X-26 through Figure X-31.

Figure X-26. Reverse Curve Sign (CW1-4).

Figure X-27. Divided Highway Ends Sign (CW6-2).

Figure X-28. Hill Sign (CW7-1).

Figure X-29. No Center Stripe Sign (CW8-12).

Figure X-30. Low Clearance Sign (CW12-2).

Figure X-31. Worker Sign (CW21-1a).

Signs with Innovative Text

In addition to signs with standardized text or symbolic messages, other signs have been used on a limited basis in an attempt to capture the attention of drivers and improve WZSL compliance. These signs are most often used for one of two purposes. One purpose is an attempt to personalize the workers in the work zone and relate them to motorists, who will then drive through the work zone more cautiously. The other purpose is to aggressively target willful violators with messages intended to shock, shame, or embarrass them into compliance.

The effectiveness of these signs varies with the actual message and design of the sign. There is often a novelty effect that exists with signs containing non-traditional messages, which must be considered when evaluating the signs' effectiveness. Initial improvements in speed limit compliance may not continue into the long term when drivers have become accustomed to the sign.

TxDOT has adopted some innovative signs, such as the "Give Us A Brake" signs, after extensive testing and review. Others are considered experimental and should be used on a limited basis. Figure X-32 through Figure X-34 show some examples.

Figure X-32. Experimental Sign with Non-Traditional Font.

Figure X-33. Give Us A Brake Warning Sign (CW21-1T).

Figure X-34. Give Us A Brake Placard Sign. (G20-9)

Section X.4.2 – Low-Cost Supplemental Devices

Signs and other treatments may be augmented by supplemental devices intended to improve the conspicuity of the treatments and more easily capture drivers' attention. Orange flags, flashing beacons, and WORK ZONE plaques are two low-cost devices that are commonly used for this purpose. Other devices, such as orange borders for speed limit signs, are not as common but have potential for great benefits at low cost. Engineers using such devices should verify that the devices are approved for use in the TMUTCD, that they have permission to install an experimental device, or that the devices do not change the nature of the treatments associated with them. Any of these devices may be used alone or in combination for any type of work zone, though they are especially suitable for short-term and maintenance projects.

Flags

Orange flags are installed in sets of two or more as part of a high-level warning device, also called a "flag tree" (see Figure X-35). A high-level warning device is designed to be seen over the top of typical passenger cars and is most commonly used in high-density road user situations to warn road users of short-term operations. An appropriate warning sign may be mounted below the flags, and standard orange flags may be used in conjunction with signs at lower heights, as shown in Figure X-36. When used in conjunction with signs, the flags must not block the sign face.

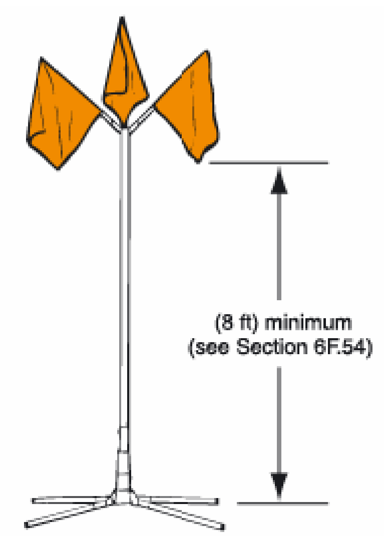


Figure X-35. High-Level Warning Device (Flag Tree).

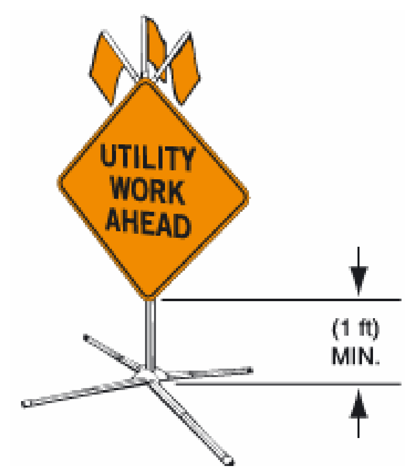


Figure X-36. Flags Mounted on Temporary Warning Sign.

Beacons

Flashing warning beacons are often used to supplement a temporary control device. Beacons shall comply with the provisions of the TMUTCD. A flashing warning beacon shall be a flashing yellow light with a minimum nominal diameter of 200 mm (8 inches). Flashing warning beacons should be operated 24 hours per day. As with flags, beacons may be used in conjunction with signs, but they must not block the sign face.

An example of an appropriate use for flashing warning beacons is the temporary terminus of a freeway, where flashing warning beacons alert drivers to the changing roadway conditions and the need to reduce speed in transitioning from the freeway to another roadway type. However, they may also be used with speed limit and other signs to increase their visibility, particularly at night.

Supplemental WORK ZONE Plaques

Figure X-37. WORK ZONE Plaque (G20-9).

Supplemental WORK ZONE plaques, such as the one shown in Figure X-37, have been approved in the *Standard Highway Sign Designs for Texas*. They are often posted above speed limit or other regulatory signs as a reminder to drivers that they are traveling through a work zone. They are sometimes posted alone at regular intervals, also as a reminder to drivers. When posted above speed limit signs, they provide an explicit message that drivers are subject to a work zone speed limit, because that is the exact message drivers read as they read the signs from top to bottom. Like other work zone signs, WORK ZONE plaques must meet color, legibility, and nighttime visibility standards as given in the TMUTCD.

Signs with Orange Borders

Like supplemental WORK ZONE plaques, orange borders on regulatory signs can be used to attract motorists' attention and reinforce the message that there is an active work zone. Orange borders are not currently a treatment identified by the TMUTCD; however, if they are applied properly they may be used without altering the basic design of the sign, as shown in Figure X-38.

Figure X-38. Freeway-Size Orange-Border Speed Limit Sign.

The orange sheeting must meet the standard of work zone orange sheeting (fluorescent, microprismatic) and must not obscure the face of the sign, including the black border around the sign's legend. A border thickness of

3 inches on all sides is recommended for non-freeway signs and 6 inches on all sides for freeway-size signs. For example, in Figure X-38, a freeway speed limit sign with a size of 36×48 inches with a 6-inch orange border on all sides will result in a composite sign with an overall size of 48×60 inches.

