Technical Report Documentation Page

1. Report No. FHWA/TX-09/0-5561-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle STUDIES TO IMPROVE THE MANAGEMENT OF REGULATORY SPEED LIMITS IN TEXAS WORK ZONES		5. Report Date October 2008 Published: December 2008
		6. Performing Organization Code
7. Author(s) Melisa D. Finley, LuAnn Theiss, Nada D. Trout and Gerald L. Ullman		8. Performing Organization Report No. Report 0-5561-1
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. Project 0-5561
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, Texas 78763-5080		13. Type of Report and Period Covered Technical Report: September 2006-August 2008
		14. Sponsoring Agency Code

15. Supplementary Notes
Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.
Project Title: Improving Regulatory Speed Limit Management in Texas Work Zones
URL: http://tti.tamu.edu/documents/0-5561-1.pdf

16. Abstract
This report describes the methodology and results of analyses performed to (1) improve existing procedures on establishing and managing work zone speed limits, and (2) evaluate new technologies and strategies that can be used to better manage work zone speed limits. Field studies indicated that motorists reduce their speed adjacent to most of the work zone conditions currently used in Texas to justify reduced work zone speed limits; however, the amount of the speed reduction is dependent upon the normal non-work zone operating speed of the roadway. Based on the field study findings, researchers recommended a 5 mph maximum speed reduction for shoulder activity and lane encroachment conditions. A 10 mph maximum speed reduction is still warranted for lane closures and temporary diversions. Speed limit reductions should be discouraged on roadways with existing speed limits less than 65 mph for all conditions except lane closures when workers are in a closed lane unprotected by barrier and only a single travel lane remains open.

Short term work zone speed limits are reduced speed limits that are posted only when work activity is present. When the work activity is not present, the short term work zone speed limit signs should be removed or covered; thereby allowing the legal speed limit for that segment to revert back to the normal non-work zone speed limit. The major challenge with short term work zone speed limits is the daily install/remove or uncover/cover process. Field studies and motorist surveys verified that electronic speed limit (ESL) signs and static flexible roll-up work zone speed limit signs are easily implemented, effective at reducing speeds, and understood by motorists. Based on these results, researchers recommended the use of ESL signs and static flexible roll-up work zone speed limit signs. Additional findings from all of the studies and detailed recommendations are discussed in the report.

17. Key Words Work Zone Speed Limits, Reduced Speed Limits, Work Zones, Speed Management, Electronic Speed Limit Signs, Roll-up Signs, Changeable Message Signs		18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 http://www.ntis.gov	
19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 172	22. Price

STUDIES TO IMPROVE THE MANAGEMENT OF REGULATORY SPEED LIMITS IN TEXAS WORK ZONES

by

Melisa D. Finley, P.E.
Associate Research Engineer
Texas Transportation Institute

LuAnn Theiss, P.E.
Associate Research Engineer
Texas Transportation Institute

Nada D. Trout
Assistant Research Scientist
Texas Transportation Institute

and

Gerald L. Ullman, Ph.D., P.E.
Senior Research Engineer
Texas Transportation Institute

Report 0-5561-1
Project 0-5561
Project Title: Improving Regulatory Speed Limit Management in Texas Work Zones

Performed in cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

October 2008
Published: December 2008

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. This report is not intended for construction, bidding, or permit purposes. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report. The engineer in charge of the project was Melisa D. Finley, P.E. (TX-90937).

ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and FHWA. The project was overseen by a TxDOT Project Monitoring Committee. Carlos Ibarra served as the project director and Wade Odell served as the Research Management Committee (RMC) 4 program coordinator. Linden Burgess, Sherri' Eaglin, Theresa Lopez, Darren McDaniel, Mark Olson, Doug Skowronek, and Rebecca Wells served as project advisors. The assistance and direction provided by these individuals over the course of the project is gratefully acknowledged.

The authors wish to acknowledge the contributions of Sandra Schoeneman, Dan Walker, Brooke Ullman, Marcus Brewer, and Sarah Young in the design and conduct of the field studies and motorist surveys for this project. The authors also wish to express their thanks to Jason Richter who assisted with the project as part of the 2007 Texas A&M University Undergraduate Transportation Scholars Program.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

INTRODUCTION

STATEMENT OF THE PROBLEM

In 2005, the Texas Legislature passed House Bill 1925, which instructed the Texas Department of Transportation (TxDOT) and highway contractors to remove or cover reduced regulatory speed limit signs in work zones whenever no hazards that necessitate the need for a reduced speed limit are present. Although TxDOT's speed zoning procedures for work zones already allowed for this, the law placed additional emphasis on proper management of reduced regulatory speed limits in work zones.

Unlike speed zoning for permanent roadway segments, the actual speeds at which motorists will travel within a particular work zone cannot be accurately predicted prior to the establishment of that work zone on the roadway. Thus, TxDOT's procedures for determining whether or not a reduced regulatory speed limit in a work zone is warranted take into consideration the type of work activity and a number of other site-specific factors. Undoubtedly, an improved understanding of the relationship between factors used to justify reduced work zone speed limits and motorist perceptions of the need to reduce their speed could improve the speed limit selection process. However, which factors are actually perceived as more hazardous by motorists and therefore result in slower speeds is still not well understood. Research was needed to improve existing guidance and procedures on establishing and managing work zone speed limits, including a better understanding of the factors that should be used to determine the need for reduced speed limits.

If the reduced speed limits are not necessary for the safe operation of traffic during certain construction operations or those days and hours the contractor is not working, the regulatory construction speed limit signs should be made inoperative by moving the signs to the edge of the right of way and facing them away from the roadway or by covering the signs when the reduced speed limits are not necessary. The daily install/remove or uncover/cover process of signs represents an additional task for the contractor that reduces overall work productivity, and thus some contractors may simply choose not to cover or remove signs. In addition, the potential exists for the contractor to simply forget to cover or remove signs when the reduced speed limit is not appropriate. Therefore, research was also needed to identify and evaluate new technologies and strategies that can be used to better manage work zone speed limits in Texas.

This report describes the efforts and results of a research project that examines both of these issues.

BACKGROUND

Overview of Speed Zoning

Most transportation professionals view the setting of appropriate regulatory speed limits on all publicly traveled roadways, including those under repair or reconstruction, as an important tool in promoting safe and efficient operations on the highway system (*1*). Properly set speed limits are believed to provide unfamiliar drivers with an indication of speeds that are considered to be safe and reasonable for that section of roadway, to reduce speed variation between vehicles and thus improve safety, and to provide a basis for enforcement to identify unreasonable drivers and issue citations. Texas law requires that drivers never exceed speeds that are safe and prudent for conditions, regardless of whether the posted speed limit indicates a higher speed is allowable (*2*). Exceeding a posted regulatory speed limit on a section of highway is considered prima facie evidence that the speed being traveled is not reasonable and prudent, and is therefore unlawful.

The Texas Transportation Commission (the Commission) has legal authority to set the maximum speed limits on a particular roadway section, based on the results of an engineering and traffic investigation (*3*). The responsibility for conducting the engineering and traffic investigations lies with TxDOT. TxDOT has formalized the procedures for establishing speed zones (as well as advisory speeds) on all roadways in the state (*4*). In most cases, the establishment of a speed zone is predicated on the assumption that most drivers operate their vehicles in a safe, reasonable, and prudent manner. The speeds that the majority of drivers choose to travel on a given roadway segment are therefore considered to be an indication of a safe and reasonable speed. The 85^{th} percentile speed, the speed at which 85 percent of drivers travel at or below at a given point on the roadway, is commonly taken to be the maximum speed considered safe and reasonable for that segment by the majority of drivers. This driver-defined maximum safe speed can then be adjusted slightly if necessary based on site factors such as crash history, narrow lane widths, or horizontal or vertical curvature that may limit sight distance (*4*). A speed limit to the nearest 5 mile per hour (mph) increment of that maximum safe speed is then typically requested for approval by the Commission.

Even though the speed limit may be based on the 85th percentile speed, many studies have reported that the speed limit is usually significantly lower than the measured 85th percentile value. For example, the Institute of Transportation Engineers (ITE) (*5*) found that for roadways with posted speed limits of 45 mph and below, most of the measured speeds are higher than the posted speed limit. When the posted speed limit is 55 mph or more, about half of the measured speeds are above the posted speed limit. This indicates that there is very little motorist compliance with existing speed limits. This may be due in part to the difficulty with predicting operating speeds (and thus the speed limit) based on the roadway geometry and roadside features (*6*,*7*,*8*,*9*,*10*,*11*,*12*).

Statutory limits, established by legislation at the national, state, or municipal level, are another way of setting speed limits. These limits are typically applied to a category of highways, vehicles, or period of time. Examples include the revoked 55 mph national speed limit, differential speed limits for passenger cars and commercial vehicles, and a maximum nighttime speed limit.

Current Speed Zoning in Texas Work Zones

Although the above procedure works well for permanent roadway segments, a different approach must be taken when determining the speed limit to be established on a roadway segment that is undergoing repair, rehabilitation, or reconstruction, since one cannot measure actual work zone driving speeds prior to the establishment of the work zone itself. The Texas Administrative Code (TAC) (*13*), *Texas Manual on Uniform Traffic Control Devices* (MUTCD) (*14*), and TxDOT *Procedures for Establishing Speed Zones* (*4*) all indicate that traffic control through construction and maintenance work zones should be designed on the assumption that motorists will only reduce their speeds through the work zone if they clearly perceive a need to do so. Reduced speed limits in work zones should be avoided as much as practical, although these decisions require engineering judgment depending on the nature of the project and other factors which affect the safety of the traveling public and construction workers. Regulatory construction speed limits should only be established where speed control is of major importance and adequate enforcement is available. In addition, reduced speed limits should only be posted in the specific portion of the work zone where conditions or restrictive features are present, not throughout the entire project.

Unfortunately, trying to predict whether a given set of work zone conditions will actually result in lower travel speeds is extremely difficult. There have been a few attempts to try and model travel speeds based on the roadway and work zone characteristics present, but only for a very limited set of conditions (*15*). Typically the selection of the maximum safe speed is based on consideration of safe stopping sight distances, construction equipment crossings, the nature of the construction project, and any other factors which are believed to affect the safety of the traveling public and construction workers. TxDOT has adopted policies and procedures for determining if a reduced regulatory speed limit should be established in a construction work zone (*16*). The procedure takes into consideration the type of work activity and a number of other site-specific factors. Table 1 presents a summary of this procedure.

It is important to recognize that the current procedure for establishing regulatory work zone speed limits in Texas comes from National Cooperative Highway Research Program (NCHRP) research recommendations from the mid-1990s (*17*). In establishing those recommendations, NCHRP researchers hypothesized that motorists may not always fully comprehend all of the hazards present in a work zone, such that actual travel speeds were not always the best indicator of what constitutes a safe and reasonable speed in that work zone. In addition, crash and traffic operations studies conducted at work zones across the country seemed to imply that the posting of work zone speed limits 10 mph below the normal limit corresponded to the smallest increase in work zone crashes, and resulted in slightly reduced speed variances through the work zone (*17*). Therefore, it was proposed that speed limits in work zones *could* be reduced from their normal, pre-work zone, levels if any of a number of potentially hazardous site conditions were present. The researchers' final recommendations were the same as those shown in Table 1. Note that in five of the seven work zone conditions, speed limit reductions up to 10 mph are allowed if any of the factors listed for each condition are present. Speed limit reductions of more than 10 mph were discouraged, since previous research had shown that motorists will not typically slow down more than 10 mph through a work zone, even if enforcement was present (*18*,*19*,*20*).

Table 1. TxDOT Work Zone Regulatory Speed Limit Determination Guidelines (*16*).

Condition	Maximum Speed Limit Reduction	Factors That Justify Speed Limit Reduction
Roadside Activity (greater than 10 ft from traveled way)	None	• None
Shoulder Activity (2 to 10 ft from traveled way)	10 mph	• Workers present for extended periods within 10 ft of travel lane(s) not protected by barriers • Horizontal curvature that might increase vehicle encroachment rate
Lane Encroachment (from edge to within 2 ft of traveled way)	10 mph	• Workers present for extended periods within 2 ft of travel lane(s) not protected by barriers • Horizontal curvature that might increase vehicle encroachment rate • Barrier or pavement edge drop off within 2 ft of travel lane(s) • Reduced design speed for stopping sight distance • Unexpected conditions
Moving Activity on Shoulder	None	• None
Lane Closure (between centerline and edge of traveled way)	10 mph	• Workers present for extended periods in the closed lane unprotected by barriers • Lane width reduction of 1 ft or more with a resulting lane width of less than 11 ft • TCDs encroaching on a lane open to traffic or in a closed lane within 2 ft of the edge of the open lane • Reduced design speed for taper length or speed change lane length • Barrier or pavement edge drop off within 2 ft of travel lane(s) • Reduced design speed for horizontal curve • Reduced design speed for stopping sight distance • Traffic congestion created by a lane closure • Unexpected conditions
Temporary Diversion	10 mph	• Lane width reduction of 1 ft or more with a resulting lane width of less than 11 ft • Reduced design speed for detour roadway or transitions • Unexpected conditions
Centerline or Lane Line Encroachment	10 mph	• Workers present on foot for extended periods in the travel or closed lanes unprotected by barriers • Remaining lane plus shoulder width is less than 11 ft • Reduced design speed for taper length or speed change lane length • Barrier or pavement edge drop off within 2 ft of travel lane(s) • Reduced design speed for horizontal curve • Reduced design speed for stopping sight distance • Traffic congestion created by a lane closure • Unexpected conditions

TCDs = Traffic Control Devices

The approach presented by NCHRP researchers and used by TxDOT is logical. In fact, speed zoning procedures in non-work zone locations also allow for speed limits lower than those implied by actual travel speeds to be posted on a roadway when other factors, such as higher than normal crash rates, exist to suggest that drivers may not be fully perceiving the true hazard of the location and thus are driving too fast for conditions (*4*). However, locations where the need for lower speed limits below actual travel speeds exists are the same locations where enforcement should be targeted in order to encourage motorist compliance and to raise motorist awareness of their surroundings.

According to the TAC and TxDOT procedures, if the reduced speed limits are not necessary for the safe operation of traffic during certain construction operations or those days and hours the contractor is not working, the regulatory construction speed limit signs should be made inoperative by moving the signs to the edge of the right of way and facing them away from the roadway or by covering the signs when the reduced speed limits are not necessary (*4,13*). As also noted in the TAC, leaving speed limit signs in place when not needed has at least three adverse effects:

- drivers ignore the signs, and by doing so, they are subject to citation;
- respect for all speed limit signs is lessened; and
- the law-abiding driver becomes a traffic hazard by observing the reduced speed.

To address this concern, TxDOT has identified both long/intermediate term and short term regulatory work zone speed limits (*21*). Long/intermediate term limits are to be included in the design of the traffic control plan when restricted geometrics with a lower design speed are present and the modification of the geometrics to a higher design speed is not feasible. Furthermore, long/intermediate term speed limits are said to be appropriate if work activity at the project occurs for more than 12 hours at a time continuously, or if any of the following conditions are present:

- rough road or damaged pavement surface,
- substantial alterations of roadway geometrics (diversions),
- construction detours,
- grade,

- width, and
- other conditions readily apparent to the driver.

As long as any of these conditions exist, the work zone speed limit signs should remain in place.

Short term work zone speed limits, on the other hand, are to be included in the design of the traffic control plans when workers or equipment are not behind concrete barriers, work activity is within 15 ft of the pavement edge, or work is actually occurring on the pavement. In these situations, short term work zone speed limit signs should be posted and visible to the motorists only when work activity is present. Work activity in the area of reduced speed should be less than 12 consecutive hours. When work activity is not present, signs should be covered with an approved sign cover or removed from the work area. According to TxDOT standards, turning the signs from view or laying signs over or down is not an allowable method of indicating that the short term work zone speed limit is not in effect (*21*). The use of short term speed limits has been emphasized in recent legislation. According to the latest language in the Texas Transportation Code, Section 201.907 (*22*):

> *"The department shall remove or cover or require the removal or covering of a sign that restricts the speed limit in a construction or maintenance work zone during any period when no hazard exists that dictates the need for a restricted speed limit."*

Although TxDOT has allowed short term work zone speed limits to be used for several years, the addition of this language suggests public frustration with how work zone speed limits are currently being applied and perceptions that reduced speed limits are in effect more often than they should be within highway work zones.

One challenge with current TxDOT procedures is in the implementation of the appropriate type of work zone speed limit (long/intermediate term versus short term) to conditions and factors present at a particular work zone. As noted previously, the use of short term work zone speed limits is appropriate where the justifications for a lower limit (unprotected workers, presence of work activity near or on the travel lanes) exist for time periods less than 12 hours duration. The speed limit signs in these types of work zones are to be removed or covered at the end of each work activity period, thereby allowing the legal speed limit for that segment to revert back to the normal non-work zone speed limit.

It is important to recognize that the daily install/remove or uncover/cover process of signs represents an additional task for the contractor that reduces overall work productivity. In addition, the potential exists for the contractor to forget or simply choose not to cover or remove signs. In effect, the failure to cover or remove the signs turns the short term limit into a long/intermediate one and further reduces the credibility of TxDOT's work zone speed limit procedures with the public.

Recently, vendors have developed and are marketing internally illuminated and other types of signs that will allow a regulatory speed limit to be displayed during portions of the day or night when work activity is occurring, and then extinguished when the reduced speed limit is no longer applicable. Such a device would simplify the short term work zone speed limit implementation process and could lead to a greater use of short term work zone speed limits in general. However, such technologies have not been used extensively for work zone speed limits in Texas. Testing is needed to determine how motorists interpret the displays and respond to the reduced speed limits posted, and their ease of use within a highway work zone.

Do Slower Speeds Improve Safety?

It is generally perceived that slowing down traffic in a work zone improves the overall safety of the work zone. Such claims are based predominantly on common sense recognition that slower vehicle speeds increase the time available for the motorist to react to any surprises in the work zone, reduce required stopping distances, and allow for more significant evasive maneuvers to be executed without further loss of vehicle control. Slower speeds past the work area also reduce wind and vacuum effects of large trucks (there are multiple anecdotal stories in industry of large trucks blowing hard hats off of workers and into active travel lanes, for example). Finally, slower vehicle speeds would presumably allow greater time for workers to move out of the way should an errant vehicle enter the workspace, and also reduce the likelihood of severe injury to workers and motorists should a crash occur.

Logically, crashes are likely to be more severe at higher operating speeds than if speeds are reduced, simply because there is more kinetic energy that has to be dissipated during the crash. However, it is not clear whether the use of reduced speed limits themselves are sufficient to drop vehicle speeds enough to significantly reduce the probability of a severe injury should an accident with a vehicle occur. In addition, vehicle crash statistics across roadway types suggest that actual operating speeds do not have a strong correlation with crash frequency (*23*). Rather, it is the variance in speed between vehicles that appears to have the greater effect on crashes (i.e., the greater the variability in vehicle speeds the greater the crash risk) (*23*,*24*,*25*,*26*). In other words, traffic moving along at a steady pace, albeit a fast one, may be safer than attempting to slow down traffic by reducing the speed limit since this can increase the variability in speeds (i.e., some drivers reduce their speed while others do not). Consequently, reducing vehicle speeds too dramatically or too quickly can sometimes reduce safety if it increases the variability in speeds between vehicles in the work zone.

How Do Motorists Drive in Work Zones?

Previous research (*27*,*28*,*29*) shows that the majority of motorists reduce their speed as they enter a work zone, further reduce their speed near the work activity, and then increase their speed after they pass the work activity and exit the work zone. The amount of speed reduction is highly variable, but typically only a small percentage of motorists reduce their speed by large amounts. Thus, throughout the work zone most motorists are still exceeding the speed limit.

A limited number of surveys conducted during that earlier NCHRP work did find that over 90 percent of drivers believed that lane closures were locations where drivers should reduce their speed (*17*). Conversely, only 25 percent of motorists believed that speed limit reductions for roadside activities were needed or justified. The perceived need for speed limit reductions for other work zone conditions and factors were less conclusive, no doubt in part to the small sample size collected. Nevertheless, the low levels of compliance with reduced work zone speed limits reported in a number of studies suggests that many conditions, factors, and combinations thereof now used to warrant lower speed limits are not perceived by motorists as justifying the need for slower speeds (*30*,*31*).