While orange borders could conceivably be used on any type of sign, they should be confined to regulatory signs. The contrast of colors between orange and white provides the best visibility compared to other colors such as blue, green, or yellow. In addition, sufficient testing has not been completed to determine whether orange borders might affect how well drivers understand messages on signs of other colors.

In recent field testing, the use of orange-border speed limit signs resulted in a negligible reduction in 85th percentile speeds (1 mph or less) and a minimal reduction in violators (3.5 percent or less).

Section X.4.3 – Speed Display Units

Speed display units are used to notify drivers of their current speed as they approach the location of the unit and to motivate speeding drivers to slow down to a compliant speed. While there are different options available for these units, the basic components are the same:

- a radar emitter/receiver,
- a microcomputer to process the reflected radar waves, and
- a readout panel to display the corresponding speeds to approaching drivers.

Speed display units may be used in any type of work zone, but because of cost and installation they are most appropriate on roadways with higher volumes or speeds.

The most common units are trailer-mounted, though there are some mounted on sign posts as temporary or permanent installations. Trailer-mounted units can be towed to the location to be monitored and can be moved within the extents of a work zone to pinpoint the location where violations are most likely to occur. Trailer units may be fully enclosed in a trailer box or they may be more compact with a single integrated emitter and readout panel; an example of the latter is shown in Figure X-39.

Figure X-39. Compact Speed Display Trailer.

Speed display trailers are most often white or orange in color. Usually they have a placard above the readout panel that reads "YOUR SPEED" or "YOUR SPEED IS," and many trailers have hardware to mount a speed limit sign above or next to the readout to remind drivers of the posted speed limit. Sign-mounted units also display a "YOUR SPEED" placard and are often mounted side-by-side with speed limit signs. Many trailer units, such as the one shown in Figure X-39, are solar-powered with a battery backup; other trailers are powered by a generator. Sign-mounted units are solar- and battery-powered.

Speed display units, in addition to making drivers aware of their current speed, commonly have a psychological effect on drivers, who may think that there is active enforcement nearby and improve their compliance. Even regular drivers tend to adjust their speed, unsure if enforcement is present. Periodic supplemental enforcement helps to reinforce this concept and improve the effectiveness of the speed display unit between periods of active enforcement. Therefore, speed display units can have a substantial effect on WZSL compliance even in the absence of enforcement, and the long-term effects do not dissipate as quickly as with other treatments.

In recent field testing, the use of a compact speed display trailer produced a reduction in 85th percentile speeds of up to 4 mph and reduced violation rates by as much as 33 percent.

Section X.4.4 – Portable Changeable Message Signs

Portable changeable message signs (PCMSs) are often used in work zones for a variety of purposes; one common purpose is to motivate drivers to comply with a work zone speed limit. Section 6F.52 of the 2003 TMUTCD states that the primary purpose of portable changeable message signs in work zones is to advise the road user of unexpected situations, including where the speed of motor vehicle traffic is expected to drop substantially.

PCMS displays often consist of up to three fixed-height rows of mini-bulbs or light-emitting diodes (LEDs). More recent PCMSs, such as that shown in Figure X-40, have a full matrix of LEDs or bulbs to permit text of different sizes or even graphics.

The TMUTCD gives standards for the design and installation of PCMSs. Portable changeable message signs shall be temporary traffic control devices with the flexibility to display a variety of messages. Each message shall consist of either one or two phases. Typically, a phase shall consist of up to three lines of eight characters per line. Portable changeable message signs should subscribe to the principles established in the TMUTCD and, to the extent practical, with the design (that is, color, letter size and shape, and borders) and applications prescribed in the TMUTCD, except that the reverse colors for the letters and the background are considered acceptable. The front face of the sign should be covered with a protective material. The color of the elements should be yellow or orange on a black background.

Figure X-40. Full-Matrix PCMS.

Portable changeable message signs should be used as a supplement to and not as a substitute for conventional signs and pavement markings. The PCMS should be visible from 0.5 mile under both day and night conditions. The message should be legible from a minimum distance of 650 ft. The message panel should have adjustable display rates, so that drivers can read the entire message at least twice at the posted speed, the off-peak 85th percentile speed prior to work starting, or the anticipated operating speed.

Standard messages shown on PCMSs include ”REDUCED SPEED AHEAD” or “SPEED LIMIT XX” to indicate to drivers that they are either approaching or within a work zone speed limit. These messages serve as clear reminders of the need for slower speeds. Other, non-traditional messages may be used to further motivate drivers to comply; these messages, like static signs with innovative text in Section X.4.1, have inconsistent results. Some messages may be very effective, while other messages may actually result in the opposite response, so engineers should exercise great care and closely monitor conditions when using a non-traditional message on a PCMS.

An increasing number of PCMS models have the capability of speed detection, using a radar emitter similar to a speed display unit (PCMR). A PCMR may be used to send specific messages to speeding drivers, similar to that shown in Figure X-41. When the radar unit detects a vehicle traveling at a speed above a preset threshold, the display changes from the default message to a message urging the driver to slow down to a compliant speed. Once the vehicle either sufficiently slows or passes the PCMS, the display reverts to its default message.

(a) First phase (b) Last phase

Figure X-41. Specific Message to Violators on PCMS with Radar.

This method has an advantage over basic PCMS operation, because the change in message helps to catch drivers' attention, especially when the new message is targeted to them. It also signals to noncompliant drivers that they are being "watched" by the sign, and may create a concern that there is active enforcement nearby, which further motivates them to slow down.

In recent field testing, the use of PCMR produced a 2 to 3 mph reduction in 85th percentile speeds and a 14 to 41 percent reduction in violators.

Section X.4.5 – Other Awareness Treatments

Other treatments may also be used to increase drivers' awareness of the presence of a work zone and the corresponding work zone speed limit. The treatments in this section are appropriate for specific conditions, are used infrequently and have limited testing, or have been specially developed and are still considered experimental. These treatments may be effective in improving work zone speed limit compliance, but the extent of their effectiveness is not well known. As engineers and researchers further explore and utilize these and other treatments, the information presented in this section may be updated to reflect the results.