Research has shown enforcement to be the most effective method of speed control available in work zones (*18*,*19*). In a work zone, reduced speed limits that correspond to motorist perceptions that reduced speeds are necessary would be less likely to need enforcement activity since actual travel speeds and the reduced work zone speed limit would be more closely aligned. On the other hand, work zones where motorists do not adequately perceive the hazard factors that are used to justify a reduced speed limit would be those in most need of enforcement, since motorists would be less likely to reduce their speeds voluntarily.

Given the fact that reduced speed limits can be justified in a large majority of work zones according to the conditions and factors listed in Table 1, it is apparent that the potential need for enforcement typically outstrips funding and manpower availability if drivers do not actually reduce their speeds in response to those reduced speed limits. Although many speed reduction technologies and enforcement surrogates have been tested over the years, most have been shown to have only a limited effect on driver behavior (*18,30,32,33,34,35*). In those same studies, one often finds dismally-low compliance rates with the work zone speed limits at their study sites, an indication of the extent to which the reduced speed limits and driver perceptions of the need to slow down are incongruous. Undoubtedly, an improved understanding of the relationship between factors used to justify reduced work zone speed limits and motorist perceptions of the need to reduce their speed could improve the speed limit selection process. In turn, this could also raise the credibility of all work zone traffic control devices with the public.

CONTENTS OF THIS REPORT

This report describes the methodology and results of analyses conducted to: 1) improve existing guidance and procedures on establishing and managing work zone speed limits, and 2) identify and evaluate new technologies and strategies that can be used to better manage work zone speed limits. Because of the duality in research project purpose, this report has been prepared in two distinct parts. Part 1 addresses the research tasks and results pertaining to the guidance and procedures on establishing and managing work zone speed limits, and Part 2 addresses the new technologies and strategies assessment.

PART 1 – GUIDELINES AND PROCEDURES ON ESTABLISHING AND MANAGING WORK ZONE SPEED LIMITS

CHAPTER 1.1:
CURRENT WORK ZONE SPEED LIMIT PRACTICE IN TEXAS

INTRODUCTION

As discussed previously, TxDOT has procedures for establishing regulatory speed limits in work zones *(4,16)*. These procedures allow for the speed limit in a work zone to be reduced by up to 10 mph under certain conditions, if one or more factors believed to justify the need for a lower speed limit are present. In order to determine the most common work zone conditions, factors, and combinations thereof currently being used as reasons to reduce the speed limit in work zones, Texas Transportation Institute (TTI) researchers conducted telephone interviews with 54 TxDOT personnel. At least one person from each TxDOT district was interviewed. Topics discussed included the following:

- current process used to determine the need for a speed limit reduction,
- work zone conditions and factors used to justify a speed limit reduction (in general),
- opinions about the current process,
- number and locations of existing work zones with speed limit reductions in their district,
- work zone conditions and factors used to justify each project's speed limit reduction, and
- speed limit reduction in place for each identified project.

Researchers also reviewed 51 requests for reduced speed limits in work zones received by the TxDOT Traffic Operations Division (TRF) between April 2006 and September 2006. Typically, the only documentation for these requests was TxDOT Form 1204 Request for Construction Speed Zone *(36)* (see Appendix A). However, this form does not specifically require documentation of the reasons used to justify the speed limit reduction; thus, in most cases TxDOT TRF personnel, through a review of plans or direct communication, identified and documented only the primary reason for the need for a reduced speed limit. In some cases, additional information, such as a letter explaining the need for the request or traffic control plans, was also available for review. Still, for a majority of the requests, researchers were unable to determine the work zone condition and if any additional factors, other than the primary one documented by TxDOT TRF, were present.

It should be noted that the interviews and review of projects documented in this chapter occurred at the beginning of the research project. Throughout the project TxDOT TRF personnel kept researchers abreast of the current TxDOT practice. Therefore, the following section contains the results from the interviews, review of projects, and communication between researchers and TxDOT TRF personnel throughout the duration of the project.

RESULTS

Most districts use the TxDOT Work Zone Speed Limit Worksheet (*16*) that is part of the set of Standard Plans maintained by TxDOT TRF to determine if there is a need for a reduced speed limit in a work zone (see Appendix B). In addition, the districts rely on safety team reviews, engineering judgment, input from the project engineer, and input from design personnel. The majority of the personnel interviewed believed that the current process works reasonably well and stated that they try to minimize the use of work zone speed limit reductions. A few districts mentioned discrepancies between TxDOT's work zone speed limit policy and the desires of contractors and law enforcement agencies. Specifically, some district personnel noted that contractors prefer to have the work zone speed limit apply to the entire length of the work zone instead of only in the immediate vicinity of the work activity. In addition, several districts commented that law enforcement agencies prefer longer term work zone speed limits over short term work zone speed limits that change more often.

The TxDOT Work Zone Speed Limit Worksheet (*16*) contains the following seven work zone conditions: roadside activity, shoulder activity, lane encroachment, moving activity on shoulder, lane closure, temporary diversion, and centerline or lane line encroachment. For the roadside activity and moving activity on shoulder conditions, no speed limit reduction is recommended. For all other conditions, a maximum allowable speed limit reduction of 10 mph may be used where at least one of the listed factors exists. Factors include:

- workers present close to or in the roadway and not protected by barrier;
- horizontal curvature that might increase vehicle encroachment rate;
- barrier or pavement edge drop off within 2 ft of traveled way;
- reduced design speed for stopping sight distance, taper length, speed change lane length, horizontal curvature, or detour;
- lane width reduction of 1 ft or more resulting in a lane width less than 11 ft;

- traffic control devices encroaching on an open travel lane or within a closed lane but within 2 ft of the edge of the open travel lane;
- traffic congestion; and
- unexpected conditions.

Not all of these factors are listed under each work zone condition. Larger reductions are allowed where work zone geometrics with reduced design speeds cannot be avoided or where unusual situations create hazardous conditions for motorists, pedestrians, or workers.

Based on the 51 requests for reduced work zone speed limits received by TxDOT TRF and information regarding the 31 projects identified by TxDOT personnel in the telephone interviews, researchers computed the percentage of projects for which each of the work zone conditions was the primary condition used to justify a reduced speed limit. Researchers also computed the percentage of projects for which each factor was present. Table 2 and Table 3 contain the percentages for the conditions and factors, respectively. While the work zone condition could not be determined for almost one half of the projects, it is evident that lane closures and temporary diversions are the most prominent work zone conditions where reduced speed limits are requested. As mentioned previously, the current TxDOT procedure does not recommend a speed limit reduction for roadside activities unless unusual situations create hazardous conditions for motorists, pedestrians, or workers. The implementation of reduced speed limits for the two roadside activity projects shown in Table 2 was due to a high number of crashes that occurred within the work zone prior to the speed reduction.

As shown in Table 3, workers present close to or in the roadway and not protected by barrier occurred in 21 percent of the projects with reduced work zone speed limits. Similarly, reduced design speed and changes in roadway alignment for lane shifts, detours, etc. were present in 20 percent of the projects. Current TxDOT work zone speed limit procedures note that the work zone speed limit should not exceed the design speed, even if this requires a speed limit reduction greater than 10 mph. TxDOT is currently working hard to reduce the use of lower design speeds for temporary diversions, lane shifts, etc. so that the speed limit does not have to be reduced for this reason alone.

Table 2. Percentage of Reduced Speed Limit Requests by Type of Work Zone Condition.

Work Zone Condition	Percent of Projects
Roadside activity	2%
Shoulder activity	2%
Lane encroachment	7%
Moving activity on shoulder	0%
Lane closure	25%
Temporary diversion	22%
Centerline or lane line encroachment	0%
Unknown	42%

Table 3. Percentage of Reduced Speed Limit Requests by Type of Work Zone Factor Present.

Work Zone Factor	Percent of Projects [a]
Unprotected workers	21%
Reduced design speed and changes in alignment (e.g., lane shifts, detours, etc.)	20%
Lane width reduction	16%
Barrier or pavement edge drop off	13%
Unexpected conditions	9%
Horizontal curvature that might increase vehicle encroachment rate	2%
Traffic control device encroachment	0%
Traffic congestion	0%
Low profile concrete barrier	1%
Miscellaneous	2%
Unknown	15%

[a] Percentages do not total 100 percent since multiple factors existed in more than one project.

Other factors typically present included: lane width reductions (16 percent), barrier or pavement edge drop off (13 percent), and unexpected conditions (9 percent). Unexpected conditions included work zones where a four-lane divided highway was converted to a two-lane, two-way roadway in one of the original directions of travel, as well as the use of temporary traffic signals to control one-way traffic on two-lane, two-way roadways.

Many contractors prefer to use low profile concrete barrier (LPCB) instead of regular concrete traffic barrier (CTB) because it is less expensive. However, it is only approved as a NCHRP Report 350 test level 2 (TL-2) barrier (*37*), which means it has only been approved for roadways where the highest impact speeds are expected to be in the 45 mph range or less. For several years, TxDOT TRF was receiving requests for speed reductions greater than 10 mph to accommodate the use of LPCB on high-speed roadways. However, as previously noted, numerous studies have shown that just posting a reduced speed limit by itself will not slow drivers down. Drivers will only reduce their speeds through the work zone if they clearly perceive a need to do so. Anecdotal evidence indicated that the LPCB was not resulting in driver decisions to reduce their speeds significantly, and so the operating speed on these facilities during construction tended to remain above 45 mph. Consequently, TxDOT is no longer allowing the speed limit to be reduced down to 45 mph for the use of LPCB on roadways with operating speeds greater than 55 mph.

The majority of the projects reviewed (84 percent) implemented a 10 mph speed limit reduction in the work zone. In contrast, only 5 percent of the projects reduced the speed limit by 5 mph. While a speed limit reduction of 5 mph may be used in lieu of the maximum allowable speed reduction (10 mph), it seems that the maximum amount is the one typically requested by TxDOT personnel.

Eleven percent of the projects had 15 mph speed limit reductions. These larger reductions were justified due to reduced design speeds for work zone geometrics (e.g., temporary diversions) or crash rates. At the end of this research project, TxDOT TRF was approving requests for 15 mph reductions for the following three reasons: 1) temporary traffic signals to control one-way traffic on two-lane, two-way roadways, 2) an asphalt roadway that will be gravel during construction, and 3) a high number of crashes (exactly what constitutes a "high" number of crashes is not currently specified, however).

Of the 31 projects identified by TxDOT personnel in the telephone interviews, 52 percent were supposed to be implemented as short term work zone speed limits (i.e., reduced speed limit only in effect when work activity is present). However, 81 percent of these projects did not cover or remove the work zone speed limit signs at the end of the work period. Thus, the reduced work zone speed limit remained in effect even though the work activity was not present.

Again, TxDOT personnel noted that pressure from contractors or law enforcement agencies influenced these actions.

SUMMARY

Overall, the conditions and factors used by TxDOT districts to justify reduced speed limits in work zones do follow the current TxDOT procedures. However, the districts find it fairly easy to justify a reduced speed limit based on the current procedures. In addition, while a speed limit reduction of 5 mph may be used in lieu of the maximum allowable speed reduction (10 mph), it seems that the maximum amount is the one typically requested by TxDOT personnel. Since 2005, TxDOT has worked hard to change personnel's philosophy about reducing work zone speed limits. However, differences between TxDOT's work zone speed limit policy and the desires of contractors and law enforcement continually plague how work zone speed limits are ultimately managed, especially with respect to the implementation of short term work zone speed limits.

CHAPTER 1.2:
MOTORIST PERCEPTIONS AND REACTIONS TO REDUCED WORK ZONE SPEED LIMITS AND OTHER WORK ZONE CONDITIONS

INTRODUCTION

The low levels of compliance with reduced work zone speed limits reported in a number of studies indicates the extent to which the reduced speed limits and motorist perceptions of the need to slow down are incongruous. In a work zone, reduced speed limits that correspond to motorist perceptions that reduced speeds are necessary would be less likely to need enforcement activity since actual travel speeds and the reduced work zone speed limit would be more closely aligned. On the other hand, work zones where motorists do not adequately perceive the hazard factors that are used to justify a reduced speed limit would be those in most need of enforcement, since motorists would be less likely to reduce their speeds voluntarily. Undoubtedly, an improved understanding of the relationship between factors used to justify reduced work zone speed limits and motorist perceptions of the need to reduce their speed could improve the speed limit selection process. However, which factors are actually perceived as more hazardous by motorists and therefore result in slower speeds are still not well understood. As part of this research project, TTI researchers designed and conducted motorist surveys and field studies to determine motorist perceptions and reaction to the factors and factor combinations used to justify reduced speed limits in work zones.

MOTORIST SURVEYS

Survey Instrument

Researchers developed a survey to obtain insight into motorists' opinions of reduced speed limits in work zones and their perceptions of the hazards present within work zones. Researchers administered the survey verbally and recorded the participants' responses on the survey form. After collecting some basic demographic information about each participant, researchers asked the following four questions.

- What percentage of the time do you spend driving through work zones? (Answer selected from four predetermined choices.)

- What percentage of these work zones has a speed limit lower than the normal posted speed limit? (Answer selected from four predetermined choices.)
- Under what work zone conditions do you feel that you need to slow down when driving through a work zone? (This question was first asked as an open-ended question and then followed up with a list of specific factors.)
- Do you feel that reduced speed limits in work zones improve safety? Why or why not?

Survey Locations

In the summer of 2007, researchers conducted the motorist surveys at Texas Department of Public Safety (DPS) offices in the following cities: Laredo, Lubbock, Paris, and Waco. Two of the survey sites (Laredo and Paris) were located in TxDOT districts that have reduced speed limits in 10 percent or less of their work zones and two of the survey sites (Lubbock and Waco) were located in TxDOT districts that have reduced speed limits in 90 percent or more of their work zones. Researchers used the 2006 work zone speed limit reduction requests received by TxDOT TRF and the number of "let" projects in 2007 to estimate the percent of the "let" projects in each district with work zone speed limit reductions. In addition, these sites were chosen in order to obtain a statewide representative sample.

Demographics

In each office, researchers recruited participants who were in line to take their driving test or who had brought someone in to take the test and were waiting for that person to finish; however participation was on a volunteer basis only. Researchers did not actively recruit to meet specific demographic criteria, but did attempt to obtain a range of participant age and education levels. A total of 476 drivers participated in the surveys across the four district locations. The survey took approximately five minutes to complete and the participants did not receive any compensation for completing the survey.

Table 4 summarizes the overall demographic distributions achieved. The subject sample consisted of slightly more females, younger drivers, and more educated drivers than was reported for the Texas driving population as a whole (*38,39*). Even so, it is believed that the results obtained from this study do represent Texas drivers reasonably well overall.

Table 4. Subject Demographics for Work Zone Speed Limit Motorist Survey.

	Gender		Age			Education			
	M	**F**	**18-39**	**40-54**	**55+**	**< HS**	**HS Grad**	**Some College**	**College Grad**
Survey Sample	45%	55%	52%	33%	15%	6%	30%	35%	29%
Texas Data (*38,39*)	50%	50%	44%	31%	25%	22%	27%	26%	25%

Results

Initially researchers hypothesized that the results would differ between the locations with a larger number of projects with reduced work zone speed limits and those with a smaller number. However, the results showed no evidence of such trends. Thus, only the overall data are reported herein.

Figure 1 shows that 44 percent of the participants thought that they spend less than one-fourth of the time driving through work zones. Another 35 percent thought they spend one-fourth to one-half of the time driving through work zones, while only 10 percent indicated they drove through work zones more than three-fourths of the time.

Although the majority of the participants thought they drove through work zones less than half of the time, 66 percent of the participants thought that the speed limit was reduced in more than half of all work zones (Figure 2). This is not surprising since based on the current TxDOT procedures reduced speed limits are warranted in a large majority of work zones.

Table 5 contains the percentage of participants that would slow down for various work zone conditions. When participants were not prompted, 43 percent stated they would slow down when workers were present and 37 percent indicated they slow down in all work zones. Interestingly, less than 10 percent of the subjects voluntarily mentioned that they would slow down for several of the conditions and factors currently used to justify reduced speed limits in work zones (i.e., lane closures, detours, narrow lanes, pavement edge drop off, and concrete barrier). When asked about specific work zone conditions, 96 percent or more stated they would slow down for all of the work zone conditions listed except workers behind barrier (85 percent of drivers would slow down) and workers located way off of the roadway (only 51 percent of drivers would slow down).

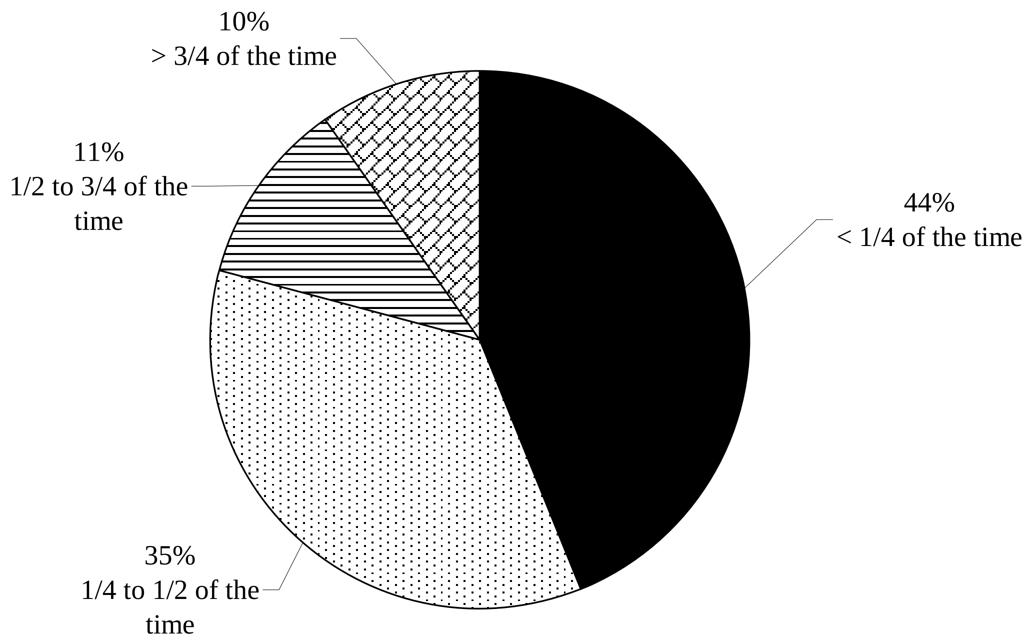


Figure 1. Percent of the Time Spent Driving in Work Zones.

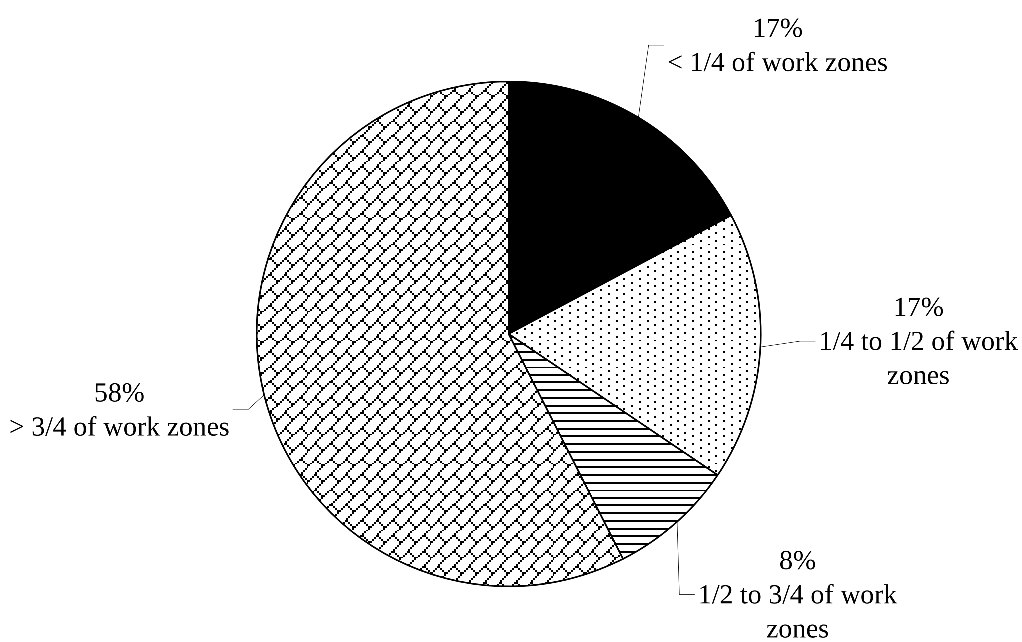


Figure 2. Percent of Work Zones with Reduced Speed Limits.