Flagging Treatments

At certain work zones, the presence of a flagger can be beneficial to improving WZSL compliance. One form of flagging has been detailed in the TMUTCD, commonly called the "alert and slow" method. In the TMUTCD method, shown in Figure X-42, the flagger slowly waves the flag in a sweeping motion with an extended arm from shoulder level to straight down without raising the flag above a horizontal position. For flaggers with a STOP/SLOW paddle, the SLOW message is continually displayed to drivers and the free hand motions, palm down, in an up-and-down motion. The flagging maneuver is performed continually whenever traffic is present.

Figure X-42. TMUTCD "Alert and Slow" Flagging Method.

An innovative flagging procedure, a modified version of the TMUTCD treatment, has been developed and tested. In the innovative procedure, the TMUTCD flagging motion is performed to get the attention of drivers, and then the flagger establishes eye contact with the drivers. Having established eye contact, the flagger motions for drivers to slow by raising and lowering his/her free hand, palm down, several times. The flagger then points to the adjacent speed limit sign to indicate the appropriate speed. Under light traffic volumes, the flagger can direct the innovative signal to each driver. When traffic volumes are heavy, the signal can be presented to drivers leading platoons and as many additional vehicles as possible. In a field test of the two flagging procedures, the innovative flagging treatment resulted in larger speed reductions than TMUTCD flagging at five of six study sites, with reductions in mean speed of 4 to 16 mph.

The biggest disadvantage of flagging is that, like enforcement, it still requires stationing a worker at a strategic location and it still results in an extra cost to the project. In addition, flagging is tedious and physically taxing work; a flagger can become distracted or fatigued, reducing the effectiveness of the method. Finally, flagging is appropriate only for work zones on certain types of roadways, particularly rural two-lane roadways.

Transverse Striping

Another method with potential for work zone speed control is transverse striping. In this method, stripes are placed at decreasing spacings across the travel lanes in advance of a work zone. When a vehicle approaches the stripes, the driver receives a visual illusion that the vehicle is accelerating, with an anticipated result that drivers will slow down. Testing of transverse striping at work zones has found them to be generally ineffective in reducing vehicle speeds. At best, transverse striping has limited potential as a work zone speed control method. It requires significant time and effort to install, which makes it applicable only to long-term work zones. In addition, crews must maintain the stripes throughout the project to avoid liability concerns.

Rumble Strips

Rumble strips consist of intermittent narrow, transverse areas of rough-textured or slightly raised or depressed road surface that alert drivers to unusual motor vehicle traffic conditions. Through noise and vibration they attract the driver's attention to such features as unexpected changes in alignment and to conditions requiring a stop. Similar to transverse striping, intervals between rumble strips may be reduced as the distance to the approached conditions diminishes in order to convey an impression that a closure speed is too fast and/or that an action is imminent. Rumble strips should be placed transverse to motor vehicle traffic movement, as shown in Figure X-43 in a non-work zone installation. They should not adversely affect overall pavement skid resistance under wet or dry conditions. In urban areas, even

Figure X-43. Rumble Strips at Non-Work Zone Location.

though a closer spacing might be warranted, care should be taken not to promote panic braking or erratic steering maneuvers by drivers. Rumble strips should not be placed on sharp horizontal or vertical curves. A sign warning drivers of the onset of rumble strips may be placed in advance of any rumble strip installation.

Rumble strips are another means available for work zone speed control; however, there has been little research on rumble strips in work zone environments. Tests of rumble strips in non-work zone situations suggest that they may be able to reduce speeds under certain conditions, but the amount of reduction may not be practically significant, generally 1 to 2 mph. As with transverse striping, rumble strips are essentially limited to long-term work zones because of the time and effort needed to install and remove them. It is likely that their effectiveness would decrease over time for regular/local drivers.

Other Devices, Systems, and Programs

There is a wide variety of other possible treatments that have potential to positively affect WZSL compliance. Most of these treatments have had little formal testing to determine their effectiveness, are not recognized by the TMUTCD, or are often used in a system with other treatments. They are presented here as concepts to consider, which may have promise if properly designed and installed, as follows:

- yellow pavement markings (with or without removal of other markings) to improve delineation through the work zone;
- lane-specific overhead signs for information;
- dedication of primary and secondary alternate routes on permanent trailblazer signs to identify major desirable alternate routes in advance;
- portable queue detectors for real-time driver information;
- fluorescent yellow-green worker vests and hard hats to improve worker visibility;
- radar-activated flagger paddles to send specific messages to speeding drivers;
- radar drones to activate radar detectors;
- simple wording changes on regulatory signs (i.e., “Speed Zone Ahead” instead of “Reduced Speed Ahead”) to increase the perceived threat of enforcement and motivate speed reductions;
- unmanned police car to increase the perceived threat of enforcement;
- highway advisory radio and web site updates to improve driver information; and
- variable speed limit (based on traffic volume, traffic speed, and weather conditions) to better relate the posted speed limit to the potential risk present in the work zone.

Various states, the Federal Highway Administration (FHWA), the American Association of State Highway Transportation Officials (AASHTO), the Transportation Research Board, and other organizations conduct research and experimentation on new traffic control and safety devices. Engineers are encouraged to stay abreast of these current efforts and to use such devices with care to avoid presenting road users with unusual or confusing situations that might be abnormal or unexpected. New traffic control devices shall conform to the provisions for design, use, and application set forth in the TMUTCD or shall be subject to experimentation, documentation, and adoption following the provisions of TMUTCD Section 1A.10.

Section X.4.6 – Summary of Awareness Treatments

Table X-2 presents a summary of previous results in field testing of awareness treatments presented in this section. Engineers may consult this table to estimate the effectiveness of a treatment that may be used on projects under their direction. Treatments presented in this section that are not listed in Table X-2 did not have published findings in their respective references or they did not have sufficient field testing to produce significant results.