Table 5. Work Zone Conditions for which Motorists Would Slow Down.

Work Zone Condition/Factor	Percent of Participants that Would Slow Down	
	Open-Ended Answers	Directly Asked Answers
All work zones	37%	NA
Workers present - In road - Near road - Behind barrier - Way off the road	43%	 99% 99% 85% 51%
Lane closures	3%	98%
Detours	1%	96%
Lane shifts	0%	98%
Narrow lanes	3%	97%
Pavement edge drop off	0%	98%
Concrete barrier	7%	NA
Rough road	5%	97%
Heavy equipment	7%	NA
Truck crossing	1%	NA

NA = Not Applicable

Overall, 98 percent of the participants thought that reduced speed limits in work zones improve safety. The main reasons provided included: allows for better control of vehicle and provides more time for motorists to react (69 percent), helps protect workers and motorists (19 percent), and decreases risk of crashes (14 percent). However, approximately 20 percent of the participants commented that there should not be a speed limit reduction when work activity is not present.

FIELD STUDIES

Study Design

Researchers conducted field studies in Texas work zones to determine motorists' reactions to the conditions, factors, and combinations thereof currently used by TxDOT to warrant reduced speed limits. While it would have been desirable to collect data for every possible condition/factor combination shown in Table 1, this could not be feasibly accomplished within the time and budget constraints of the project. Instead, researchers selected work zones with reduced speed limits that contained the condition/factor combinations commonly used by TxDOT personnel to justify reduced speed limits in work zones (refer to Table 2 and Table 3).

At each work zone, researchers used hand held LIDAR speed measurement equipment to collect the speed of free flow vehicles at multiple locations (e.g., a control location upstream of the work zone, downstream of the reduced work zone speed limit sign, near specific hazards used to justify the speed limit reduction, near the end of the work zone, etc.). At each data collection location, researchers collected the speed of a minimum of 125 passenger vehicles. Researchers did collect some commercial vehicle speed data; however, since similar sample sizes could not be obtained at all of the data collection locations across all of the work zones, researchers did not utilize the commercial vehicle speed data in the analysis. Data were collected in both directions, when applicable, on weekdays during non-peak periods under favorable weather conditions. Depending on the work activity (day or night work, long/intermediate term or short term work zone speed limits, etc.) and traffic volumes at each site, data were collected during the day, at night, or both during the day and at night.

During data collection, researchers also monitored and documented any erratic maneuvers that occurred, as well as the presence of any law enforcement in the vicinity. Researchers also contacted the local law enforcement office with responsibility to patrol at each site to gather additional insights into the amount of enforcement that typically occurred. Researchers documented the site characteristics on a written standardized data collection form, with global positioning system (GPS) equipment and associated software, in photographs, and with drive-through videos. If needed, researchers obtained and reviewed traffic control plans from TxDOT.

Study Locations

As shown in Table 6, researchers collected data during the day at 12 work zones in Texas. At all but one of these sites, researchers collected data in both directions of travel. At three of the sites researchers also collected data at night. Overall, researchers collected the speed of 17,683 vehicles at 138 locations. Consistent with the findings in Chapter 1.1, the majority of these work zones had work zone speed limits 10 mph below the normal non-work zone speed limit. The other sites either had a 5 mph or 15 mph speed reduction for the work zone.

Table 6. Field Study Locations and Characteristics.

Site No.	City or County	District	Road	Direction	Time of Day	No. of Nodes	Non-Work Zone Speed Limit (mph)	Work Zone Speed Limit (mph)	Speed Reduction (mph)	Enforcement Present?
1	Littlefield	Lubbock	US 84	EB	Day	8	70	60	10	Yes
				WB	Day	7	65	60	5	
2	Edmonson	Lubbock	SH 194	EB	Day	2	70	60	10	No
				WB	Day	4	70	60	10	
3	Amarillo	Amarillo	I-40	EB	Day	7	70	60	10	No
					Night	4	65	60	5	
				WB	Day	5	70	60	10	
4	College Station	Bryan	SH 6	NB	Day	9	70	55	15	Yes
					Night	6	65	55	10	
				SB	Day	8	70	55	15	
					Night	6	65	55	10	
5	Huntsville	Bryan	SH 30	EB	Day	4	60	50	10	No
6	Waco	Waco	SL 340	NB	Day	4	60	45	15	No
				SB	Day	6	60	45	15	
7	Waco	Waco	I-35	NB	Day	3	70	60	10	No
				SB	Day	3	65	60	5	
8			SL 340	EB	Day	3	60	45	15	No
				WB	Day	3	60	50	10	
9	Waco	Waco	FM 2113	NB	Day	3	60	50	10	No
				SB	Day	4	60	50	10	
10	Hillsboro	Waco	I-35	NB	Day	9	70	60	10	No
				SB	Day	5	70	60	10	
					Night	2	65	60	5	
11	Burleson	Fort Worth	I-35	NB	Day	5	65	55	10	Yes
				SB	Day	5	65	55	10	
12	Parker/ Palo Pinto	Fort Worth	I-20	EB	Day	6	70	60	10	No
				WB	Day	7	65	60	5	

US = United States; SH = State Highway; I = Interstate; SL = State Loop; FM = Farm-to-Market; EB = Eastbound; WB = Westbound; NB = Northbound; SB = Southbound; Nodes = Data Collection Locations

The 15 mph reductions were justified due to a high number of crashes (site 4) or a limited access roadway being diverted onto a frontage road (site 6 and site 8).

As shown in Table 7, the study sites included three of the five work zone conditions for which the speed limit may be reduced (i.e., lane encroachment, lane closure, and temporary diversion). In addition, many of the factors used to warrant reduced speed limits in work zones were present.

Data Reduction and Analysis

At each site, researchers computed the following descriptive statistics for each data collection location: sample size, mean speed, variance, standard deviation, 85th percentile speed, and the percent of vehicles exceeding the speed limit. Appendix C contains these descriptive statistics. Researchers did not use statistical analysis to determine if there were significant differences between the mean speed, variance, and percent of vehicles exceeding the speed limit at each site. Instead, researchers utilized the 85th percentile speed (i.e., operating speed) to assess motorists' reaction to various work zone condition/factor combinations. Speed reductions were computed as the difference between the 85th percentile normal operating speed of the roadway (measured upstream of the work zone) and the 85th percentile speed at the work zone condition/factor combinations of interest.

Results

Speed Characteristics Upstream of Work Zone

First, researchers reviewed the 85th percentile speed data collected upstream of the work zones to identify trends in normal operating speeds on the facilities. As shown in Figure 3, independent of the posted speed limit motorists tend to drive 0 to 10 mph over the speed limit. At half of the sites the 85th percentile speed was more than 5 mph over the speed limit. This higher tolerance range led to normal operating speeds as high as 68 mph, 75 mph, and 77 mph on roadways with 60 mph, 65 mph, and 70 mph posted speed limits, respectively.

Table 7. Conditions and Factors Used to Justify Speed Limit Reductions at Field Study Locations.

Site No.	Direction	Order of Conditions and Factors Encountered by Motorists			
		First	Second	Third	Other
1	EB	RLC	TD (main lanes) (50)	Unexpected condition [a]	
	WB	LLC	Unexpected condition [a]		
2	EB	Lane shift	Lane encroachment Workers unprotected near traveled way Pavement edge drop off Narrow lanes TCD encroachment		
	WB	Lane shift			
3	EB	RLC	TD (main lanes) (45)	Barrier w/in 2 ft of inside lane	
	WB	LLC	Barrier w/in 2 ft of inside lane		
4	NB	Unexpected condition [b]	TD (frontage road) (55)		LLC [d]
	SB	TD (frontage road) (55)	Unexpected condition [b]		
5	EB	RLC	TD (main lanes) (50)		
6	NB	LLC	TD (frontage road) (50)	Unexpected condition [c]	
	SB	TD (frontage road) (50)	Unexpected condition [c]		
7	NB SB	Barrier w/in 2 ft of inside lane			LC [e]
8	EB	TD (frontage road) (50)	Unexpected condition [b]		
	WB	TD (frontage road) (50)			
9	NB	Lane shift	Lane encroachment Workers unprotected near traveled way Pavement edge drop off Narrow lanes TCD encroachment		
	SB	Narrow lanes			
10	NB SB	Unexpected condition [b] Barrier w/in 2 ft of inside lane			LLC [f]
11	NB SB				LC [e]
12	EB	LLC	Barrier w/in 2 ft of inside lane		
	WB	RLC	TD (main lanes) (45)	Barrier w/in 2 ft of inside lane	

RLC = Right Lane Closure; LLC = Left Lane Closure; TCD = Traffic Control Device; LC = Lane Closure
TD (main lanes) (#) = Temporary Diversion onto opposite direction main lanes (design speed)
TD (frontage road) (#) = Temporary Diversion onto frontage road (design speed)
[a] Crossing traffic.
[b] Construction entrances.
[c] Intersections and driveways.
[d] LLC in temporary diversion on one day of data collection, workers unprotected in closed lane.
[e] Speed reduction for lane closures, but none were present during data collection.
[f] Speed reduction for lane closures, one present during nighttime data collection, workers unprotected in closed lane.

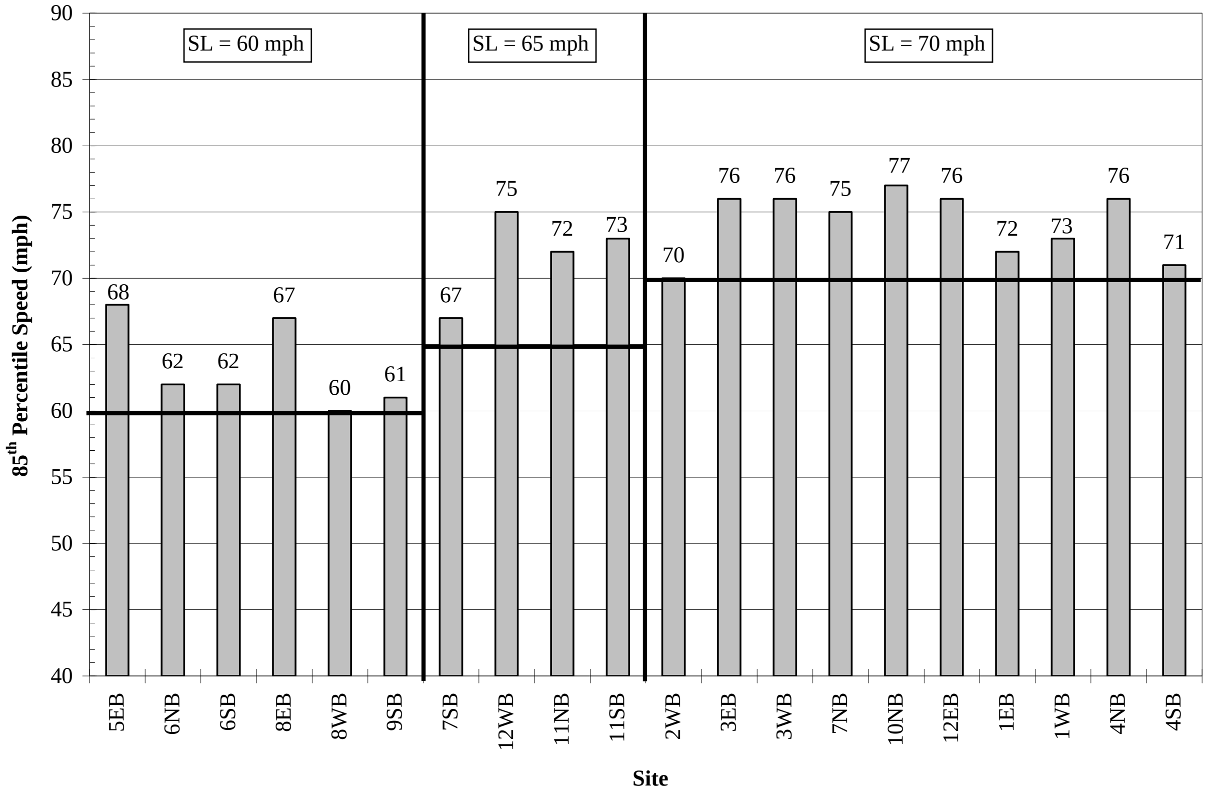


Figure 3. 85th Percentile Speeds Upstream of the Work Zone.

Speed Characteristics Downstream of Work Zone Speed Limit

Next, researchers compared the normal operating speed of the roadway upstream of the work zone to the operating speed downstream of the reduced work zone speed limit to determine whether simply lowering the speed limit effected motorist's speed choice. Researchers did not include sites where the first work zone speed limit sign was in close proximity to another work zone condition (e.g., lane closure, temporary diversion, etc.), in order to isolate the effects of the work zone speed limit sign itself.

Figure 4 shows that in general the 85th percentile speed decreased downstream of the work zone speed limit (WZSL) sign. At two sites (2WB and 12EB) there was no change in the 85th percentile speed, while at one site an increase occurred (7SB). Four of the sites (11NB, 11SB, 1EB, and 4NB) had active enforcement within the work zone on the day of data collection. In addition, at two of these sites (1EB and 4NB) law enforcement actively patrolled the work zone on a daily basis throughout the duration of the project. Nevertheless, a large speed reduction (10 mph) downstream of the work zone speed limit sign was only achieved at one of these sites (4NB), and even with this large speed reduction the operating speed was still 11 mph over the reduced speed limit.

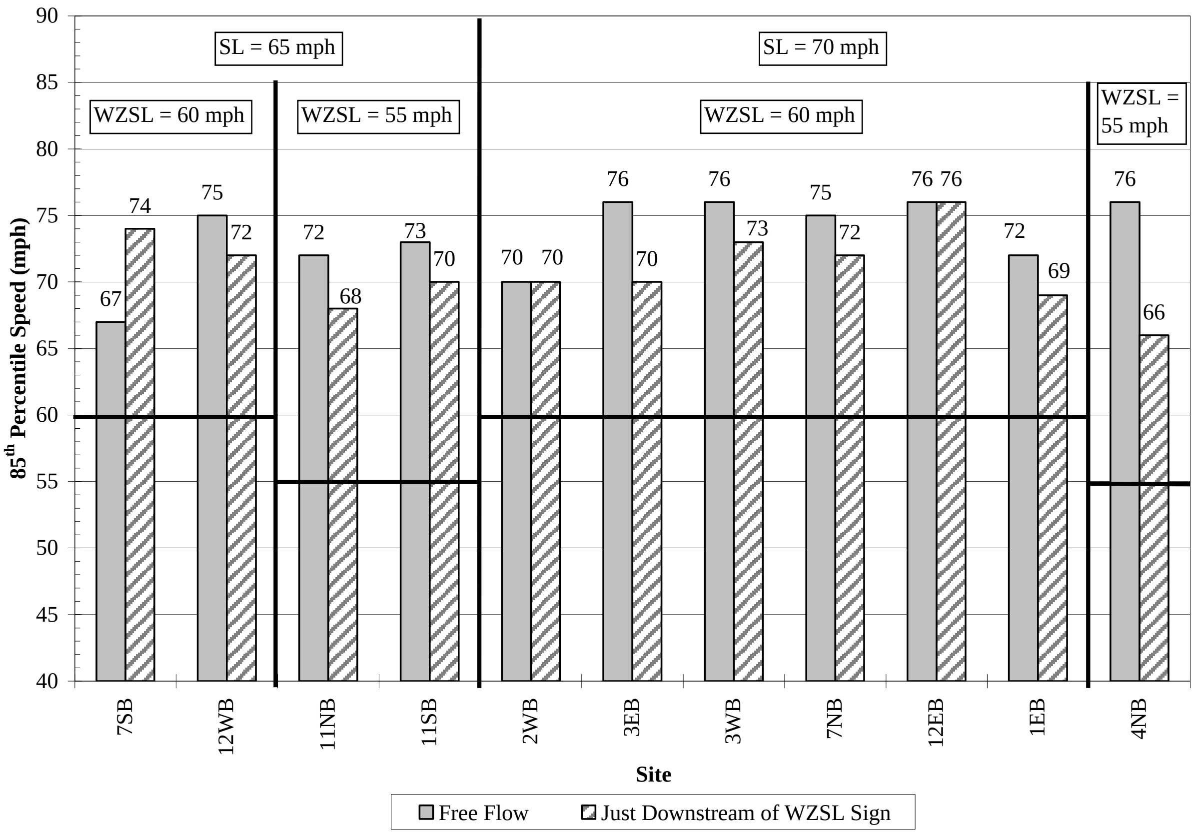


Figure 4. 85th Percentile Speed Changes Downstream of the Reduced Work Zone Speed Limit.

Removing the sites that had active enforcement, the reduction in speed downstream of the work zone speed limit ranged from 0 to 6 mph and averaged 3 mph (if one considers the increase in speed at site 7SB an anomaly). In addition, at all but one of the sites the speed reduction downstream of the work zone speed limit was 3 mph or less. While the 85th percentile speed downstream of the work zone speed limit did decrease slightly, the operating speeds were still

9 to 16 mph over the reduced work zone speed limit. These findings are consistent with previous research (*27*,*28*).

Overall, it does appear that motorists slightly decrease their speed downstream of the work zone speed limit. However, since the normal operating speeds on these facilities were typically more than 5 mph over the normal non-work zone speed limit (Figure 3), the small speed reductions (3 mph on average) still resulted in 85th percentile speeds 9 to 16 mph over the reduced work zone speed limit. In addition, the small speed reductions occurred at sites with speed limit reductions of 5 and 10 mph; thus, when no other work zone conditions are present it does not appear that motorists utilized the amount of the speed limit reduction to determine how much they should reduce their speed.

Speed Characteristics at Sites with Lane Encroachment

Currently in Texas, a maximum speed reduction of 10 mph may be used when activities encroach upon the area from the edge of the traveled way to 2 ft from the edge of the traveled way (i.e., lane encroachment). Researchers collected speed data at two sites with lane encroachment (site 2 and site 9) that had 10 mph work zone speed limit reductions (70 mph reduced to 60 mph and 60 mph reduced to 50 mph, respectively). Both of these sites were two-lane roadways where one direction of travel had been shifted onto the shoulder and the other direction was traveling in the opposite direction's original travel lane. The lane encroachment work activity was on one side of the road only and included the following work zone factors that can currently be used to justify a reduced work zone speed limit:

- unprotected workers,
- pavement edge drop off within 2 ft of a travel lane,
- narrow lanes (10 ft), and
- cones encroaching into the travel lane.

Researchers felt that this combination of factors represented a worst case scenario.

Table 8 shows the speed changes that occurred at two sites with lane encroachment. At site 2 the work zone factors were actually adjacent to or in the opposite direction of travel (i.e., eastbound). The speed change in the eastbound direction could not be computed because there was not a safe place for researchers to collect speed data upstream of the work zone. However, since the roadway upstream of the work zone was similar in both directions and the 85th percentile speeds in both directions were 65 mph, researchers felt that the westbound data accurately reflected motorists' driving behavior in both directions. Similarly at site 9 the work zone factors were actually adjacent to or in the opposite direction of travel (i.e., northbound); however, in the southbound direction the lanes were also less than 11 ft wide.

Table 8. 85th Percentile Speed Changes at Lane Encroachment.

Site	Data Collection Location 1		Data Collection Location 2			Speed Change L1-L2 (mph)
	Description	85th Percentile Speed (mph)	Description	Work Zone Factor(s)	85th Percentile Speed (mph)	
2WB	Upstream of WZ (SL=70)	70	LE (WZSL=60)	UW [a] PEDO [a] NL [a] TCDE [a]	65	-5
9SB	Upstream of WZ (SL=60)	61	LE (WZSL=50)	UW [a] PEDO [a] NL [a,b] TCDE [a]	60	-1

WZ = Work Zone; SL = Speed Limit; LE = Lane Encroachment; UW = Unprotected Workers; PEDO = Pavement Edge Drop Off; NL = Narrow Lanes; TCDE = Traffic Control Device Encroachment

[a] Work zone factor was adjacent to or in the opposite direction of travel.

[b] Work zone factor was in the direction of travel.

Based on the speed change data in Table 8, it appears that motorists decrease their speed adjacent to lane encroachment situations by a greater amount when the normal operating speed upstream of the work zone is higher. Adjacent to the lane encroachment at site 2, the 5 mph speed reduction resulted in the 85th percentile speed (65 mph) being within 5 mph of the work zone speed limit (60 mph). In contrast, the 1 mph reduction at site 9 did not practically change the operating speed. Thus, the 85th percentile speed next to the lane encroachment was equal to the non-work zone speed limit, but 10 mph over the work zone speed limit.

Based on these findings, it seems that a maximum speed reduction of 5 mph would be more applicable for lane encroachments with unprotected workers, pavement edge drop off within 2 ft of a travel lane, lane widths reduced to 10 ft, and traffic control devices encroaching into the travel lane. Furthermore, it may not be necessary to reduce the speed limit even by 5 mph if operating speeds are already near or below 60 mph.

Speed Characteristics at Sites with Lane Closures

Lane closure activities are those that encroach upon the area between the centerline and the edge of the traveled way. Currently in Texas, a maximum speed reduction of 10 mph may also be used for lane closures. Researchers collected speed data at four sites with lane closures. At two of the sites (site 3 and site 12), in one direction of travel (3WB and 12EB) a left lane closure was in place to reduce the number of open lanes from two to one. In the opposite direction of travel (3EB and 12WB) traffic was reduced from two lanes to one lane using a right lane closure and then diverted through a crossover into the left lane of the opposite direction of travel (3WB and 12EB). Along the two-lane, two-way section of roadway, the two directions of the travel were separated by concrete barrier that was within 2 ft of the travel lanes. At site 3, the speed limit was reduced from 70 mph to 60 mph for the work zone (a 10 mph speed limit reduction). This was also the case in the eastbound direction at site 12. However, in the westbound direction at site 12, the speed limit was only reduced by 5 mph, since the normal non-work zone speed limit was 65 mph. Based upon a review of the speed reduction data, the critical influence point (data collection location with the largest speed change) was after the left lane closure in the two-lane, two-way section for sites 3WB and 12EB, and in the crossover for sites 3EB and 12WB.

The third site (5EB) was similar to the first two sites; however, researchers only collected data in the direction of travel with a right lane closure followed by crossover. The work zone speed limit was 10 mph below the normal non-work zone speed limit (60 mph reduced to 50 mph). At this site, researchers considered the critical influence point to be in the crossover.

At the fourth site (4NB) the left lane closure was actually in a crossover that diverted both of the main lanes off of the original roadway onto a frontage road using an existing exit ramp that had been widened. During data collection, the left lane was closed just upstream of the temporary diversion, throughout the diversion, and along the frontage road where commercial vehicles parked in the closed lane to unload bridge piers. Unprotected workers and construction equipment were located in the lane closure on the frontage road. The work zone speed limit for this construction project (55 mph) was implemented approximately 9 miles upstream of the lane closure at the beginning of an adjacent construction project that did not involve active work in the travel lanes nor did it require any roadway alignment changes, but it had experienced a high number of crashes. Regular active enforcement within the adjacent construction project resulted in a large speed reduction throughout the project. Therefore at this site, comparisons utilized the 85th percentile speed immediately upstream of the lane closure instead of upstream of the work zone to determine the speed changes. At this site, researchers considered the critical influence point to be after the left lane closure adjacent to workers.

Table 9 shows the speed changes that occurred at the four sites with lane closures. At site 3 and site 12 where operating speeds were very high approaching the work zone, the 85th percentile speed at the critical influence points decreased by 7 to 10 mph, showing that motorists do decrease their speed when they encounter an apparent need to do so. These speed reductions resulted in 85th percentile operating speeds between 66 and 69 mph. While these operating speeds are still more than 5 mph over the reduced work zone speed limit (60 mph), they are similar to the "tolerance" levels drivers were traveling at upstream of the work zone.

It should be noted that design speed of the temporary diversions (i.e., crossovers) was 45 mph. A higher design speed may have resulted in smaller speed reductions. However, then the critical influence points would have been located after the crossovers in the two-lane, two-way sections (similar to the opposite direction of travel). While not included in Table 9, the speed reductions at these two points were 7 and 9 mph (for 12WB and 3EB, respectively) which are similar to those in the opposite direction of travel that did not encounter a temporary diversion. Thus, the controlling factor seems to be the two-lane, two-way operations with concrete barrier separating the opposite directions of travel.

While site 5 had similar characteristics (i.e., a right lane closure followed by crossover), the lower initial operating speed (68 mph) and higher temporary diversion design speed (50 mph) resulted in a lower speed reduction (4 mph). Since the operating speed upstream of the work zone (68 mph) was 8 mph over the normal non-work zone speed limit (60 mph), and the speed reduction was small (4 mph) compared to the speed limit reduction (10 mph), the 85th percentile speed in the crossover (64 mph) was 14 mph over the work zone speed limit (50 mph). If the speed limit had not been reduced (i.e., remained at 60 mph), the operating speed in the crossover would have been within 5 mph of the speed limit (assuming the same reduction in speed would have occurred regardless of the speed limit posted).

Table 9. 85th Percentile Speed Changes at Lane Closures.

Site	Data Collection Location 1		Data Collection Location 2			Speed Change L1-L2 (mph)
	Description	85th Percentile Speed (mph)	Description	Work Zone Factor(s)	85th Percentile Speed (mph)	
3WB	Upstream of WZ (SL=70)	76	LLC (WZSL=60)	2L2W BS	66	-10
12EB	Upstream of WZ (SL=70)	76	LLC (WZSL=60)	2L2W BS	69	-7
3EB	Upstream of WZ (SL=70)	76	RLC (WZSL=60)	TD (DS=45)	68	-8
12WB	Upstream of WZ (SL=65)	75	RLC (WZSL=60)	TD (DS=45)	66	-9
5EB	Upstream of WZ (SL=60)	68	RLC (WZSL=50)	TD (DS=50)	64	-4
4NB	Upstream of LLC & TD (SL=55)	65	LLC & TD [a] (WZSL=55) (DS=55)	UW	58	-7
4NB	Upstream of LLC & TD (SL=55)	65	LLC & TD [a] (WZSL=55) (DS=55)	--	63	-2

WZ = Work Zone; SL = Speed Limit; LLC = Left Lane Closure; RLC = Right Lane Closure; 2L2W = Two-Lane, Two Way; BS = Barrier Separated; TD = Temporary Diversion; DS = Design Speed; UW = Unprotected Workers (no barrier)
-- No work zone factors present.
[a] Two northbound main lanes were being diverted onto frontage road. During data collection, the left lane was closed just upstream of the temporary diversion, throughout the diversion, and along the frontage road.

Again, researchers do not know whether a higher design speed (e.g., one equal to the normal speed limit) would have impacted speed choice, but it is assumed that a higher design speed would produce an even smaller speed change. If this were the case, the critical influence point would have been located after the crossovers in the two-lane, two-way section where no traffic control devices or barrier were used to separate the two directions of travel. While not included in Table 9, the speed reduction at this point was equal to the speed reduction at the crossover; thus, motorists did not further reduce their speed once in the two-lane, two-way section. Since the operating speeds adjacent to the concrete barrier in the two-lane, two-way sections for site 3 and site 12 were all greater than 65 mph, researchers do not think that the use of concrete barrier between opposing travel directions at site 5 would have led to further speed reductions (considering the operating speed was already less than 65 mph).

At site 4, the 85^{th} percentile speed adjacent to unprotected workers and equipment in the closed lane (58 mph) was 7 mph less than the 85^{th} percentile speed immediately upstream of the lane closure. Again, it appears that motorists do decrease their speed when they encounter a perceived apparent need to do so (i.e., the presence of workers and equipment operating right next to the open travel lane). While data were not collected at sites with more than one travel lane remaining open, researchers believe that the speed reductions adjacent to the work activity would have been less since motorists would have more room to maneuver.

Researchers also collected data when the lane closure was in place but no work activity was occurring in the closed lane (i.e., between deliveries of the bridge piers). The last row of Table 9 shows these data. Similar to the findings at site 5, when workers were not present the lane closure and temporary diversion did not result in a large speed reduction (2 mph).

Based on the results in Table 9, it seems that a maximum speed reduction of 10 mph is justified on roadways with higher operating speeds when the work zone traffic control plan includes: 1) lane closures or crossovers to temporarily divert traffic, and 2) traffic traveling on a two-lane, two-way roadway section with concrete barrier within 2 ft of the travel lanes. However, these same conditions do not seem to justify a reduced speed limit when the existing speed limit is less than 65 mph. At all operating speeds, a 10 mph maximum speed reduction seems reasonable when workers are in a closed lane unprotected by barrier and only a single travel lane remains open in the work zone.

Speed Characteristics at Sites with Temporary Diversions

Currently in Texas, a maximum speed reduction of 10 mph may also be used for activities requiring a temporary diversion to be “constructed.” Data for “constructed” temporary diversions (i.e., crossovers) were discussed in conjunction with the lane closure data above.

Researchers collected speed data at two sites with temporary diversions that used existing exit ramps with some modifications (e.g., extended pavement, widened width to accommodate two lanes, etc.). While these temporary diversions were not "constructed," researchers wanted to investigate their impacts on motorists' speed choice.

At the first site (site 6) only one lane of traffic was diverted onto the frontage road. In the southbound direction, upstream of the temporary diversion there was only one lane of traffic since this section of roadway was a two-lane, two-way facility. In the northbound direction, the roadway was a four-lane divided facility; thus, a left lane closure was used to reduce the number of open lanes from two to one prior to entering the temporary diversion. At site 6, the speed limit (60 mph) was not reduced for the temporary diversion. At the second site (site 8) temporary diversions were used in both directions of travel to divert two main lanes of traffic from the original roadway to the frontage road. Similar to site 6, the speed limit (60 mph) at site 8 was not reduced for the temporary diversion.

Table 10 shows that the speed changes at these sites were mixed. Negligible speed changes occurred on facilities with operating speeds upstream of the work zone closer to 60 mph. While a 3 mph reduction occurred at the site with the highest operating speed upstream of the work zone, this speed decrease did not result in an operating speed lower than the normal speed limit. Overall, these data imply that a speed limit reduction is not needed prior to temporary diversions that utilize existing exit ramps and have design speeds of at least 50 mph. The impact on speed choice with these same types of temporary diversions with lower design speeds is not known.

Speed Characteristics at Sites with Unexpected Conditions

"Unexpected conditions" are listed as a factor that can be used to justify a speed limit reduction in work zones. As the name implies, these conditions are not always readily apparent to motorists. Researchers collected data at three sites where "unexpected conditions" were used to justify a reduced speed limit. At the first site (site 10) the work activity was in the median between the two directions of travel and concrete barrier was used to separate the work activity from the active travel lanes. At various locations there were openings in the concrete barrier to allow for construction vehicles to enter and exit the work area. At these entrances trucks would have to slow down in the left lane (which was open to traffic) before turning into the work area. The speed limit at site 10 was reduced from 70 mph to 60 mph.

Table 10. 85th Percentile Speed Changes at Temporary Diversions.

Site	Data Collection Location 1		Data Collection Location 2			Speed Change L1-L2 (mph)
	Description	85th Percentile Speed (mph)	Description	Work Zone Factor(s)	85th Percentile Speed (mph)	
6NB	Upstream of WZ (SL=60)	62	TD (SL=60) (DS=50)	--	60	0
6SB	Upstream of WZ (SL=60)	62	TD (SL=60) (DS=50)	--	63	+1
8EB	Upstream of WZ (SL=60)	67	TD (SL=60) (DS=50)	--	64	-3

SL = Speed Limit; TD = Temporary Diversion; DS = Design Speed
-- No work zone factors present.

At the second site (site 4) the temporary diversion of a limited access facility onto a frontage road resulted in what work zone designers judged to be unexpected conditions (e.g., driveways, intersections, turning traffic, etc.) that warranted a reduced speed limit. As discussed previously, the 15 mph speed limit reduction (70 mph to 55 mph) at this site was warranted based on the occurrence of a high number of crashes in an adjoining project, and the work zone was actively patrolled by law enforcement on a daily basis.

At the third site (site 1) a four-lane divided facility was converted to a two-lane, two-way facility using lane closures and crossovers; however, since this was not a limited access facility motorists crossing over the roadway under construction had to watch for traffic from both directions before proceeding whereas prior to construction motorists only crossed one direction of travel at a time. Local law enforcement actively enforced the speed limit at site 1 which was reduced from 70 mph to 60 mph.

Table 11 shows that while a 6 mph speed reduction occurred at site 10, the operating speed adjacent to one of the active construction entrances was still 11 mph over the work zone speed limit (60 mph). This is not surprising since the "unexpected condition" of trucks entering and exiting the work area was not readily apparent to motorists unless they were directly impacted by a truck entering or exiting the traffic stream. In contrast, at the sites where enforcement was used on a regular basis to emphasize the need to slow down (site 1 and site 4), 85th percentile speeds at the "unexpected condition" locations decreased by 10 to 18 mph. At site 1, these speed reductions resulted in operating speeds lower than the work zone speed limit (60 mph). While the operating speed at site 4 was still 6 mph over the work zone speed limit, it was closer to the work zone speed limit than the operating speed at the site without enforcement. Overall, these data support the theory that when the hazardous condition used to justify a reduced speed limit is not readily apparent to motorists, they are less likely to reduce their speeds voluntarily. Therefore, work zones where motorists do not adequately perceive the hazardous condition would be those most in need of enforcement.

Table 11. 85th Percentile Speed Changes at Unexpected Conditions.

Site	Data Collection Location 1		Data Collection Location 2			Speed Change L1-L2 (mph)
	Description	85th Percentile Speed (mph)	Description	Work Zone Factor(s)	85th Percentile Speed (mph)	
10NB	Upstream of WZ (SL=70)	77	CE (WZSL=60)	UC	71	-6
4SB	Upstream of WZ (SL=70)	71	FR (WZSL=55)	UC	61	-10
1EB	Upstream of WZ (SL=70)	72	2L2W (WZSL=60)	UC	54	-18
1WB	Upstream of WZ (SL=60)	73	2L2W (WZSL=60)	UC	57	-16

WZ = Work Zone; SL = Speed Limit; CE = Construction Entrance; FR = Frontage Road;
UC = Unexpected Conditions; 2L2W = Two-Lane, Two-Way

Short Term Work Zone Speed Limits

All of the work zones included in the field studies used long term work zone speed limits; thus, the reduced speed limit was in effect 24 hours a day, seven days a week. However, at three sites (site 7, site 10, and site 11) there were no restricted geometrics or other conditions readily apparent to motorists for the speed limit reductions. Discussions with TxDOT personnel confirmed that the reduced speed limits were requested and granted since lane closures with unprotected workers were used at various times throughout the projects' durations. While TxDOT initially planned to implement short term work zone speed limits only when the lane closures were in place, long term work zone speed limits had been implemented instead due to the desires of local law enforcement for the reduced speed limit to always be in effect.

As shown in Table 12, the 85th percentile speed at these sites typically decreased downstream of the reduced work zone speed limit and then practically remained the same adjacent to the roadside work activity even though at some sites concrete barrier was located within 2 ft of the inside lane. Researchers believe that the concrete barrier had less of an effect on motorists' speed choice at these sites since more than one travel lane was open; thus, the motorists were not as "restricted" by the concrete barrier (as compared to two-lane, two-way operations with barrier dividing opposing directions of travel). All of the operating speeds throughout the work zones remained above 65 mph, which is well above the reduced speed limits. Obviously, motorists did not perceive a need to slow down to the posted work zone speed limit since the work activity was removed from the active travel lanes and there was no other apparent hazard.

As discussed previously, at site 11 the ingress and egress of construction trucks entering the work area (i.e., "unexpected condition") was another valid reason for implementing reduced speed limits. When there was no work activity present and thus trucks were not using the construction entrances, the reduced work zone speed limit could have been removed. In addition, when the reduced work zone speed limit was in effect for the "unexpected condition" law enforcement should have been used to actively enforce it.

Overall, short term work zone speed limits should have been utilized at all three of these sites (as initially planned). However, it appears that differences between TxDOT's work zone speed limit policy and law enforcement's speed limit philosophies seem to be hindering the implementation of short term work zone speed limits. TxDOT needs to educate law enforcement about their work zone speed limit policy and offer solutions that both agencies can use to better manage and enforce short term work zone speed limits.

Table 12. 85th Percentile Speed Characteristics at Sites that Should Have Implemented Short Term Work Zone Speed Limits.

Site	Data Collection Location Description	Speed Limit (mph)	85th Percentile Speed (mph)
7NB	Upstream of WZ	70	75
	Downstream of WZSL	60	72
	Roadside work activity [a]	60	73
7SB	Upstream of WZ	65	67
	Downstream of WZSL	60	74
	Roadside work activity [a]	60	70
10NB	Upstream of WZ	70	77
	Downstream of WZSL	60	70 [b]
	Roadside work activity [a,c]	60	71
	Roadside work activity [a]	60	74
10SB	Upstream of WZ	70	76 [d]
	Downstream of WZSL	60	71
	Roadside work activity [a,c]	60	71
11NB	Upstream of WZ	65	72
	Downstream of WZSL	55	68
	No work activity	55	73
	Roadside work activity	55	71
11SB	Upstream of WZ	65	73
	Downstream of WZSL	55	70
	Roadside work activity	55	67
	No work activity	55	69

[a] Barrier within 2 ft of the inside travel lane.
[b] Data collection site in horizontal curve. The angle at which speed data were collected may have produced lower speeds than actually present.
[c] Adjacent to construction entrance.
[d] Average of data collected on I-35W and I-35E.

SUMMARY

Motorist Survey

Overall, 66 percent of the motorists surveyed thought that the speed limit was reduced in more than half of all Texas work zones. This is not surprising based on the many conditions, factors, and combinations thereof now used to justify the reduced speed limits in work zones.

While 98 percent of the participants thought that reduced speed limits in work zones improve safety, they prefer that the speed limit reduction be removed when no work activity is present.

Since numerous studies have shown low levels of compliance with reduced work zone speed limits, some may question whether the participants would actually slow down for the work zone conditions addressed. However, the survey results only indicate that the participants would slow down from their normal operating speed for these work zone conditions. This does not necessarily imply that they would slow down to the posted work zone speed limit. Nonetheless, the survey results do suggest that motorists are aware of the potential hazards present in work zones and believe that they adjust their speeds accordingly when they encounter such hazards.

Field Studies

Surprisingly, at half of the field study sites the 85^{th} percentile speed upstream of the work zone was 5 to 10 mph over the normal non-work zone speed limit. Consistent with previous research, in general the 85^{th} percentile speeds downstream of a reduced work zone speed limit sign decreased slightly (on average by 3 mph); however, the operating speeds were still 9 to 16 mph over the work zone speed limit. In addition, the speed reduction downstream of the work zone speed limit sign was fairly consistent across the sites although the sites included both 5 and 10 mph speed limit reductions. Therefore when no other work zone conditions are present, it does not appear that motorists utilized the amount of the speed limit reduction to judge how much they should reduce their speed.

Researchers observed motorists' driving behavior (i.e., speed choice) adjacent to several work zone condition/factor combinations currently used to justify reduced speed limits in work zones. Based on the results of the field studies, researchers concluded the following.

- A 5 mph maximum speed reduction is more applicable for lane encroachment conditions with unprotected workers, pavement edge drop off within 2 ft of a travel lane, lane widths reduced to 10 ft, and traffic control devices encroaching into the travel lane. Furthermore, it may not be necessary to reduce the speed limit even by 5 mph if operating speeds are already near or below 60 mph.
- Even though data were not collected for shoulder activities, researchers expect that motorists' speed choice would be similar to those found next to lane encroachment situations.