Table X-2. Summary of Results from Field Testing of Awareness Treatments.

Treatment	Source	Reduction in Mean Speed	Reduction in Violators
Innovative Signs	Georgia Tech (2003)	0-2 mph	NR
Orange-Border Speed Limit Signs	TTI (2005)	≤1 mph	≤3.5 percent
Speed Display Trailer	U. of Nebraska (1995)	4-5 mph	20-40 percent
	U. of Nebraska (2001)	"Statistically significant at all locations"	
	TTI (2000)	3-5 mph	NR
	TTI (2005)	3 mph	33 percent
PCMS	TTI (1982)	2-5 mph	NR
	TTI (1984)	0-5 mph	NR
PCMR	Georgia Tech (2003)	7-8 mph	NR
	TTI (2005)	2-3 mph	14-41 percent
Flagging	TTI (1982)	3-16 mph	NR
	TTI (1984)	4-16 mph	NR
Transverse Striping	TTI (1990)	"Generally ineffective"	
Rumble Strips	TTI (2003)	1-2 mph	NA
NOTE: NR = Not reported NA = Not applicable			

SECTION X.5 – DESIGN TREATMENTS

Design treatments are used to encourage work zone speed limit compliance by modifying a driver's behavior. Some of these treatments are devices or combinations of devices that can be installed and removed simply, while others are permanent installations suitable only for long-term use. All of these treatments are intended to suggest to drivers a particular course of action as they drive through the work zone and encourage them to take that course of action, which will likely carry them through the work zone at a compliant speed.

Four categories of treatments are discussed in this section:

- channelizing devices,
- lane and shoulder width,
- the late merge system, and
- enforcement shoulders.

A number of these treatments are discussed in Chapter 6F of the 2003 *Texas Manual on Uniform Traffic Control Devices*, which engineers should consult for the proper design and installation of the treatments. In addition, TxDOT Standard Plan Sheets have guidance specific to work zones for selected treatments; engineers should review the Plan Sheets prior to installing the treatments listed here.

Section X.5.1 – Channelizing Devices

According to the TMUTCD, the function of channelizing devices is to warn road users of conditions created by work activities in or near the roadway and to guide road users. These devices include:

- cones,
- tubular markers,
- vertical panels,
- drums,
- barricades, and
- temporary raised islands.

Channelizing devices provide for smooth and gradual motor vehicle traffic flow from one lane to another, onto a bypass or detour, or into a narrower traveled way, as shown in Figure X-44. They are also used to separate motor vehicle traffic from the work

Figure X-44. Channelizing Drums Guiding Drivers through a Work Zone at an Intersection.

space, pavement drop-offs, pedestrian or bicycle paths, or opposing directions of motor vehicle traffic.

Channelizing devices, in addition to guiding drivers to and through the proper travel path, can also be used to promote the selection of a given speed. Channelizing devices reinforce the alignment of a temporary roadway, and they provide positive guidance through a temporary driving path that differs from the permanent markings on a permanent roadway. In either case, channelizing devices can be used to influence drivers' speed, if properly installed.

The TMUTCD states that the spacing of channelizing devices should not exceed a distance in feet equal to 1.0 times the speed limit in mph when used for taper channelization, and a distance in feet equal to 2.0 times the speed limit in mph when used for tangent channelization. When channelizing devices have the potential of leading motor vehicle traffic out of the intended motor vehicle traffic space, the channelizing devices should be extended a distance in feet of 2.0 times the speed limit in mph beyond the end of the transition area.

Cones

Traffic cones have usefulness as both an awareness treatment and a design treatment. They may be used to:

- channelize road users,
- divide opposing motor vehicle traffic lanes,
- divide lanes when two or more lanes are kept open in the same direction, and
- delineate short-duration maintenance and utility work.

Because of their small size and weight, as shown in Figure X-45, crews should take steps to ensure that cones will not be blown over or displaced by wind or moving motor vehicle traffic. However, if placed properly, cones can have a small effect on drivers' speeds by alerting them to work zone conditions and marking the proper travel path.

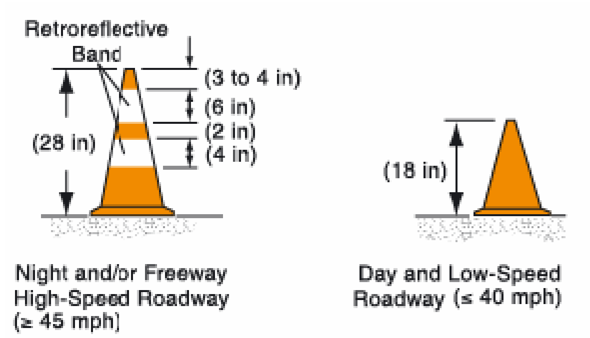


Figure X-45. Diagram of Traffic Cones.

Some cones are constructed with bases that can be filled with ballast. Others have specially weighted bases or weight such as sandbag rings that can be dropped over the cones and onto the base to provide added stability. However, to maximize safety, ballast should be kept to the minimum amount needed.

Drums

Drums are highly visible, have good target value, give the appearance of being formidable obstacles, and, therefore, command the respect of road users. They are portable enough to be shifted from place to place within a temporary traffic control zone in order to accommodate changing conditions, but are generally used in situations where they will remain in place for a prolonged period of time.

Because of their appearance as obstacles, drivers tend to leave as much space as possible between their vehicles and the drums. In narrow alignments, drums have a constricting effect on the driving path, which reduces the free space between drums and vehicles. Drivers often compensate for this lack of space by traveling at a slower speed to improve control of the vehicle and ability to compensate to avoid colliding with a drum. For low- to moderate-speed work zones, drums installed close to the driving path, as in Figure X-46, can have a speed reduction effect on the traffic stream.

Figure X-46. Drums as Channelizing Devices.