- Independent of operating speed, a 10 mph maximum speed reduction is warranted when workers are in a closed lane unprotected by barrier and only a single lane remains open in the work zone. When more than one travel lane will remain open, speed reductions less than 10 mph should be considered.
- For lane closures where unprotected workers is not a factor, a 10 mph maximum speed reduction is justified on roadways with existing speed limits greater than or equal to 65 mph when the lane closure results in only a single lane remaining open and concrete barrier is within 2 ft of the travel lane. However these same conditions do not seem to justify a reduced speed limit when the existing speed limit is less than 65 mph. In addition, reduced speed limits do not seem warranted for lane closures on roadways with existing speed limits greater than or equal to 65 mph when more than one travel lane remains open (and unprotected workers is not a factor).
- A 10 mph maximum speed reduction is justified on roadways with existing speed limits greater than or equal to 65 mph when the work zone traffic control plan includes a "constructed" temporary diversion (i.e., crossover) and traffic traveling on a two-lane, two-way roadway with concrete barrier within 2 ft of the travel lanes. However these same conditions do not seem to justify a reduced speed limit when the existing speed limit is less than 65 mph.
- A speed limit reduction is not needed prior to temporary diversions that utilize existing exit ramps and have design speeds of at least 50 mph.
- Some hazardous work zone conditions used to justify reduced speed limits in work zones (e.g., construction entrances, turning traffic, crash history, etc.) are not adequately perceived by motorists and thus are in the most need of enforcement since motorists are less likely to reduce their speeds voluntarily.
- Differences between TxDOT's work zone speed limit policy and law enforcement's speed limit philosophies are hindering the implementation of short term work zone speed limits. TxDOT should educate state and local law enforcement agencies about their work zone speed limit policy and offer solutions that both agencies can use to better manage and enforce short term work zone speed limits.

CHAPTER 1.3:
NATIONAL COMPARISON OF WORK ZONE SPEED LIMIT LAWS

INTRODUCTION

The Texas legislature has established prima facie speed limits on all public roadways in Texas. Recognizing that the prima facie speed limits are not always appropriate for specific roadway conditions, the Texas legislature has assigned the Texas Transportation Commission the authority to set regulatory speed limits for specific roadway segments. This authority is defined in Section 545.353 of the Texas Transportation Code, the relevant parts of which are presented in Figure 5 below (*3*).

As noted in subsection (a), the law only allows the Texas Transportation Commission to establish a prima facie speed limit on a section of roadway by means of an order documented in the meeting minutes of the Commission. Consequently, speed limits can only be changed when the Commission meets. Furthermore, the subsection refers to “a” prima facie speed limit (singular tense), which indicates that only one speed limit can be defined at a time for a given roadway segment through the Commission minute order process.

Theoretically, a reduced speed limit could be changed during the time a work zone is in place if a second request was taken to the Commission and once again approved in its meeting minutes. However, the practicality of preparing multiple speed limit reduction requests and then timing their submission to the Commission to match up with changes in work zone conditions is very limited. As a result, a speed limit reduction request is normally based on the worst-case conditions that are anticipated to exist at any time while the work zone is in place. Then, the reduced speed limit sign is either left covered until the time that the worst-case conditions occur in the work zone, or established as a long term speed limit that remains in place for the duration of the work zone. This latter approach is almost mandated if there is any need for a second, smaller speed limit reduction any other time during the course of work activities at the site. For example, TxDOT might perceive the need for only a 5 mph reduction in the speed limit most of the time in a work zone where the lane widths have been reduced slightly, but desire a 10 mph speed limit reduction during times when work crews are at the site and in close proximity to traffic moving through the work zone. Under current Texas law, TxDOT would be forced to request a 10 mph speed limit reduction for those times when the workers are present, and either leave that reduction up at other times (even though a 5 mph speed limit reduction would be more applicable), or leave the normal speed limit in place during the times when no work activity is present (although a 5 mph reduction may be desired for reduced lane widths) and then post the 10 mph reduced speed limit only during those hours when workers are present.

§ 545.353. AUTHORITY OF TEXAS TRANSPORTATION COMMISSION TO ALTER SPEED LIMITS.

(a) If the Texas Transportation Commission determines from the results of an engineering and traffic investigation that a prima facie speed limit in this subchapter is unreasonable or unsafe on a part of the highway system, the commission, by order recorded in its minutes, and except as provided in Subsection (d), may determine and declare:
   (1) a reasonable and safe prima facie speed limit; and
   (2) another reasonable and safe speed because of wet or inclement weather.

(b) In determining whether a prima facie speed limit on a part of the highway system is reasonable and safe, the commission shall consider the width and condition of the pavement, the usual traffic at the affected area, and other circumstances.

(c) A prima facie speed limit that is declared by the commission under this section is effective when the commission erects signs giving notice of the new limit. A new limit that is enacted for a highway under this section is effective at all times or at other times as determined.

.
.
.

(e) The commission, in conducting the engineering and traffic investigation specified by Subsection (a), shall follow the "Procedure for Establishing Speed Zones" as adopted by the commission. The commission may revise the procedure to accommodate technological advancement in traffic operation, the design and construction of highways and motor vehicles, and the safety of the motoring public.

(f) The commission's authority to alter speed limits applies:
   (1) to any part of a highway officially designated or marked by the commission as part of the state highway system; and
   (2) both inside and outside the limits of a municipality, including a home-rule municipality, for a limited-access or controlled-access highway.

(g) For purposes of this section, "wet or inclement weather" means a condition of the roadway that makes driving on the roadway unsafe and hazardous and that is caused by precipitation, including water, ice, and snow.

Figure 5. Texas Transportation Code Excerpts Regarding Speed Limits *(3)*.

Texas law does specifically authorize TxDOT to remove or cover reduced work zone speed limit signs when they are not needed, thereby returning the speed limit to its pre-work zone value, as shown in Figure 6.

> § 201.907. REMOVING OR COVERING SIGNS IN CONSTRUCTION OR MAINTENANCE WORK ZONE.
>
> (a) In this section, "construction or maintenance work zone" has the meaning assigned by Section 472.022.
>
> (b) The department shall remove or cover or require the removal or covering of a sign that restricts the speed limit in a construction or maintenance work zone during any period when no hazard exists that dictates the need for a restricted speed limit.

Figure 6. Texas Statutes Regarding Covering of Work Zone Speed Limit Signs.

SPEED LIMIT RESTRICTIONS IN OTHER STATES

Authorization to Use Variable Speed Limits

Other states appear to have more flexibility in how they establish regulatory speed limits. A number of states (Delaware, Indiana, Virginia, and Washington) have specific language that allows variable speed limits (VSLs) to be displayed, if desired (Table 13). Delaware, Virginia, and Washington each have specific roadways where variable speed limits have been implemented.

Although the language is fairly consistent across the four states shown, it should be noted that no such language exists in the statutes for two other states (Missouri and Tennessee) which also allow variable speed limits on part of its roadway system (Table 14). In Missouri, the transportation and highway commission is granted authority to reduce the speed limits, but without the minute order requirement that exists in Texas law. In Tennessee, the Department of Transportation (DOT) is empowered to modify speed limits on roadways, although the transportation commissioner must issue a policy statement regarding the reduced speed limit that is to be placed in effect once appropriate signs are installed. Presumably, such statements can be issued at any time without the need for any type of formal meeting. (Tennessee does not have multiple transportation commissioners, making scheduled meetings where business of this nature can be formally addressed unnecessary.)

Table 13. Statutes in VSL States Explicitly Authorizing VSLs.

State and Statute or Code	Relevant Sections
Delaware (Title 21, Chapter 41, Subchapter VII) *(40)*	The Department shall declare a reasonable and safe maximum limit thereat, which limit shall be effective when posted. *Such maximum limit may be declared to be effective either part or all of the time and differing limits may be established for different times of the day, for different types of vehicles, for different weather conditions and when other significant factors differ. Such maximum limits may be posted on fixed or variable signs*.
Indiana (Title 9, Article 21, Chapter 5) *(41)*	A maximum speed limit under this section may be declared to be effective at all times or at times indicated on the signs. *Differing limits may be established for different times of day, different types of vehicles, varying weather conditions, and other factors bearing on safe speeds. The differing limits are effective when posted on appropriate fixed or variable signs*.
Virginia (Title 46.2, Chapter 8, Section 881) *(42)*	The Commonwealth Transportation Commissioner is expressly *authorized to establish and indicate variable speed limits on such structures or roadways to be effective under such conditions as would in his judgment, warrant such variable limits, including but not limited to darkness, traffic conditions, atmospheric conditions, weather, emergencies, and like conditions which may affect driving safety*. Any speed limits, whether fixed or variable, shall be prominently posted in such proximity to such structure or roadway as deemed appropriate by the Commonwealth Transportation Commissioner.
Washington (Title 46, Chapter 61, Section 400) *(43)*	*(A) maximum speed limit may be declared to be effective at all times or at such times as are indicated upon the said signs; and differing limits may be established for different times of day, different types of vehicles, varying weather conditions, and other factors bearing on safe speeds, which shall be effective (a) when posted upon appropriate fixed or variable signs.*

Table 14. Statutes in VSL States without Explicit Authorization of VSLs.

State and Statute or Code	Relevant Sections
Missouri (Chapter 304, Section 304.010)*(44)*	On any state road or highway where the speed limit is not set pursuant to a local ordinance, the highways and transportation commission may set a speed limit higher or lower than the uniform maximum speed limit provided in subsection 2 of this section, if a higher or lower speed limit is recommended by the department of transportation. The department of public safety, where it believes for safety reasons, or to expedite the flow of traffic a higher or lower speed limit is warranted, may request the department of transportation to raise or lower such speed limit, except that no speed limit shall be set higher than seventy miles per hour.
Tennessee (Title 55, Chapter 8, Section 153) *(45)*	The department of transportation is empowered to lower the speed limits prescribed in § 55-8-152 in business, urban or residential districts, or at any congested area, dangerous intersection *or whenever and wherever the department shall determine, upon the basis of an engineering and traffic investigation, that the public safety requires a lower speed limit*. Engineering and traffic investigations used to establish special speed zone locations and speed limits by municipalities on state highways shall be made in accordance with established traffic engineering practices and in a manner that conforms to the Tennessee manual on uniform traffic control devices (MUTCD). The investigations shall be documented and documentation shall be maintained by the jurisdiction performing or sponsoring the investigation. When the department shall determine that it is necessary to reduce the speed limits set in subsection (a), the commissioner shall so indicate the reduced speed limit via a letter of policy statement, and the commissioner shall cause signs indicating the new speed limit to be erected.

Based on these examples, one could conclude that it is the Texas Transportation Commission meeting minute order requirement to alter speed limits in Texas law that is most constraining when attempting to adjust work zone speed limits to conditions as they are changed over the course of a project. One way in which this constraint could be overcome would be for the Texas legislature to grant TxDOT authority to determine and post appropriate speed limits in work zones, separate from the way that speed limits are established for normal, non-work-zone conditions. In fact, this is the approach that has been taken by Oklahoma *(46)*. Oklahoma law is very similar to Texas law in that the state highway commission is authorized to establish speed limits for most situations. However, a special statute targeted specifically at work zone speed limits has been included to allow the DOT itself to determine the appropriate speed limit in a work zone and to post that speed limit without formal approval by the commission (Figure 7).

> §47-11-802. ESTABLISHMENT OF STATE SPEED ZONES.
>
> Whenever the *State Highway Commission shall determine* upon the basis of an engineering and traffic investigation that any maximum speed hereinbefore set forth is greater or less than is reasonable or safe under the conditions found to exist at any intersection or other place or upon any part of the state highway system, said *Commission may determine and declare a reasonable and safe maximum limit thereat which, when appropriate signs giving notice thereof are erected, shall be effective at all times, or during hours of daylight or darkness or at such other times as may be determined* at such intersection or other place or part of the highway.
>
> 46-11-806. Special Speed Restrictions
>
> C. Where any state or federal highway or turnpike shall be under construction, maintenance, or repair or when a detour shall have been designated by reason of construction, maintenance, or repairs in progress and *a maximum safe, careful, and prudent speed shall have been determined by the Oklahoma Department of Transportation* on the highway or highway detour or by the Oklahoma Transportation Authority on the turnpike or turnpike detour during the period of the construction, maintenance, or repairs *and shall have plainly posted at each terminus thereof and at not less than each half mile along the route thereof the determined maximum speed*, no person shall drive any vehicle upon the portion of the highway or the highway detour or upon the portion of the turnpike or the turnpike detour at a speed in excess of the speed so determined and posted.

Figure 7. Speed Limit Statutes in Oklahoma *(46)*.

As another example of how some states accommodate reduced speed limits in work zones, Minnesota law normally requires the transportation commissioner to authorize a speed limit based on the results of a traffic and engineering investigation *(47)*. However, this requirement is explicitly waived for work zone situations, as shown in Figure 8.

169.14 SPEED LIMITS, ZONES
Subd. 4. **Establishment of zones by commissioner.** On determining upon the basis of an engineering and traffic investigation that any speed set forth in this section is greater or less than is reasonable or safe under the conditions found to exist on any trunk highway or upon any part thereof, *the commissioner may erect appropriate signs* designating a reasonable and safe speed limit thereat, *which speed limit shall be effective when such signs are erected*.

Subd. 5d. **Speed zoning in work zone; surcharge.** (a) The commissioner, on trunk highways and temporary trunk highways, and local authorities, on streets and highways under their jurisdiction, may authorize the use of reduced maximum speed limits in highway work zones. *The commissioner or local authority is not required to conduct an engineering and traffic investigation before authorizing a reduced speed limit in a highway work zone.*

Figure 8. Speed Zoning Statutes in Minnesota (*47*).

SUMMARY

Relative to several other states, current Texas law is fairly restrictive in terms of establishing reduced speed limits in work zones. Most of the difficulties lie in the need to establish a single speed limit on a roadway segment through an order documented in the meeting minutes of the Texas Transportation Commission. Whereas current law allows TxDOT to deactivate a work zone speed limit when not needed (by removing or covering the sign that designates the lower speed limit), it does not provide TxDOT with the flexibility to easily accommodate changes in geometrics or traffic conditions that occur as a highway project is completed.

It does appear that changes to the current code would be needed to provide additional flexibility to TxDOT to address changing conditions in a work zone through changes in a reduced work zone speed limit. Several other states have recognized the need for this flexibility and have laws on their books to grant the DOT or its representative the authority to determine and post appropriate work zone speed limits. Given that a precedent has been set, TxDOT should consider requesting legislative action to grant authority to the Executive Director or his designee to establish work zone speed limits, rather than the Texas Transportation Commission.

PART 2 – ALTERNATIVE WORK ZONE SPEED LIMIT DEVICES

CHAPTER 2.1: IDENTIFICATION OF ALTERNATIVE WORK ZONE SPEED LIMIT DEVICES

INTRODUCTION

According to the TxDOT Barricade and Construction (BC) Standard Sheets (*21*), the use of short term work zone speed limits is appropriate when work activity is within 15 ft of the pavement edge or actually on the pavement and workers or equipment are not behind concrete barrier. In these situations, short term work zone speed limits should be posted and visible to motorists only when work activity is present, and should only be posted in the vicinity of the work activity, not throughout the entire project.

When work activity is not present, the short term work zone speed limit signs should be removed or covered; thereby allowing the legal speed limit for that segment to revert back to the normal non-work zone speed limit. Turning signs from view or laying signs over or down is not an allowable method of indicating that the short term work zone speed limit is not in effect.

It is important to recognize that the daily install/remove or uncover/cover process of signs represents an additional task for the contractor that reduces overall work productivity. In addition, the potential exists for the contractor to forget or simply choose not to cover or remove signs. In effect, the failure to cover or remove the signs turns the short term limit into a long/intermediate one and further reduces the credibility of TxDOT's work zone speed limit procedures with the public.

Recently, vendors have developed and are marketing internally illuminated and other types of signs that will allow a reduced regulatory speed limit to be displayed during portions of the day or night when work activity is occurring, and the normal non-work zone regulatory speed limits to be displayed when the reduced speed limit is no longer applicable. Such a device would simplify the short term work zone speed limit implementation process and could lead to a greater use of short term work zone speed limits in general. Thus, during the first year of the research project TTI researchers identified and critiqued alternative technologies for better managing short term work zone speed limits. Based on these findings, researchers made recommendations for further evaluations.

ALTERNATIVE DEVICES

The alternative work zone speed limit devices identified and critiqued by researchers were grouped into three categories: portable static speed limit signs, electronic speed limit (ESL) signs, and various other technologies. The following sections describe these categories in more detail.

Portable Static Speed Limit Signs

In Indiana, trailer-mounted static speed limit signs with flashing beacons are used to indicate reduced speed limits in work zones (Figure 9). This device's portability allows it to be easily moved along with the work activity; therefore, potentially reducing the occurrence of installing work zone speed limit signs throughout the entire project. When the beacons are flashing, the reduced speed limit is in effect. When the beacons are not flashing, the reduced speed limit is not in effect (i.e., the normal non-work zone speed limit is in effect.)

This concept is similar to the use of flashing beacons in school zones to indicate when reduced school zone speed limits are in effect. However, according to the Texas Transportation Code *(22)*, a work zone speed limit sign can only be made inoperative by removing or covering the sign. Thus, Texas law does not currently allow for flashing beacons to be used to indicate whether or not a short term work zone speed limit is in effect. In addition, previous research *(48)* found that this device produced mixed results with respect to reducing speeds. In 2007, these devices cost approximately $4000 (including everything shown in Figure 9 plus two additional speed limit signs).

Figure 9. Example of Portable Static Speed Limit Sign Used in Indiana.

Flexible reflective roll-up work zone warning signs (diamond shape) are used extensively in Texas for short term stationary and short duration operations due to their ease of use (can quickly be installed/removed and are more portable). Interestingly, TTI researchers identified a few vendors that currently sell flexible roll-up speed limit signs (Figure 10). In 2008, these signs cost approximately $175 each (does not include sign stand).

Figure 10. Example of Flexible Roll-up Work Zone Speed Limit Sign.

Another potential static technology explored by researchers was STOP/SLOW automated flagger assistance devices (AFADs). Via remote operation, these devices can either display a STOP sign or a SLOW sign to approaching motorists. Researchers talked with multiple vendors about retrofitting and/or redesigning AFADs for the display of two speed limit signs (normal non-work zone and reduced work zone speed limits) in order to more easily change between the two speed limits and eliminate the need to remove or cover the signs each day. However, without extensive changes to the typical AFAD design this could not be easily accomplished. In addition, further adaptations would be required if the use of a third speed limit sign (i.e., nighttime non-work zone) was needed. Researchers could not obtain a cost estimate since this application of an AFAD was not readily available.

Electronic Speed Limit Signs

In the past 10 years, the desire to use variable speed limits under normal traffic conditions, as well as in work zones, has increased in the United States. To help implement variable speed limits, vendors developed ESL signs. There are two types of ESL signs: static signs with internally illuminated changeable numbers (Type 1) and fully illuminated speed limit signs (Type 2). Figure 11 shows these two types of ESL signs, respectively.

a) Type 1 **b) Type 2**

Figure 11. Examples of the Two Types of ESL Signs.

Several vendors sell Type 1 ESL signs; however, currently only a few of these vendors readily offer trailer-mounted versions. Type 1 ESL signs are typically comprised of a standard speed limit sign (R2-1) with white or orange light emitting diodes (LEDs) that display numbers from zero to 99. The LEDs may be white or orange according to the Texas MUTCD (*14*). Even though the number display is dimmed at night, the internally illuminated numbers tend to be visible before the retroreflective “SPEED LIMIT” legend.

In 2007, researchers only identified one vendor of Type 2 ESL signs. At that time, the Type 2 ESL sign could display a 48 by 60 inch reverse screen speed limit sign (white LEDs on a black background). Per a letter from the Federal Highway Administration (FHWA) (*49*), the Type 2 ESL sign conforms to the requirements of the MUTCD Chapters 2A and 2B (*50*); thus, no experimentation is necessary. The Type 2 ESL sign displays 18 inch numbers from zero to 99. The main advantage to the Type 2 ESL sign is that the whole sign is internally illuminated; so at night the “SPEED LIMIT” legend and numbers are visible at the same time.

Both types of ESL signs allow for the posted speed limit to be adjusted without having to physically change the sign. Thus, ESL signs can be used to more easily change between the reduced work zone speed limit, normal non-work zone daytime speed limit, and normal non-work zone nighttime speed limit (when needed). However, the process by which this is accomplished varies between vendors. While some Type 1 ESL signs can be controlled manually at the device, most are designed to be remotely controlled via wireless communication (e.g., pager, cell phone, personal digital assistants [PDAs], webpage interface). Permanent installations can also use hard wire connections (e.g., dial-up, fiber, Ethernet, etc.). Some of the Type 1 ESL signs also include a scheduling feature similar to those used to control flashing beacons on school zone speed limit sign assemblies. In theory, personnel could create a speed limit schedule for a highway project for a given time period (e.g., week, month, year, etc.); however, unlike school zones highway work activity periods vary from day to day (e.g., begin or end earlier or later than planned, cancelled due to weather, etc.).

A Bluetooth™ enabled PDA with special software must be used to communicate with the Type 2 ESL sign. A speed limit schedule must be developed on a desktop computer, transferred to the PDA, and then uploaded to speed limit sign. More than one speed limit schedule may be created and personnel can override the scheduling. However, overriding the scheduling does not allow personnel to change the speed limit. Instead, it just places the sign into the "default" mode (which is user defined). Concerns regarding the use of wireless communications include:

- additional cost of wireless communication devices (pager, cell phones, PDA, etc.);
- additional cost of data services (for those that require internet access);
- additional cost for software;
- training; and
- not being able to change the speed limit in the field.

Most ESL signs also have event logging capabilities that can be used to document the date and time of speed limit changes. In addition, radar and cameras can be added to some ESL signs to collect data (e.g., the date, time, and speed of passing vehicles, vehicle count, compliance, etc.). Trailer-mounted ESL signs are battery operated and use solar panels to recharge the batteries. In 2007, trailer-mounted Type 1 ESL signs and Type 2 ESL signs cost approximately $10,000 and $11,000, respectively (there are additional costs for data logging, scheduling feature, software, and remote communications).

Recently, Type 1 ESL signs were evaluated in Utah to determine motorist response to speed limits that varied based on work zone conditions (*51*). The 2.5 month study was conducted on I-80 during a crackseal project that required the roadway to be restricted to one travel lane in each direction at all hours for the duration of the project. The Type 1 ESL sign consisted of a 30 inch by 36 inch standard speed limit sign with 18 inch by 12 inch illuminated numbers. Vehicle speed data were collected under three different signing conditions:

- standard 65 mph speed limit signs;
- ESL sign posted at 65 mph 24 hours a day, 7 days a week; and
- ESL sign varying between 55 mph during the day (work activity) and 65 mph at night (no work activity).

The results showed that both the average speed and variation in speeds were reduced when the Type 1 ESL signs were used. The Type 1 ESL signs also resulted in greater compliance than the standard speed limit signs. However, TTI researchers did identify several issues with the data collection and analysis methodology. The primary issue was that at various times congestion occurred due to the construction activity and resulted in vehicle speeds dropping into the 10 to 30 mph range. However, in the data analysis the congested and non-congested data were not separated. Thus, the descriptive statistics computed included both types of situations, which depending upon the number of occurrences and duration of the congestion could have resulted in lower average speeds, less variation in speed, and higher compliance rates.

Overall, the main advantage of both types of ESL signs is that multiple speed limits (short term work zone, normal non-work zone daytime, and normal non-work zone nighttime) can be shown to motorists with one sign. The major disadvantage of both types of ESL signs is that in most cases personnel cannot change the speed limit displayed on the sign in the field. In addition, wireless communication devices and additional software are needed to program the speed limit shown on the signs.

Other Various Technologies

Portable changeable message signs (PCMSs) are traffic control devices commonly used in work zones to notify motorists of unexpected conditions, including speed reductions. As shown in Figure 12, speed limit messages are typically created using multiple lines of text which do not resemble standard speed limit signs (R2-1). Therefore, this display is considered a warning message instead of a regulatory message and thus is used to supplement posted regulatory speed limit signs.

Figure 12. Example of Speed Limit Message on a PCMS.

In the past few years, full-matrix PCMSs have become available. These devices come with pre-programmed and user-programmed graphics. While the graphics typically displayed are construction warning signs (diamond shape), according to discussions with vendors it is possible to display a speed limit sign (rectangular shape). Although, vendors have recently introduced full-color, full-matrix PCMSs to the market, the majority of full-matrix PCMSs in use today only utilize one LED color (e.g., orange). According to the Texas MUTCD (*14*), it would seem that a graphic display of a rectangular speed limit sign on a PCMS comprised of only orange LEDs would not constitute a regulatory speed limit. However, it is unknown whether an all white LED graphic display of a rectangular speed limit sign on a PCMS would be considered a regulatory speed limit sign, although the concept is similar to the Type 2 ESL sign which was approved by FHWA. In 2007, a full-matrix PCMS (orange LED color only) cost approximately $20,000.

Louvered signs are another type of technology that could potentially be used to display short term work zone speed limits. These signs are comprised of vertical or horizontal louvers. Graphics can be applied to both sides of the louvers and the stationary background (if included in the design), allowing for up to three images. Currently, this type of technology is mainly used in the advertising industry; thus, no cost estimates were readily available.

EVALUATION RECOMMENDATIONS

Based on the critique of the alternative technologies identified for better managing short term work zone speed limits, researchers recommended that TxDOT evaluate flexible reflective roll-up static work zone speed limit signs and Type 1 ESL signs. Since these technologies have not been used extensively for work zone speed limits in Texas, researchers recommended that field studies be conducted to determine how motorists respond to reduced speed limits posted on the devices and the ease of use of the devices within a highway work zone. In addition, researchers recommended that motorist surveys be used to assess motorist understanding and opinions of the devices.

TxDOT was also interested in the trailer-mounted static speed limit signs with flashing beacons and the concept of utilizing full-matrix PCMS to display work zone speed limit signs, even though these devices cannot currently be used to establish work zone speed limits based on current Texas law and TxDOT standards, respectively. Therefore, researchers recommended that these two devices also be further explored in the motorist survey.

CHAPTER 2.2: LONG TERM STUDY OF ELECTRONIC SPEED LIMIT SIGNS IN A WORK ZONE

TTI researchers conducted a long term study of the Type 1 ESL signs at a work zone on US-59 south of Linden in the Atlanta District. The purpose of the study was to determine: 1) the effect of the ESL signs on vehicle speeds; 2) motorist understanding and opinion of the ESL signs; and 3) law enforcement's opinions of the ESL signs. To accomplish this, researchers performed a "before-after" field study, conducted motorist surveys, and held police discussion groups.

TYPE 1 ESL SIGNS

Figure 13 shows the two types of ESL signs used in the long term field study. Atlanta District TxDOT personnel constructed four semipermanent ESL signs from "YOUR SPEED" signs that were no longer being used by the district. Each sign consisted of a speed limit sign, a power supply, a light-sensing photocell, and a controller switch. Each sign had an 18 inch by 24 inch work zone sign (G20-9) and a 24 inch by 36 inch speed limit sign (R2-1) with a changeable LED lamp matrix with a two-digit orange numeric display. The sign height was 7 ft from the near edge of pavement to the bottom of the sign. The power supply consisted of a solar panel and battery system that provided continuous power for the LED display. The controller switch had two settings: non-work zone and work zone. When the controller switch was set to the non-work zone function, a 70 mph speed limit was displayed during the day, and a 65 mph speed limit was displayed at night. The photocell detected ambient light conditions to determine which non-work zone speed limit should be displayed. When the controller switch was set to the work zone function, a 60 mph speed limit was displayed. The semipermanent ESL signs were wired such that only these speed limits could be displayed on the sign.

a) Semipermanent

b) Trailer-Mounted

Figure 13. Type 1 ESL Signs Used in Long Term Field Study.

According to a specification developed by TTI researchers, two trailer-mounted ESL signs were manufactured by a third-party vendor for use on the project. Appendix D contains a copy of the specification. These signs consisted of a 1400 lb single-axle trailer, a speed limit sign, a power supply, and a controller box. The signs did not originally include a 24 inch by 36 inch work zone sign (G20-9), but they were later retrofitted to be consistent with the four semipermanent ESL signs. The speed limit sign (R2-1) was 48 inches by 60 inches with a changeable LED lamp matrix with a two-digit orange numeric display. Similar to the semipermanent ESL signs, the bottom of the trailer-mounted ESL sign was 7 ft above the near edge of pavement and the power supply consisted of a solar panel and battery system.

The controller box consisted of an aluminum cabinet housing a panel of knobs and toggle switches that would allow the operator to select the normal (i.e., non-work zone) or work zone speed limit functions (Figure 14). The normal speed limit function had separate controls for day and night, which allowed the operator to set both daytime and nighttime speed limits. The sign was capable of displaying speed limits ranging from 5 to 80 mph, in 5 mph increments. The controller box also included a light-sensing photocell that detected ambient light conditions. If the speed limit function toggle switch was set to normal speed limit and the "AUTO/DAY/NIGHT" switch was set to "AUTO," the detection of nighttime conditions through the photocell would automatically trigger the display of the nighttime speed limit. When daytime conditions were detected, the daytime speed limit would automatically be displayed.

Figure 14. Trailer-Mounted ESL Sign Controller Box.

The controller box also had some data storage capability, which retained a log of the time, date, and numeric display each time the speed limit was changed. The memory could store up to 200 speed limit changes before it started overwriting the oldest data. The data log could be downloaded through a serial port to a laptop computer using commonly available HyperTerminal software.

FIELD STUDY

Researchers conducted the long term field study in the Atlanta District on a US-59 widening project that was about 9 miles in length. The existing rural four-lane undivided section was being converted to a four-lane divided section by adding southbound lanes on the west side. In general, the roadway cross section consisted of four 12-ft lanes with no shoulders, except for a small portion of the project that was two lanes with 10-ft paved shoulders. During the data collection period, all of the travel lanes remained open, but material-hauling equipment would frequently enter and exit the traffic stream during the day, depending on the location of the work. The normal non-work zone speed limit and work zone speed limit were 70 and 60 mph, respectively. Since the contractor's work was generally focused in one area at a time, daily speed reductions were not needed along the full length of the project. Thus, TxDOT used the ESL signs to reduce the speed limit only in locations where:

- the contractor was actively working, and/or
- material-hauling equipment was entering/exiting the traffic stream.

It should be noted that a small section of the project contained a detour, or realignment, to temporarily move traffic further east. The geometric conditions in the detour required the work zone speed limit to be 60 mph in this section for the duration of the project, even during the experimentation with the ESL signs.

Study Design

The primary data collected during the field study were free flow vehicle speeds at various sites within and outside of the work zone. Researchers collected free flow speed data with hand held LIDAR speed measurement equipment. In order to obtain an adequate sample size for statistical analysis, at least 125 data points were collected for each direction (NB/SB) at each site, including both passenger cars and commercial vehicles. Researchers documented the site characteristics on a written standardized data collection form, with GPS equipment and associated software, in photographs, and with drive-through videos.

Data were collected before the installation of the ESL signs and twice after the installation of the ESL signs. Figure 15 shows the locations of the work zone speed limit signs (static and ESL) during these three time periods in relation to the zones in which the contractor was working.

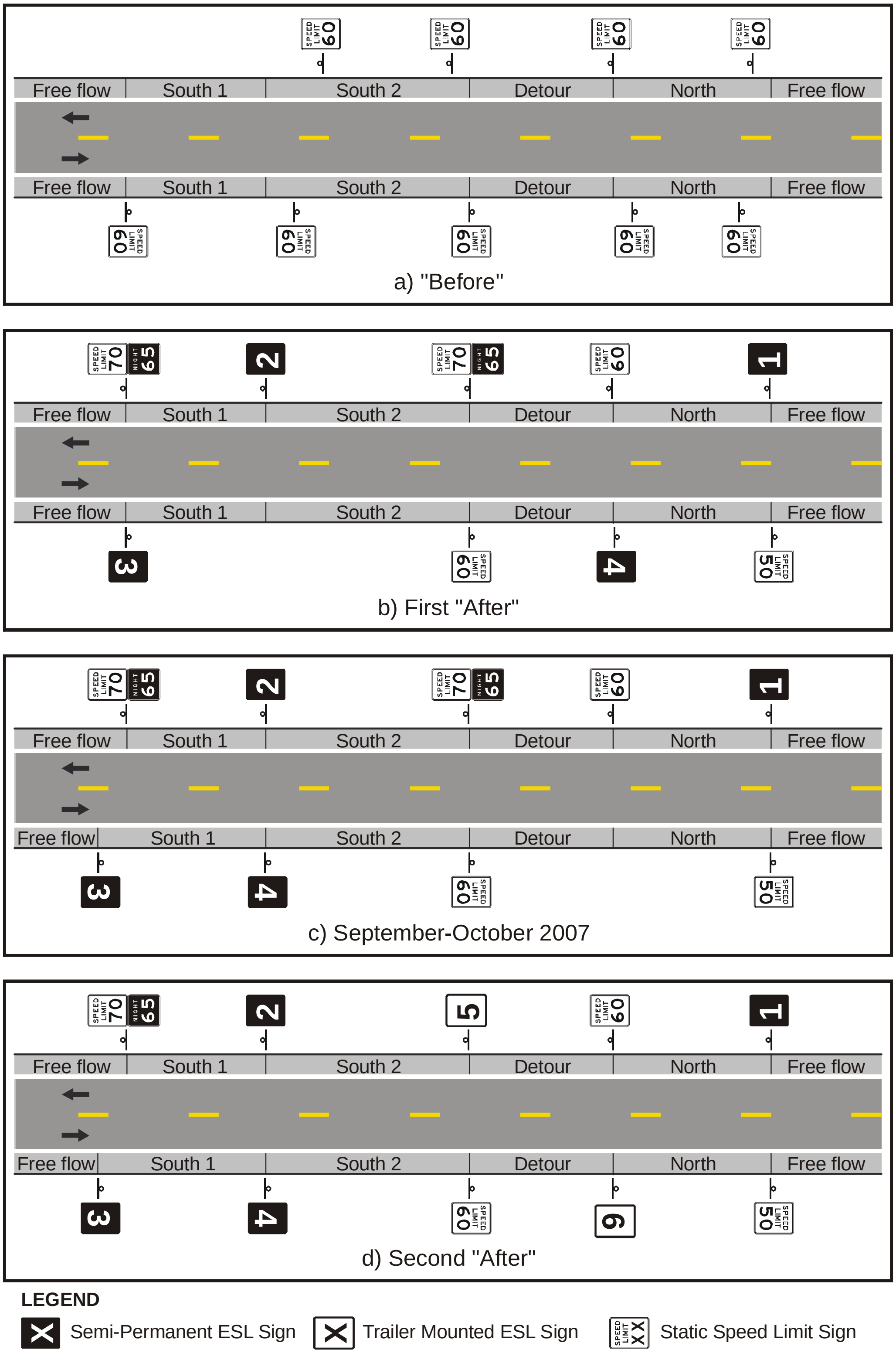


Figure 15. Treatment Locations during Each Data Collection Period.

The first data collection period was in May of 2007, prior to installation of the ESL signs, when the reduced work zone speed limit was posted using several standard static 60 mph regulatory speed limit signs with work zone signs (Figure 15a). These signs reduced the speed limit in the work zone 24 hours a day, seven days a week, whether or not work activity was present. At that time, the exact locations for the future ESL sign installations were not known. Data were collected at 14 different sites, which were approximately three-fourths of a mile apart. Twelve of the sites were located within the reduced work zone speed limit. The other two sites were located upstream of the work zone in both directions in order to obtain data regarding normal operating conditions of the roadway. Researchers collected daytime speed data at all sites and nighttime speed data at four sites. However, it should be noted that no work activity occurred at night.

Figure 15b shows the four semipermanent ESL signs installed in July of 2007. The ESL sign locations formed two separate and distinct zones in which the inspector could reduce speed limits as needed dependent upon the location of the work activity. The south 1 and north zones were approximately 1.6 and 1.9 miles in length, respectively. In the southbound direction after the detour a static 70/65 mph sign was displayed when no speed reduction was desired in the south 2 zone. However, a similar sign was not used at the beginning of the south 2 zone in the northbound direction; therefore, the speed limit displayed on the ESL sign at the beginning of south 1 zone also applied to the south 2 zone.

The first "after" data were collected in August of 2007, about 30 days after the semipermanent ESL signs were installed, in order to reduce impacts of any novelty effects from the signs. Daytime and nighttime data were collected at the same locations as during the "before" period. During this phase of data collection, the ESL signs were being used to reduce the work zone speed limit from 70 mph to 60 mph in the south zone on a daily basis, since the contractor was performing earthwork on the south end of the project and dump trucks were entering and exiting the active travel lanes. The north zone speed limit was not regularly being reduced, but was temporarily reduced from 70 mph to 60 mph for one day for some minor grading work.

As shown in Figure 15c, in September of 2007, two of the semipermanent signs were relocated in anticipation of the contractor's work progressing southward, as well as to accommodate future work on an adjacent project on the south end. By moving the northbound semipermanent ESL sign at the beginning of the south zone (sign 3 in Figure 15c) further south, the south zone was extended by 1.1 miles. The northbound semipermanent ESL sign at the beginning of the north zone (sign 4 in Figure 15c) was also moved. It was placed in the northbound direction at the beginning of a newly created middle zone which was 3.4 miles in length. However, there was no corresponding southbound ESL sign to regulate speeds in the southbound direction of the middle zone. Instead, the inspector continued to use a static 70/65 mph sign when no speed reduction was desired in the southbound middle zone. Movement of the northbound semipermanent ESL sign at the beginning of the north zone (sign 4 in Figure 15c) also removed the inspector's ability to regulate speeds in the northbound direction of the north zone.

In October of 2007, when the researchers returned to collect the second "after" data, the contractor was performing paving work just south of the detour. However, reducing the speed limit on the northbound semipermanent ESL sign at the beginning of the middle zone would have also reduced the speed limit in the northbound direction for the north zone, because an ESL sign was no longer present after the detour at the beginning of the north zone. Thus, the inspector had not been using the ESL signs since September, because he did not want to reduce the speed limit in sections where no activity was occurring. The researchers felt that sign credibility may have been impacted by the lack of use of the ESL signs and therefore, no data were collected in October.

After discussions with the inspector and Atlanta District personnel, the researchers developed a plan to establish the desired speed reduction zones with use of the two trailer-mounted ESL signs. By adding these ESL signs, a bidirectional middle zone was created to accommodate the inspector's need to reduce the speed limit in both directions near the paving work activity, and the north zone was re-established in both directions. Figure 15c shows the resulting sign configuration.

In December of 2007, the researchers conducted the second "after" data evaluation. At this time, data were collected at the same 14 sites as in previous data collection periods plus one additional site on the south end was added in order to obtain normal operating conditions of the roadway (i.e., relocation of semipermanent signs on the south end of the project altered the free flow data collection location). During this phase of data collection, the ESL signs were being used to reduce the work zone speed limit from 70 mph to 60 mph in the middle zone on a daily basis, since the contractor was performing paving work in the middle zone and concrete trucks were entering and exiting the active travel lanes. Prior to the second "after" data collection period, neither the north nor south zone speed limit was regularly being reduced, but each was temporarily reduced from 70 mph to 60 mph for one day during this data collection period for work activities. As in the two previous data collection periods, nighttime data were collected at four locations.

ESL Sign Utilization

The TxDOT inspector manually recorded the use of the ESL signs to reduce the work zone speed limit in a log book. From the time when the semipermanent ESL signs were installed (July) until the first "after" data collection period (August), the ESL signs were used to reduce the work zone speed limit to 60 mph on 82 percent of the contractor's work days. Similarly, from the first "after" data collection period (August) until the sign relocations occurred (September), the ESL signs were used to reduce the work zone speed limit to 60 mph on 80 percent of the contractor's work days. After the sign relocations, the ESL signs were not used at all to reduce the work zone speed limit for approximately one month. After the addition of the trailer-mounted ESL signs, the ESL signs were only used on 40 percent of the contractor's work days to reduce the work zone speed limit to 60 mph. This reduction is due to the fact that haul trucks were able to access the paving operation without entering the active traffic lanes, so no speed limit reduction was necessary. Overall, during the long term field study the ESL signs were used on 67 percent of the contractor's work days.

In order to obtain information about the ease of use of the ESL signs, researchers interviewed the TxDOT inspector. Overall, the inspector felt that using the ESL signs benefitted the project and that speeds were "somewhat" reduced when the ESL signs were displaying the reduced speed limit. The solar power was mentioned as a desirable feature, since an outside power source was not required to operate the ESL signs. The inspector also felt that the appearance of the ESL signs was different than the normal work zone speed limit signs, which made them more noticeable, especially at night. In addition, he indicated that both the semipermanent and trailer-mounted signs were easy to use, and that he would like to see them used again on another project.