Speed reduction is not the primary use of drums, however, so engineers must ensure that the drums are properly installed for the purpose of warning and channelization. The TMUTCD provides the following instructions for installing drums. Drums used for road user warning or channelization shall be constructed of lightweight, deformable materials. They shall be a minimum of 36 inches in height and have at least an 18-inch minimum width regardless of orientation. Metal drums shall not be used. The markings on drums shall be horizontal, circumferential, alternating orange and white retroreflective stripes 4 to 6 inches wide. Each drum shall have a minimum of two orange and two white stripes with the top stripe being orange. Any non-retroreflectorized spaces between the horizontal orange and white stripes shall not exceed 3 inches wide. Drums shall have closed tops that will not allow collection of construction debris or other debris.

Tubular Markers

Tubular markers may be used effectively to:

- divide opposing lanes of road users,
- divide motor vehicle traffic lanes when two or more lanes are kept open in the same direction, and
- delineate the edge of a pavement drop-off where space limitations do not allow the use of larger devices.

Because of their use in areas with limited space, they can help to reinforce the message to drivers that a heightened level of caution is necessary and a slower speed is beneficial.

One advantage to tubular markers is that their installation is often permanent rather than temporary, which provides more of an obstacle to avoid than a traffic cone. However, tubular markers have less visible area than other devices, as shown in Figure X-47, and should be used only where space restrictions do not allow for the use of other more visible devices. Tubular markers should be stabilized by affixing them to the pavement, by using weighted bases or weights such as sandbag rings that can be dropped over the tubular markers and onto the base to provide added stability. As with cones, ballast should be kept to the minimum amount needed.

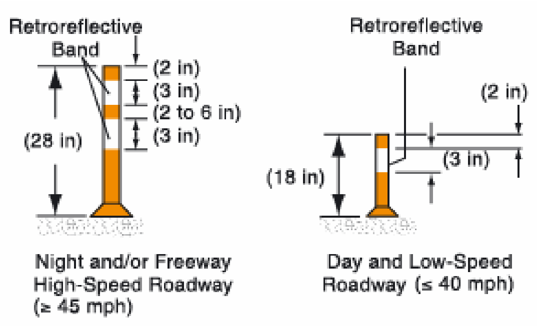


Figure X-47. Diagram of Tubular Markers.

Edgeline Channelizers

Edgeline channelizers are intended to be used to channelize traffic by indicating the edge of the travel way. As shown in Figure X-48, they are based on a 42-inch two-piece cone with an alternate striping pattern: four 4-inch retroreflective bands, with the center of the top band at approximately 36 inches and the others located successively below the first with approximate 2-inch gap between bands.

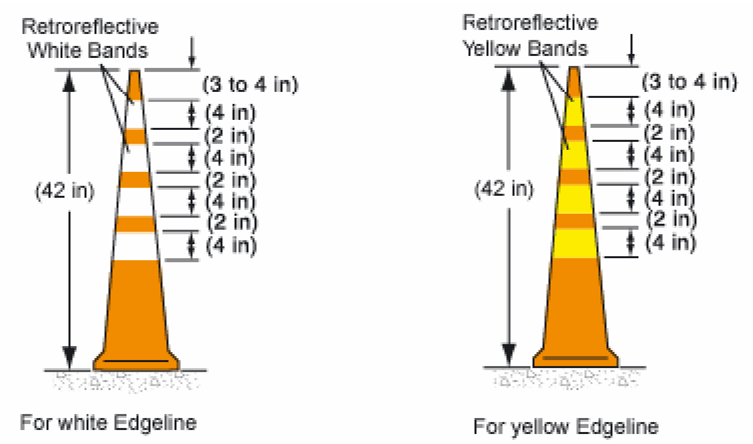


Figure X-48. Diagram of Edgeline Channelizers.

According to the TMUTCD, these devices shall not be used to separate lanes of traffic (opposing or otherwise). The color of the band shall correspond to the color of the edgeline (yellow for left edgeline, white for right edgeline) for which the device is substituted or for which it supplements. The base shall weigh a minimum of 30 lb.

Because they are restricted to edgeline use only, edgeline channelizers are most useful for WZSL compliance on two-lane roads, where all drivers are in close proximity to the devices.

Temporary Traffic Barriers

Temporary traffic barriers are devices designed to help prevent penetration by vehicles while minimizing injuries to vehicle occupants, and designed to protect workers, bicyclists, and pedestrians. They are also used for certain special events or in other temporary traffic control contexts where separation and channelization of vehicle and pedestrian movements are needed. Temporary traffic barriers, including shifting portable or movable barrier installations to accommodate varying directional motor vehicle traffic demands, may be used to separate two-way motor vehicle traffic.

The TMUTCD states that temporary traffic barriers shall not be used solely to channelize road users, but also to protect the work space. For nighttime use, the temporary traffic barrier shall be supplemented with delineation. Temporary traffic barriers should not be used for a merging taper except in low-speed urban areas. Temporary traffic barriers should not be used for a constricted/restricted temporary traffic control zone. When it is necessary to use a temporary traffic barrier for a merging taper in low-speed urban areas or for a constricted/restricted temporary traffic control zone, the taper shall be delineated and the taper length should be designed to optimize road user operations considering the available geometric conditions. When used for channelization, temporary traffic barriers should be of a light color for increased visibility.

The nature of temporary traffic barriers as a protection for workers and equipment sends a message to drivers that extra caution is required in the area and lower speeds are appropriate. However, because the protective requirements of a temporary traffic control situation have priority in determining the need for temporary traffic barriers, their use should be based on an engineering study. In order to mitigate the effect of striking the end of a temporary traffic barrier, the end shall be installed in accordance with AASHTO's *Roadside Design Guide* by flaring until the end is outside the acceptable clear zone or by providing crashworthy end treatments.

Section X.5.2 – Width of Lanes and Shoulders

The width of the travel path has an effect on the speed that drivers choose. When presented with wide lanes and shoulders, drivers feel more comfortable at higher speeds. Conversely, when lane width and/or shoulder width is reduced, drivers tend to slow down to maintain their comfort level. Lane and shoulder width can be defined by striping, channelizing devices, or the physical width of the paved surface, depending on the nature of the work zone and the traffic control plan associated with it.

A research project tested two effective lane width reduction treatments, one with a 12.5-ft lane width and the other with an 11.5-ft lane width. Cones were used as the narrowing device for both treatments. At freeways and urban arterial sites, the cones were placed on both edgelines but not on the lane lines. At two-lane, two-way highway sites, cones were placed on the edge of the travel lane and on the centerline. For a given site, the two treatments had approximately the same effect on speeds, with observed reductions of 0 to 8 mph. There were slightly greater reductions for the 11.5-ft width, but the reductions were neither statistically nor practically significant. A related finding was that even though the mean speeds were reduced, the speed variance actually increased.

An important finding in that project was that cones proved to be somewhat hazardous devices for effectively reducing lane widths below 12 ft. At the 11.5-ft width, cones were hit frequently, and on one occasion they were knocked into the travel lane causing erratic maneuvers and stoppage of traffic. Concrete barriers could be used in these cases in lieu of cones, although the ease of portability would be lost.

The most important factor to consider is the safety of drivers and workers in the work zone. The widths of the travel lanes and shoulders must be adequate to safely serve the anticipated traffic through the work zone and allow workers to complete the project with sufficient separation from the traffic stream. While narrower lanes may have an effect on improving compliance, this effect cannot take precedence over a safe work zone design.

Section X.5.3 – Late Merge

The Pennsylvania Department of Transportation (PennDOT) originally developed and implemented the “late merge” concept to improve vehicle operations at work zone merge areas, which would conceivably reduce road rage caused by queue jumping. In the PennDOT application, static signing is used to instruct drivers to remain in both lanes until they reach the merge point. At the merge point, a second static sign instructs motorists to take turns proceeding into the work zone activity area. Though the primary purpose of this concept is to improve merging behavior, a side benefit could be significantly reduced speeds entering the work zone.

The University of Nebraska performed an evaluation of the late merge concept on a four-lane rural interstate highway. Researchers found that the technique led to a capacity approximately 18 percent higher than a traditional merge situation. Researchers also reported approximately 75 percent fewer merging conflicts and 30 percent fewer incidents of lane straddling. A statistical analysis of the data produced speed distributions for congested (late merge) and uncongested (normal merge) flow. The mean speed for the congested flow was approximately 34 mph lower than the uncongested mean speed.

Ultimately, this strategy is designed to improve vehicle operations in the traffic queue upstream of a work zone lane closure. Therefore, it is most effective for temporary short-term lane closures where engineers expect traffic demands to exceed the capacity of the work zone over the entire duration of the work activity. Despite the potential benefits of the strategy, a TTI study concluded that contractors appear somewhat hesitant to employ the technique on projects where the traffic control plan has already been prepared and approved. It would be necessary to specifically integrate the strategy into the traffic control plan documents of future projects for implementation to move forward.

Section X.5.4 – Enforcement Shoulders

Enforcement shoulders, or pullout enforcement areas, are used to provide enforcement officers with a safe location to issue citations within a work zone of otherwise narrow cross-section. Enforcement shoulders can be classified as both a design treatment and an enforcement treatment, because the shoulders must be included as part of the design of the traffic control pattern in order to implement them. Depending on the length of the work zone, multiple pullout areas are positioned at regular intervals, with sufficient length for acceleration and deceleration.

Research was conducted on the spacing and length of shoulder enforcement areas, surveying the interests of both enforcement agencies and construction contractors. The need was to balance the contractor's desire for a work zone with minimal disruption and the agencies' need for a safe place to issue citations to offenders. The survey responses led the researchers to recommend spacing shoulder pullout areas between 2.0 and 3.0 miles. Additionally, the responses provided an indication of the length of work zone that can reasonably accommodate enforcement activities. Researchers also performed a review of the AASHTO *Green Book* for acceleration/deceleration guidelines and a study of the driving behavior of passenger car drivers after a traffic stop in non-work zone locations. Based on these elements, the researchers concluded that a 0.25-mile long pullout area would be sufficient for a highway work zone with a speed limit of 60 mph; the ideal length would be 1700 ft.

Properly implemented, enforcement shoulders can be a very effective treatment for improving WZSL compliance, because they remove the violating driver's confidence that there is no possibility of being issued a traffic citation in a work zone with a narrow cross-section. Drivers who are concerned about enforcement are much more likely to comply with the speed limit.

Section X.5.5 – Summary of Design Treatments

Table X-3 presents a summary of previous results in field testing of design treatments presented in this section. Engineers may consult this table to estimate the effectiveness of a treatment that may be used on projects under their direction. Treatments presented in this section that are not listed in Table X-3 did not have published findings or did not have sufficient field testing to produce significant results.

Table X-3. Summary of Results from Field Testing of Design Treatments.

Treatment	Source	Reduction in Mean Speed	Reduction in Violators
Lane Narrowing	TTI (1984)	0-8 mph	NR
"Late Merge"	U. of Nebraska (1999)	34 mph	NR
NOTE: NR = Not reported			

SECTION X.6 – ENFORCEMENT TREATMENTS

Enforcement is considered to be by far the most effective method of improving work zone speed limit compliance. The fear of a traffic citation is often greater than the fear of collision or injury for many drivers and a visible enforcement presence validates that fear. The primary method of enforcement involves one officer observing traffic, either from a stationary position or “floating” within the traffic stream, and making traffic stops to issue citations to violators. There are also variations on this method, some of which are described in this section, that can be used within work zones to improve the effectiveness of enforcement efforts.

One of the primary drawbacks to enforcement is the cost necessary to pay for one or more officers to monitor traffic; another is often the lack of sufficient space within the work zone to stop a violator and issue a citation. Some concepts to address these obstacles will also be discussed in this section.

Section X.6.1 – Routine Enforcement

Routine enforcement (see Figure X-49) is conducted by officers who pass through or near a work zone in the course of their normal patrol route or some other part of their duties. If a speed limit violation occurs when an officer is present, the officer will issue a citation. This type of enforcement relies on an officer driving through the area in close proximity to a violator to have effectiveness.

Figure X-49. Routine Enforcement Traffic Stop.

It has a much lower cost than other types of enforcement treatments, because all of the cost is absorbed by the enforcement agency’s normal operation; however, it also usually has much lower effectiveness because of the limited enforcement presence.