Data Analysis

The descriptive statistics of interest for defining the observed vehicle speeds were sample size, mean speed, variance, standard deviation, and the percent of vehicles exceeding the speed limit. Appendix E contains these descriptive statistics for each site during each time period. Since there was no work being performed by the contractor at night, during all of the nighttime data collection time periods the speed limit was 65 mph. Researchers used the night data to verify that speeds in the work zone did not change between study periods.

In order to evaluate the effectiveness of the ESL signs in reducing speeds, researchers grouped the individual sites into zones corresponding to the locations of the ESL signs, as shown in Table 15. The site numbers appear in the table in order from south, at the top of the table, to north, at the bottom of the table. Due to the creation of the middle zone in the second "after" period, researchers divided the south zone into two zones in the "before" period and first "after" period so that similar comparisons across time periods could be made.

Table 15. Zones for Each Data Collection Period.

Site Number	Data Collection Period					
	"Before"		First "After"		Second "After"	
	North Bound	South Bound	North Bound	South Bound	North Bound	South Bound
15	N/A	N/A	N/A	N/A	70 mph	70 mph
1	70 mph	70 mph	70 mph	70 mph	N/A	N/A
2	South 1	South 1	South 1	South 1	South 1	South 1
3	South 1	South 1	South 1	South 1	South 1	South 1
4	South 2	South 2	South 2	South 2	Middle	Middle
5	South 2	South 2	South 2	South 2	Middle	Middle
6	South 2	South 2	South 2	South 2	Middle	Middle
7	South 2	South 2	South 2	South 2	Middle	Middle
8	N/A	N/A	N/A	N/A	N/A	N/A
9	Detour	Detour	Detour	Detour	Detour	Detour
10	N/A	N/A	N/A	N/A	N/A	N/A
11	North	North	North	North	North	North
12	North	North	North	North	North	North
13	N/A	N/A	N/A	N/A	N/A	N/A
14	50 mph	50 mph	50 mph	50 mph	50 mph	50 mph

N/A = Not Applicable

During the "before" and first "after" period, researchers collected data upstream of the work zone in both directions (site 1 and site 14) in order to assess the normal operating conditions of the roadway. Prior to the second "after" period, relocation of semipermanent signs on the south end of the project resulted in site 1 being within the south zone of the work zone; thus, during the second "after" period researchers collected data at a new site upstream of the south end of the project (site 15). Although data were still collected at site 1 during the second "after" period, it was not included in the analysis in order to maintain similar comparisons across time periods for the south zone.

As discussed previously, researchers selected the data collection locations prior to installation of the four semipermanent ESL signs. After the installation of these signs, several of the data collection sites (site 8, site 10, and site 13) were located close to the ESL signs. During both "after" periods, researchers noted that some drivers were making speed adjustments as they passed these data collection sites; therefore, data from these sites were not included in the final analysis.

For each zone, the sample size, mean speed, variance, standard deviation, and percent exceeding the posted speed limit were computed. Researchers then used t-test pairwise comparisons to determine if there were significant differences among the mean speeds between time periods and among various uses of the ESL signs within a time period (i.e., displaying normal non-work zone speed limit and work zone speed limit). In addition, researchers utilized a two-sided F-test and a test of proportions (z-test) to compare the variances in speed and percent of vehicles exceeding the speed limit, respectively. Researchers used a 95 percent level of confidence (alpha = 0.05) for all statistical analyses.

Results

Table 16 presents the before-and-after analysis of the mean speed in each zone when the work zone speed limit was reduced to 60 mph. In the "before" period, static 60 mph work zone speed limit signs were used throughout the entire length of the project to reduce the speed limit 24 hours a day, seven days a week, whether or not work activity was present. In both "after" periods, the ESL signs were used to display the 60 mph reduced work zone speed limit. A comparison of mean speeds from the "before" period and the two "after" periods shows mixed effects of the ESL signs (i.e., some increases in mean speed and some decreases in mean speed).

Even though several of the changes in mean speed were statistically significant, practically there was no difference in mean speeds when using a static work zone speed limit sign versus the ESL signs (less than 2 mph difference). So, while the ESL signs were only used to reduce the speed limit in the work zone when work activity was present, they did not result in lower mean speeds as researchers anticipated. However, the ESL signs also did not negatively impact speeds.

Table 16. Comparison of Mean Speeds with Posted Speed Limit of 60 mph.

Dir.	Zone	Mean Speed (mph)			Difference (mph)		
		"Before" Static	First "After" ESL	Second "After" ESL	"Before" & First "After"	"Before" & Second "After"	First "After" & Second "After"
NB	South 1	64.5	62.7	65.0	-1.8 [a]	+0.5	+2.3 [a]
	South 2/ Middle	64.6	N/A	64.4	N/A	-0.2	N/A
	North	62.7	63.4	62.5	+0.7	-0.2	-0.9 [a]
SB	South 1	62.8	63.0	63.5	+0.2	+0.7[a]	+0.5
	South 2/ Middle	62.3	N/A	62.3	N/A	0.0	N/A
	North	59.4	60.1	60.7	+0.7 [a]	+0.6	+1.3 [a]

NB = Northbound; SB = Southbound; N/A = Not Applicable
[a] Statistically significant change in mean speed at a 95 percent level of confidence (t-test).

Table 17 shows the percentage of vehicles exceeding the posted speed limit across time periods. Again, the effects of the ESL signs were inconsistent (i.e., both significant increases and decreases in the percent of vehicles exceeding the speed limit occurred.) This variability may be due to the fact that the work activity progressed south throughout the data collection periods. Thus, in each time period the vehicle speeds measured at the data collection sites were impacted differently dependent upon the data collection site's location relative to the locations where haul trucks were frequently entering and exiting the active travel lanes. Speed variances for each zone, by direction, were also compared across time periods; again researchers could not identify any distinct patterns or trends.

Table 17. Comparison of Percent of Vehicles Exceeding the Posted Speed Limit of 60 mph.

Dir.	Zone	Percent Exceeding Speed Limit			Difference (mph)		
		"Before" Static	First "After" ESL	Second "After" ESL	"Before" & First "After"	"Before" & Second "After"	First "After" & Second "After"
NB	South 1	76%	66%	81%	-10% [a]	+5%	+15% [a]
	South 2/ Middle	76%	N/A	77%	N/A	+1%	N/A
	North	66%	68%	67%	+2%	+1%	-1%
SB	South 1	66%	70%	75%	+4%	+9% [a]	+5% [a]
	South 2/ Middle	64%	N/A	65%	N/A	+1%	N/A
	North	38%	45%	53%	+7% [a]	+15% [a]	+8% [a]

NB = Northbound; SB = Southbound; N/A = Not Applicable
[a] Statistically significant change in mean speed at a 95 percent level of confidence (z-test).

In order to determine if motorists would react to a change in the speed limit on a short term basis, mean speeds were compared within each data collection period with the ESL sign speed limits set at both 70 mph and 60 mph. As shown in Table 18, in all cases, mean speeds decreased significantly when the work zone speed limit was reduced using the ESL signs, indicating that motorists did react to the reduced work zone speed limit. All of the reductions were generally in the 2 to 3 mph range, which is consistent with previous research (*52,53*). Researchers anticipate that the same reductions would have occurred as a result of the use of static work zone speed limit signs. However, changing between the normal non-work zone and work zone speed limits could not have been as easily accomplished.

Table 18. Comparison of Mean Speeds with ESL Display at 70 mph and 60 mph.

Dir.	Zone	First "After" Period			Second "After" Period		
		70 mph	60 mph	Change	70 mph	60 mph	Change
NB	South	N/A	N/A	N/A	67.2	65.0	-2.2 [a]
	North	65.5	63.4	-2.1 [a]	65.8	62.5	-3.3 [a]
SB	South	N/A	N/A	N/A	67.3	63.5	-3.8 [a]
	North	62.3	60.1	-2.2 [a]	62.5	60.7	-1.8 [a]

NB = Northbound; SB = Southbound; N/A = Not Applicable
[a] Statistically significant change in mean speed at a 95 percent level of confidence (t-test).

MOTORIST SURVEYS

Researchers conducted a survey to assess motorist understanding and opinion of the ESL signs used on the US-59 project. The surveys were conducted outside of several local businesses in the cities of Linden and Jefferson. Linden is located in Cass County and is adjacent to the north end of the US-59 project. Jefferson is located in Marion County near the south end of the US-59 project.

Study Design

Researchers approached potential respondents and asked for voluntary participation in the survey. Potential participants were then asked if they had recently traveled through the work zone located on US-59 between Linden and Jefferson. If they had not recently traveled through the work zone, researchers thanked them for their time, but did not administer the remainder of the survey.

Researchers administered the survey verbally to 100 participants (all of which had recently traveled through the US-59 work zone) and recorded their responses on the survey form. Each survey took about five minutes to complete and the participants received no compensation.

First, researchers collected basic demographic data about each participant, including gender, age, education, and zip code of residence. The researchers then asked the following questions.

- Can you describe the speed limit signs that you saw driving through the work zone?
- Is this the sign that you saw (displayed photo of ESL sign)?
- What do you think the sign is telling you?
- Do you think the speed limit changes?
- When do you think there would be a need to change the speed limit?
- Do you think this sign was effective at displaying speed limits appropriate for the existing conditions?
- Do you think you could get a speeding ticket for going over the speed limit shown on this sign?
- Is there anything about the sign that you like or dislike?

Participants

Researchers did not actively recruit to meet specific demographic criteria, but did attempt to obtain a range of participant ages and education levels. Table 19 shows the demographics for the survey respondents/subjects. Based on the zip code data provided by the respondents, the majority were local residents, with 82 percent citing Linden or Jefferson zip codes, and another 14 percent citing zip codes within a 30 mile radius of the work zone. The remaining 4 percent gave zip codes that were more than 30 miles away.

Table 19. Subject Demographics for US-59 Motorist Survey.

	Gender		Age			Education			
	M	F	18-39	40-54	55+	< HS	HS Grad	Some College	College Grad
Survey Sample	38%	62%	29%	38%	33%	8%	35%	27%	30%

Results

Of the 100 survey participants, 84 percent had seen the ESL signs in the US-59 work zone. From this group, 82 percent recognized that the ESL sign was displaying the speed limit. Another 8 percent not only recognized the ESL sign as a speed limit sign, but also perceived that the speed limit was changeable. Some of the remaining respondents (7 percent) first thought that the sign was a "YOUR SPEED" sign.

When participants were asked directly if they thought the speed limit displayed on the sign changed, 98 percent responded positively. Of these, 27 percent indicated that they thought the speed limit changed based on conditions, such as time of day, presence of workers, or both. Another 29 percent said they thought it changed simply because it had a digital display, while another 16 percent stated they actually saw the speed limit on the sign change.

When participants were asked when they thought there would be a need to change the speed limit, 56 percent cited the presence of workers. Another 20 percent of the respondents indicated that changing work conditions would require a speed limit change, and 10 percent noted that day or night conditions would require a speed limit change. Weather conditions were also mentioned by 8 percent of the respondents.

When participants were asked if they thought the sign was effective at displaying speed limits that were appropriate for the existing conditions, 88 percent responded positively. When asked to explain their responses, 62 percent indicated that the ESL sign changed based on conditions, and another 26 percent thought that the ESL sign was more visible and easy to read. All of the respondents (100 percent) stated that they could receive a speeding ticket for going over the speed limit shown on the ESL sign.

POLICE DISCUSSION GROUP

Researchers conducted discussion groups with local law enforcement that patrol the US-59 work zone to obtain their opinions of the ESL signs. In total, researchers met with four Texas DPS law enforcement officers. The first discussion group included three officers from Cass County, while the second discussion group included one officer from Marion County.

Study Design

Researchers developed a discussion guide to set the agenda for the group discussion and provide direction to the TTI facilitator. The discussion guide was divided into four parts. Part 1 focused on the law enforcement officers' general perceptions of reduced work zone speed limits. Part 2 addressed the work zone on US-59 between Linden and Jefferson, and Part 3 looked at the ESL signs located within this work zone. Finally, Part 4 was used to obtain the officers' overall suggestions, issues, or concerns with the use of ESL signs.

Prior to beginning the discussion, each officer filled out an information form that included some general questions about their expertise and concerns about speed limits in work zones and their enforcement. The objective of these questions was not only to encourage the officers to focus on law enforcement in work zones during the discussion but to obtain an unbiased opinion about work zone speed limits and their enforcement prior to the discussion.

At the beginning of the discussion, researchers explained that the purpose of the discussion was to obtain their expert opinions about reduced speed limits in work zones and the ESL signs being used in the work zone located on US-59 between Linden and Jefferson. Each officer interviewed was told that the questions should be answered based on their personal experience and their observation of motorists' driving behavior in their county. Officers were also told that the interview would be anonymous and that their names would not be used in any reports. Researchers then conducted the discussion group.

Results

Based on the input received on the information form and the first part of the discussion, the officers thought the following about work zone speed limits in general.

- The speed limit should be reduced in all work zones, but reduced speed limits are especially needed when workers are present.
- In most cases, the work zone speed limit should be reduced more.
- Reduced work zone speed limits should be posted throughout the whole work zone.
- The work zone speed limit should be the same throughout the whole work zone. This includes both directions of travel, even if one direction is currently not under construction.
- The work zone speed limit should not be changed too often so that the officers and motorists will know the speed limit from the time they enter the work zone until they reach the end of the work zone.
- More advance warning is needed for reduced work zone speed limits.
- Depending on the location and type of work zone, it is sometimes hard to enforce work zone speed limits.
- A method is needed to help officers know when workers are present.

With respect to the work zone located on US-59 between Linden and Jefferson, officers felt that prior to the installation of the ESL signs most motorists did not comply with the reduced work zone speed limit of 60 mph and that this remained the case even after the ESL signs were installed (i.e., ESL signs did not affect vehicle speeds). However, officers did feel that the ESL signs were more visible than standard static speed limit signs and thus could potentially make motorists more aware of the speed limit. Additional advantages of the ESL signs identified by officers were:

- the digital display was easy to read,
- the ability to automatically change between daytime and nighttime speed limits, and
- the log that was kept showing every time the speed limit was changed and that the sign was working properly.

While the officers liked the ESL signs, they expressed the following concerns regarding the signs:

- officers would need to be notified when the speed limit was reduced and what reduced speed limit was posted,
- not being able to prove what speed limit was displayed on the sign and that the sign was functioning properly,
- obtaining the log and using it in court cases,
- potential motorist confusion if the speed limit was changed too often,
- potential motorist confusion with "YOUR SPEED" signs (and the use of this excuse to get out of a citation),
- the orange color of the speed limit numbers indicating an advisory sign instead of a regulatory sign and the related effects on enforcement,
- what is displayed if the sign malfunctions, and
- vandalism.

SUMMARY

In the long term study, the Type 1 ESL signs were used to reduce the speed limit in the US-59 work zone only when work activity was present (i.e., implementation of a short term work zone speed limit). While the field study results did not indicate a practical difference in mean speeds when the ESL signs were used compared to standard static speed limit signs that reduced the speed limit 24 hours a day, seven days week, it also did not indicate that the ESL signs negatively impacted operations. In addition, the ESL signs allowed the TxDOT inspector to more easily change between the normal non-work zone speed limit and reduced work zone speed limit on a daily basis. Most importantly, the motorist surveys in the area showed that the public understood the ESL signs and recognized that the speed limit on the ESL signs changed based on conditions (e.g., workers present, changing work conditions, time of day, etc.); therefore, improving the credibility of TxDOT's work zone speed limit procedures with the public.

The discussions with local law enforcement once again exemplified the differences in philosophies between law enforcement and TxDOT regarding the implementation of reduced work zone speed limits. However, all of the officers thought the ESL signs were beneficial.

CHAPTER 2.3: SHORT TERM FIELD STUDIES OF ALTERNATIVE WORK ZONE SPEED LIMIT SIGN DEVICES

In Texas, reduced work zone speed limits are not typically implemented for maintenance projects, such as seal coat operations, due to the time it takes to install/remove the temporary speed limit signs compared to the time it takes to conduct the work activity. When reduced work zone speed limits are used, they are commonly posted at the beginning of the project limits, since it is difficult to keep the temporary speed limit signs in the vicinity of the work activity given that these operations move fairly quickly down the roadway. Both the trailer-mounted Type 1 ESL signs and flexible roll-up static work zone speed limit signs can be implemented more quickly and moved more easily to keep up with operations than standard temporary speed limit signing. Thus, researchers evaluated these devices at two short term stationary work zones in Texas to determine how motorists respond to reduced speed limits posted on these two alternative devices compared to standard work zone speed limit signing.

TREATMENTS

Table 20 shows the characteristics of the three treatments evaluated in the short term field studies. The trailer-mounted ESL signs were described in detail in Chapter 2.2. According to the TxDOT Traffic Control Plans for the I-30 work zone, the contractor's speed limit signs and work zone signs were supposed to be 48 inches by 60 inches and 36 inches by 24 inches, respectively. However, the actual signs used by the contractor on the day that researchers collected data were much smaller.

Many vendors currently sell flexible reflective roll-up work zone warning signs (diamond shape) but only a few of them presently sell roll-up regulatory signs (rectangular in shape). Discussions with vendors revealed that the maximum size of an off-the-shelf roll-up speed limit sign was 48 inches by 60 inches. While this was the desired size of the speed limit sign for this project, TxDOT standards *(21)* require that a work zone sign (G20-9) be placed on top of the speed limit sign. Consequently, researchers worked directly with one vendor to specially manufacturer a roll-up work zone speed limit sign. In addition, a typical portable sign stand used to mount roll-up warning signs 1 ft above the pavement could not be used due to the desired larger sign size. Thus, researchers worked with the vendor to modify another type of existing portable sign stand to hold the roll-up work zone speed limit signs. Due to the design limitations of the modified portable sign stand, the overall sign height could not exceed 72 inches. Therefore, the final roll-up work zone speed limit signs consisted of a retroreflective white 36 inch by 48 inch speed limit sign (R2-1) and a 36 inch by 24 inch retroreflective orange work zone sign (G20-9).

Table 20. Short Term Field Study Treatments.

	Standard Signs	**ESL Signs**	**Roll-up Signs**
			
Speed Limit Sign Size (inches) [a]	24 by 30	48 by 60	36 by 48
Work Zone Sign Size (inches) [a]	24 by 18	36 by 24	36 by 24
Mounting Height [b]	7 ft	7 ft	1 ft

[a] Width by length.
[b] Measured from the bottom of the sign to the near edge of the pavement.

Typically, for short term work zone operations flexible roll-up advance warning signs are mounted on portable supports at a 1-ft mounting height. Therefore, TTI researchers wanted to evaluate the flexible roll-up work zone speed limit signs at a 1-ft mounting height. While the Texas MUTCD (*14*) infers that speed limit signs may be used on portable supports (Section 6F.03), it also states that temporary traffic control regulatory signs shall conform to the standards for regulatory signs presented in Part 2 of the Texas MUTCD (Section 6F.06). In Part 2 the mounting height of signs on the side of the road must be at least 7 ft, unless specifically stated otherwise for a particular sign elsewhere in the manual (Section 2A.18). Therefore, historically TxDOT has interpreted this to mean that all regulatory signs must be mounted at least 7 ft above the pavement. However, for these field studies, TxDOT approved a one foot mounting height.

STUDY LOCATIONS AND STUDY DESIGN

TTI researchers conducted the short term field studies at work zones on I-30 and US-59. Both of these facilities are four-lane divided roadways in the Atlanta District. The work activity was a seal coat operation that required one lane to be closed. At both sites, researchers collected data during the day when there was a right lane closure. The normal non-work zone speed limit and reduced work zone speed limit were 70 mph and 60 mph, respectively. The sign treatments were located on both sides of the roadway.