Section X.6.2 – Regular Supplemental Enforcement

Compared to routine enforcement, supplemental enforcement involves the use of officers whose sole purpose is to enforce the speed limit in the work zone. Previous studies indicate that police officers utilize three main types of enforcement activities: stationary, traffic control, and mobile. The stationary technique entails positioning the police vehicle in a highly visible portion of the work zone. The officer remains in the vehicle and uses its presence to help control speeds through the work zone. Officers involved with traffic control are out of their vehicles and are providing instructions to the motorist as they pass through the work zone. Finally, the mobile technique entails having one or more officers continually drive through the work zone and, if necessary, pull over vehicles that are violating the laws within the work zone.

A recent survey of state law enforcement personnel found that of the states surveyed, the stationary technique was most commonly used. However, the mobile technique is also used frequently and may be on the increase. The enforcement presence in the work zone can be effectively increased simply by increasing the number of police patrols in the area near the work zone, even by extending the additional patrols to cover the area just prior to and just after the work zone. In general, the officers surveyed felt that the mobile patrols were more effective because of the flexibility that “being on the move” provided.

Several research projects document the effect that extra enforcement has on safety and operations within the work zone environment. Results show that stationary enforcement techniques tend to be the most effective in reducing speeds through the work zone. Such techniques reduced speeds by up to 12 mph in some cases. The mobile enforcement techniques preferred by officers reduced speeds by less than 5 mph throughout the work zone. The speed reductions were most dramatic for the vehicles that could “see” the enforcement vehicle in the traffic stream. While most transportation departments and law enforcement agencies feel that increased enforcement in work zones increases safety, direct measurements of accident reductions are not easily found. Often the benefit is a reduction in fatalities, because of the lower speeds, even though there may be a negligible change in the total number of accidents.

Regular supplemental enforcement employs officers who have a constant presence in or near the work zone, particularly during hours when workers are present. Often, regular supplemental enforcement is part of a broader safety and enforcement program, and it stations officers at the work zone for five to seven days per week for weeks at a time. With this treatment, regular drivers through the area “learn” that enforcement is usually present and adjust their speed to a compliant level for the entire work zone. Eventually, officers issue only a few citations, mainly to non-regular drivers who have not been influenced by the slower speeds of the regular drivers. Regular supplemental enforcement is most useful at work zones with significant violation rates present or anticipated throughout the day and the week.

The cost of regular supplemental enforcement is an obstacle that prevents more widespread use. The salaries of the officers must be paid through a limited number of ways. Extra enforcement in work zones can either be provided on a cooperative or dedicated basis. Cooperative enforcement entails the use of on-duty officers that simply increase their regular patrol area to include the work zone. In contrast, dedicated enforcement agreements provide additional officers specifically for the purpose of enforcing the work zone. In almost all cases off-duty officers are utilized for the additional enforcement.

Work zone safety campaigns may have funding available for dedicated officers at selected work zones; however, the funds most often come from state construction funds slated for the particular project. Additional funding sources, such as utilizing revenues from work zone fines, are also available in some states. Nationwide, the state DOT performs the actual hiring of the officers in about half the cases and the contractor in charge of the construction project in the remaining cases. In either case, construction funding must absorb the cost, which increases the cost of the project. If regular supplemental enforcement is to be used, the funding source must be identified in advance of its deployment, preferably during the bid process of the project.

Section X.6.3 – Periodic Supplemental Enforcement

Periodic supplemental enforcement is similar to regular supplemental enforcement, except that officers are not continuously deployed. Periodic enforcement may be utilized during only peak hours or certain days of the week. Periodic enforcement may also be deployed on a somewhat random scale so that regular drivers do not become accustomed to the enforcement schedule. Periodic supplemental enforcement is useful for work zones that may be developing violation problems and an enforcement presence targeted to those problems will greatly improve compliance.

The cost of periodic enforcement can be much less than regular enforcement, but the effectiveness will also be reduced to a certain degree. Periodic enforcement is most effective on regular drivers, who will remember that they have seen officers in the work zone in the past and may slow down even when an officer is not present. Non-regular drivers will probably not be influenced unless an officer is actually enforcing the speed limit when they travel through the area.

Section X.6.4 – Enforcement Shoulders/Turnouts

As discussed in Section X.5.4, enforcement shoulders, or pullout enforcement areas, are used to provide enforcement officers with a safe location to issue citations within a work zone of otherwise narrow cross-section. Enforcement shoulders can be classified as both a design treatment and an enforcement treatment, because the shoulders must be included as part of the design of the traffic control pattern in order to be implemented. Depending on the length of the work zone, multiple pullout areas are positioned at regular intervals, with sufficient length for acceleration and deceleration.

Officers can use these shoulders to observe and monitor traffic from a stationary position within the work zone, and they can use them to execute traffic stops and issue citations.

Section X.6.5 – Team Enforcement

Another way to address the obstacle of limited cross-section is through the use of team enforcement. With this method, multiple officers (usually two) are positioned in or near the work zone in the same direction of travel. The officer positioned upstream monitors the traffic and observes speeds; when a violation is observed that officer notifies an officer positioned downstream of the work zone. The downstream officer, having received the vehicle information and speed by radio, then makes a traffic stop on that vehicle when it exits the work zone and there is sufficient space to safely issue a citation.

The cost of this treatment is higher than other enforcement treatments, because there must be funding for multiple officers' salaries, which often minimizes the use of this treatment. However, if funding is available, this allows officers to safely monitor traffic and enforce the speed limit in work zones with reduced cross-sections. In addition, the presence of multiple enforcement vehicles at the same work zone also increases the effect on drivers' compliance, as compared to a single enforcement vehicle.

Section X.6.6 – Psychological Devices

In attempts to motivate compliance at reduced cost and labor, project engineers and enforcement agencies have tested a number of devices intended to make drivers think that enforcement is active, even when it is not. These devices have a much lower cost than actual enforcement and are usually easy to install. There are few established guidelines on using these devices, and their effectiveness can vary greatly, so they should be used with discretion. However, if properly installed at key locations, or if used in conjunction with actual enforcement, they can have some effect on improving compliance, particularly in the short term.

“Dummy” Cars

Various enforcement agencies have parked empty patrol vehicles, sometimes called “dummy” cars, at or near work zones in an effort to persuade drivers that enforcement is active and motivate them to slow to compliant speeds (see Figure X-50). The cost and effort of this treatment is very minimal, and it can be very effective for short periods of time, especially for non-regular drivers. In this method, drivers see the parked patrol vehicle ahead and adjust their speed accordingly. The primary drawback to this method is that when drivers realize the vehicle is unmanned, as shown in Figure X-50, they often resume their previous speed. To counteract this effect, some agencies place mannequins or other apparatus in the vehicle to look like an officer is present. This variation has moderately higher success, but violators significantly above the speed limit realize the vehicle is unmanned when they are not pursued.

Figure X-50. Empty Patrol Vehicle.

For very short-distance work zones, such as maintenance activities, this treatment can be useful to improve compliance in the immediate vicinity of workers and equipment. This treatment can also be used in conjunction with supplemental enforcement to extend the "footprint" of the officers' presence. Care must be taken that vehicles are not parked in a position to create a collision hazard or a sight distance obstruction.

Cutouts

In an attempt to accomplish the same results as a "dummy" car, agencies with few cars to spare have developed vehicle cutouts, two-dimensional images of patrol vehicles. Often these cutouts depict the rear of a vehicle as if it was parked on the roadside like a "dummy" car, an example of which is shown in Figure X-51. Other cutouts have been created to resemble the side of a car, which may be parked on a side road or in a parking lot, perpendicular to the direction of traffic.

Depending on the quality of the image, cutouts generally have limited effectiveness at improving compliance. The closer drivers get to the cutout, the more obvious it is that it is not a real vehicle. However, for limited applications and as reminders that officers are conducting enforcement elsewhere, they can have some benefit at a very minor cost.

(a) Cutout car positioned on shoulder. (b) Close-up of cutout in dark conditions.

Figure X-51. Cutout of Patrol Vehicle.

Radar Drones

Radar drones are intended to activate radar detectors in vehicles driving near their locations. They simulate active radar from enforcement and motivate drivers to slow down, and they can be placed within “dummy” cars for added benefit. However, they have had minimal effectiveness in field testing, primarily because of two factors. First, radar detectors are illegal in many states and, therefore, radar drones are undetected by many drivers who do not own radar detectors. Second, similar to “dummy” cars, once a violator realizes that there is, in fact, no active enforcement, he or she will continue at their previous excessive speed. This problem is compounded by the fact that many radar detectors are located in commercial trucks; truck drivers will often notify other truck drivers via citizen’s band radio that there is a drone nearby that they can ignore. In summary, radar drones can have modest effectiveness if installed in limited applications for short periods of time at locations with high percentages of vehicles with radar detectors.

Section X.6.7 – Remote/Automated Enforcement

The concept of effective speed enforcement in work zones is related to the ability of an enforcement officer to verify a violation and then safely issue the citation. As mentioned previously in this section, the ability of officers to safely monitor traffic and execute a traffic stop is often hindered by the characteristics of the work zone, primarily in work zones where there are narrow lanes and narrow or no shoulders. To address this problem, researchers have proposed the concept of remote speed enforcement. Remote speed enforcement (or automated speed enforcement) devices utilize a radar or lidar unit that detects speeds of oncoming traffic. The device takes a picture of the vehicle's license plate (and of the driver if needed in certain jurisdictions). Figure X-52 shows an example of such a picture (altered in this document to obscure the license plate).

Figure X-52. Image of Speeding Vehicle Taken through Remote Enforcement.

Typically, in automated enforcement, these photographs are used to mail traffic citations or warnings to the registered owner of the vehicle. The system offers a chance to improve work zone safety since officers do not have to pursue, or attempt to pull over, vehicles within the work zone.

Researchers proposed a similar idea for remote enforcement to use an officer with a remote device to enforce WZSLs. The device is stationed upstream of the work zone to "watch" for violators; the officer is positioned downstream to issue citations to violators. When an upstream violation occurs, the device records the picture and sends the image to the officer, who issues the citation; this keeps the actual enforcement activity out of the work zone where movements are restricted. The device also may be installed within a changeable message sign or speed display unit (as shown in Figure X-53) to notify drivers that their excessive speed has been recorded.

A field test of a remote enforcement system produced results such that downstream observers could identify between 84 and 88 percent of vehicles based on transmitted

Figure X-53. Simplified Diagram of Positioning of Devices in Remote Enforcement.

images. The results were unaffected by the distance between the camera and observer; the results were also independent of whether vehicles were photographed from the front or the back. Discussions with law enforcement officers led to the conclusion that there was significant potential for use, but there may be some initial legal challenges to the use of this system until it is accepted by the courts. Some officers felt the system could be used in the existing legal structure and would provide a safety benefit to enforcement personnel. However, other officers felt that some modifications would be necessary before they could use the system in Texas. Texas Department of Public Safety representatives felt that it would need to be tested in the courts in order to assess the legal ramifications of the system.

Consequently, this treatment has not been fully tested in Texas. Further study is necessary to determine its legal viability in addition to its effectiveness; a project engineer choosing to further explore this treatment must consider these issues and coordinate with the appropriate law enforcement agencies in order to ensure that testing is conducted legally.

Section X.6.8 – Summary of Enforcement Treatments

Table X-4 presents a summary of previous results in field testing of enforcement treatments presented in this section. Engineers may consult this table to estimate the effectiveness of a treatment that may be used on projects under their direction. Treatments presented in this section that are not listed in Table X-4 did not have published findings in their respective references or they did not have sufficient field testing to produce significant results.

Table X-4. Summary of Results from Field Testing of Enforcement Treatments.

Treatment	Source	Reduction in Mean Speed	Reduction in Violators
Supplemental Enforcement	Iowa State U. (2003)	0-12 mph	NR
NOTE: NR = Not reported			