At the I-30 site researchers evaluated all three treatments. However, at the US-59 site researchers were only able to collect data for the two alternative devices, since according to the original project plans the contractor was not responsible for providing standard work zone speed limit signs (given that a reduced speed limit was not initially requested). In addition, there was a limitation on the amount of time available for data collection. The contractor planned to install a 2-mile lane closure, conduct the work activity, and then remove the lane closure. This process was to be repeated for the entire length of the project; therefore, the work activity would progressively move down the road in 2-mile segments instead of having the lane closure extend the entire length of the project. However, researchers desired to compare the treatments at the same locations to reduce the potential for confounding effects (e.g., changes in sight distance, roadway alignment, intersections, etc.). Discussions between researchers, TxDOT, and the contractor resulted in the beginning of the lane closure (and thus the reduced work zone speed limits) remaining in place long enough for only two treatments to be evaluated.

Similar to the long term field study in the Atlanta District, researchers collected free flow speed data with hand held LIDAR speed measurement equipment and documented the work zone and roadway characteristics at each site. At each site, speed data were measured approximately one to two miles upstream of the work zone in order to calculate the normal operating speed of the facility (i.e., free flow speed) and approximately 1000 ft downstream of the treatments to assess motorists' reactions to the various reduced work zone speed limit signs. Due to the short duration nature of the work activities, speed data could not be collected at additional locations within the work zone itself. In order to obtain an adequate sample size for statistical analysis, spot speeds were collected for at least 125 passenger vehicles and 25 commercial vehicles at each data collection location.

DATA ANALYSIS

First, researchers computed the following descriptive statistics for each treatment at each data collection location at each site: sample size, mean speed, variance, standard deviation, 95 percent confidence interval of the mean speed, and the percent of vehicles exceeding the speed limit. Appendix F contains these descriptive statistics.

Researchers utilized a one-way analysis of variance (ANOVA) to determine if there was a significant difference among the mean speeds at each site. Tukey's honestly significant difference (HSD) was then used to make all pairwise comparisons between groups. A two-sided F-test and a test of proportions were used to compare the variances in speed and percent of vehicles exceeding the speed limit, respectively. With respect to the latter test, the two proportions were considered statistically different when the test statistic, Z, was greater than 1.96. Researchers used a 95 percent level of confidence (alpha = 0.05) for all statistical analyses.

RESULTS

Table 21 contains the mean speed and percent of vehicles exceeding the speed limit for each treatment (i.e., standard signs, ESL signs, and roll-up signs) and the mean speed upstream of the work zone at each site. The free flow speeds among the treatments at each site were not statistically different, verifying that traffic conditions just upstream of the work zone remained the same throughout both evaluations.

At both sites, all of the treatments resulted in significantly lower mean speeds downstream of the reduced work zone speed limit signs compared to the free flow location (4 to 9 mph decrease). In addition, at both sites the mean speeds downstream of the ESL signs and the roll-up signs were not statistically different. However, at the I-30 site, the mean speeds downstream of the two alternative devices (62.8 and 63.8 mph) were significantly lower (2.9 and 1.9 mph) than the mean speed downstream of the standard treatment (65.7 mph). In addition, at the I-30 site, the percent of motorists exceeding the speed limit downstream of standard treatment (81 percent) was greater than for the alternative devices (64 and 71 percent) (Z-statistics = 3.328 and 1.937, respectively). At both sites, there was not a significant difference in the percent of motorists exceeding the speed limit downstream of the two alternative devices (I-30 and US-59 Z-statistics = 1.406 and 1.869, respectively). However, the ESL signs did result in 7 to 10 percent fewer motorists exceeding the speed limit.

Table 21. Short Term Field Study Results.

Site	Treatment	Mean Speed (mph)			Percent Exceeding the Speed Limit Downstream of Treatment
		Free Flow	Downstream of Treatment	Delta	
I-30	Standard	70.0 (n=149)	65.7 (n=160)	-4.3	81%
	ESL	69.9 (n=150)	62.8 (n=158)	-7.1	64%
	Roll-up	70.2 (n=159)	63.8 (n=157)	-6.4	71%
US-59	ESL	69.1 (n=154)	59.7 (n=154)	-9.4	36%
	Roll-up	68.4 (n=163)	60.3 (n=156)	-8.1	46%

As discussed previously, the variation in vehicle speeds appears to have a greater effect on crashes (i.e., the greater the variability in vehicle speeds the greater the crash risk). At the US-59 site speed variance was not statistically significant between the two alternative devices or between the two data collection locations. At the I-30 site the variation in speed was also not statistically significant between treatments; however, the speed variances downstream of the treatments (24.3 to 28.7 mph^2) were statistically higher than the speed variances upstream of the work zone (approximately 14 mph for all three treatments). Thus, independent of the reduced work zone speed limit treatment, at the I-30 site the reduced work zone speed limit resulted in an increase in the differences in vehicle speeds.

OTHER ISSUES

Many TxDOT maintenance contracts that include short term operations such as seal coats, utilize traffic control plans straight from the TxDOT Traffic Control Plan Standards *(54)*. However, these plans do not include information on the location of work zone speed limit signing (both the reduced speed limit and accompanying advance warning of the reduced speed limit) with respect to the work activity and other required work zone signing (e.g., lane closure). The TxDOT Barricade and Construction Work Zone Speed Limit Standard *(21)* can be referenced, but it only shows the general location of these signs with respect to the work activity.

Thus, the contractor and TxDOT inspector ultimately determine the location of the work zone speed limit signing in the field. The other option is to create a traffic control plan that shows the signs necessary to implement a work zone speed limit in relationship to the signs needed for the specific condition for which the reduced speed limit was warranted (e.g., lane closure).

Figure 16 shows an excerpt from the traffic control plan created by TxDOT for the I-30 site to show the placement of the work zone speed limit signing with respect to the required lane closure signing. While it is clear that the work zone speed limit signing should be located in advance of the lane closure signing, the distance between the work zone speed limit signs and the first lane closure signs is only a minimum distance. This is also true for the distance between the speed reduction signs and the work zone speed limit signs. Thus, dependent upon where the contractor actually places these signs, they may not be in the vicinity of the work activity, but still meet the requirements of the traffic control plan.

Another complication was identified when researchers sketched the locations of the work zone speed limit signing on the TxDOT standard traffic control plan for a one lane closure on a freeway (TCP-(6-1)-98) which was also included in the I-30 plans (Figure 17). When the work zone speed limit signing is placed at the minimum distances given in Figure 16, these signs are located between the "ROAD WORK AHEAD 1 MILE" signs and the "RIGHT LANE CLOSED ½ MILE" signs, instead of in advance of the lane closure signing. While both locations of the work zone speed limit signing are acceptable, leaving the location of these signs open for interpretation leads to inconsistent applications.

A few states have incorporated reduced regulatory speed limits (and accompanying advance warning of the reduced limits) into the overall temporary traffic control plan standard sheets for various work operations. In this way, the relationship between the advance warning signs for the work zone operation and those for the reduced work zone speed limit are defined for field crews deploying the temporary traffic control. Figure 18 through Figure 21 provide examples of these standards from Minnesota, Michigan, Oklahoma, and Illinois, respectively. One sees that each of these states took a slightly different approach. The Minnesota DOT (MnDOT) chose to only incorporate the "REDUCED SPEED AHEAD" sign into the advance warning sign sequence for the lane closure and to display the actual reduced speed limit sign once past the transition zone and in the work area. In Michigan, both the "REDUCED SPEED AHEAD" sign and the "SPEED LIMIT XX MPH" sign itself (shown as 45 mph in Figure 19) were incorporated into the advance warning sign sequence for the lane closure, after the text-based "RIGHT LANE CLOSED" sign and the symbolic right lane closed sign, respectively. In Oklahoma, the "REDUCED SPEED AHEAD" sign was located upstream of the lane closure advance warning sign sequence, and the "SPEED LIMIT XX MPH" was placed between the text and symbolic right lane closed signs. Finally, the Illinois DOT (IDOT) standards make no use of a reduced speed limit ahead sign and present only a speed limit sign between two text-based right lane closed signs that precede a symbolic right lane closed sign (IDOT uses one additional right lane closed sign than is required by the MUTCD(*50*)). In the IDOT configuration, the work zone speed limit is posted more than 4000 ft from the merging taper of the work zone.

Whereas these state DOTs chose to integrate the speed limit signs into the appropriate traffic control plan standard sheets, the Wisconsin DOT opted to include their guidance as design notes for the relative standard drawings that would potentially include a reduced work zone speed limit. These design notes, depicted in Figure 22, describe the location that the "REDUCED SPEED AHEAD" sign would be located (500 ft before the "WORK ZONE 1 MILE" sign) as well as the "SPEED LIMIT XX MPH" sign (500 ft beyond the "RIGHT LANE CLOSED ½ MILE" sign).

SUMMARY

Overall, both the Type 1 ESL signs and flexible roll-up static work zone speed limit signs resulted in lower mean speeds and percent of vehicles exceeding the speed limit downstream of the reduced work zone speed limit compared to standard temporary speed limit signing. Researchers also confirmed that these devices can be implemented more quickly and moved more easily to keep up with operations than standard temporary speed limit signing. However, it was noted that the permanent non-work zone speed limit signs would need to be covered and uncovered when the reduced work zone speed limit was in effect. Prior to implementation, researchers recommend that TxDOT develop standards for these types of signs and ensure they conform to any applicable TxDOT Departmental Material Specifications (*55*) and are compliant with current criteria for crashworthy work zone traffic control devices (*37*).

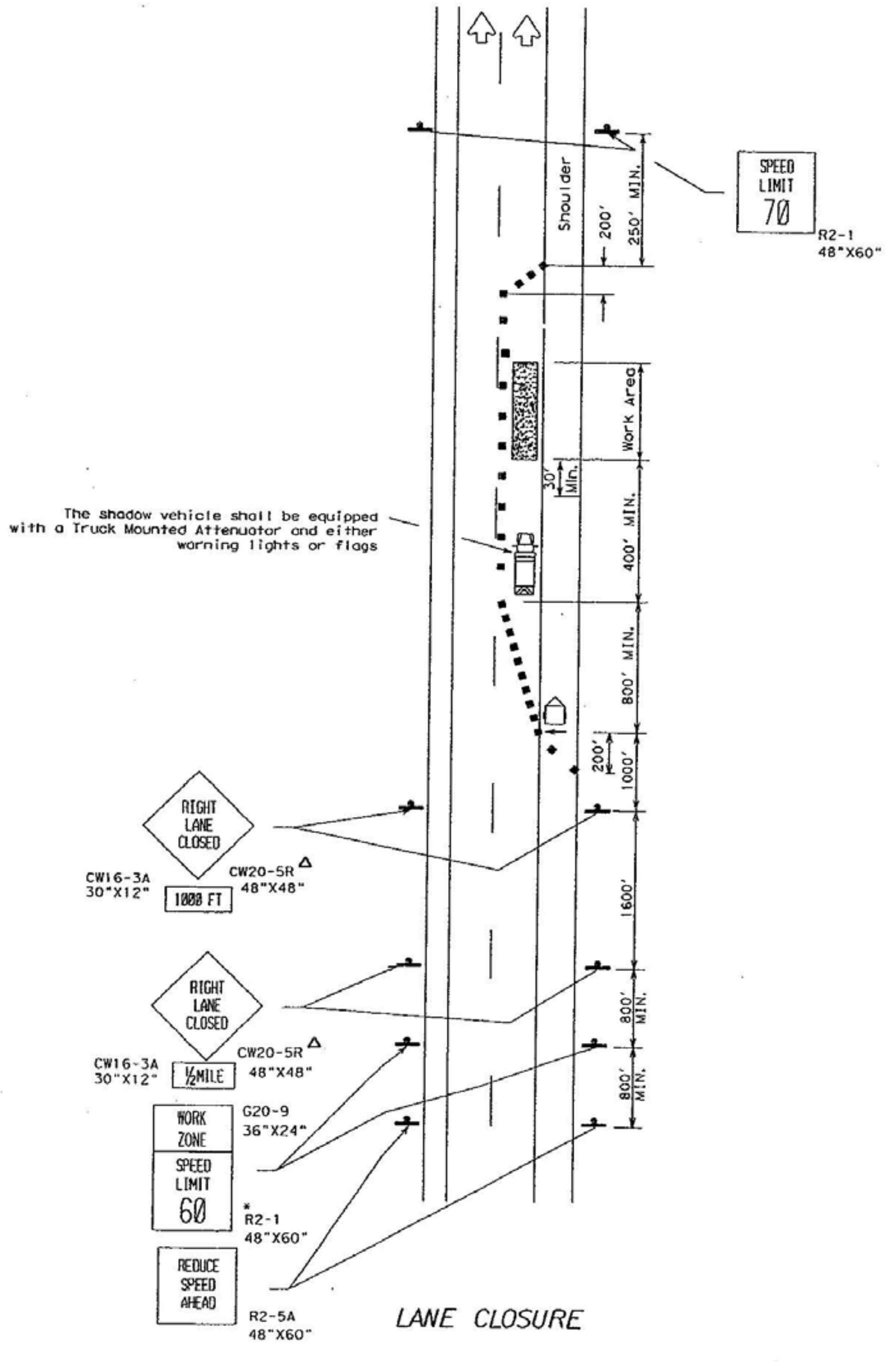


Figure 16. Excerpt from I-30 Traffic Control Plans – Lane Closure with Reduced Work Zone Speed Limit.

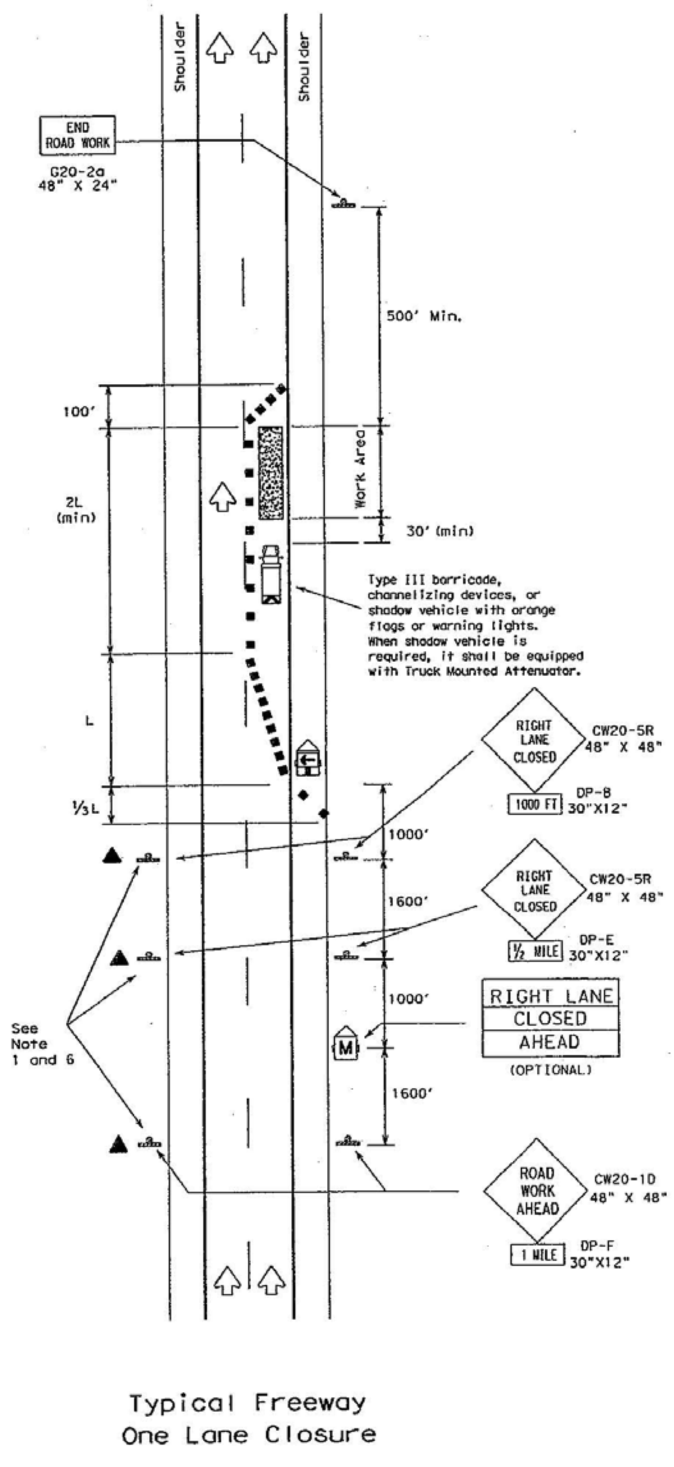
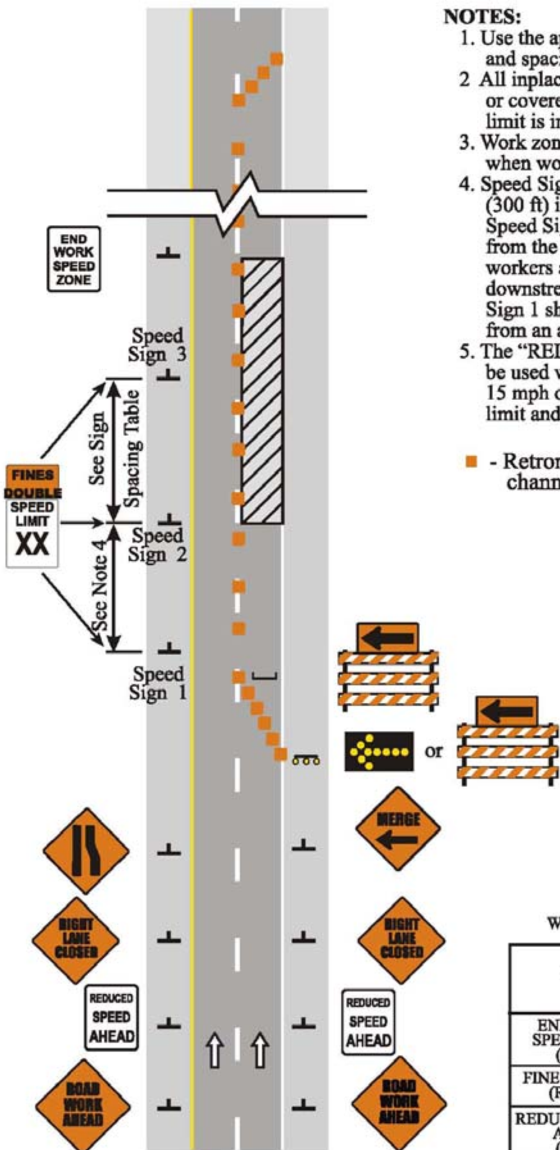


Figure 17. Excerpt from I-30 Traffic Control Plans – TCP-(6-1)-98.



NOTES:

1. Use the appropriate layout for advance signing and spacing.
2. All inplace Speed Limit signs shall be removed or covered when the reduced work zone speed limit is implemented.
3. Work zone speed limit signs should be removed when workers are not present.
4. Speed Sign 1 should be located at least 90 m (300 ft) in advance of Speed Sign 2. Speed Sign 2 should be located directly across from the first active work area (where the workers are present). As workers proceed downstream through the work area, Speed Sign 1 shall be no more than 760 m (2500 ft) from an active work area.
5. The "REDUCED SPEED AHEAD" sign shall be used when there is a speed reduction of 15 mph or greater between the normal speed limit and the work zone speed limit.

■ - Retroreflective channelizing device.

*TYPICAL SPACING FOR WORK ZONE SPEED LIMIT SIGNS

Work Zone Seed Limit	Confirming Speed Limit Sign Spacing	
(mph)	(meters)	(feet)
20 - 35	400	1300
40 - 55	760	2500

MINIMUM SIGN SIZES FOR WORK ZONE SPEED LIMIT SIGNING

Sign	Posted Speed Limit Prior to Work Starting	
	0 - 40 mph	45 - 75 mph
END WORK SPEED ZONE (R2-6a)	600 x 750 mm (24" x 30")	600 x 750 mm (24" x 30")
FINES DOUBLE (R2-X8P)	600 x 450 mm (24" x 18")	900 x 600 mm (36" x 24")
REDUCED SPEED AHEAD (R2-5a)	600 x 750 mm (24" x 30")	900 x 1200 mm (36" x 48")
SPEED LIMIT (R2-1)	600 x 750 mm (24" x 30")	900 x 1200 mm (36" x 48")

WORK ZONE SPEED LIMIT
MULTI-LANE ROAD

LAYOUT 2

Figure 18. Typical Application of Lane Closure on a Multilane Road with a Reduced Speed Limit in Minnesota.

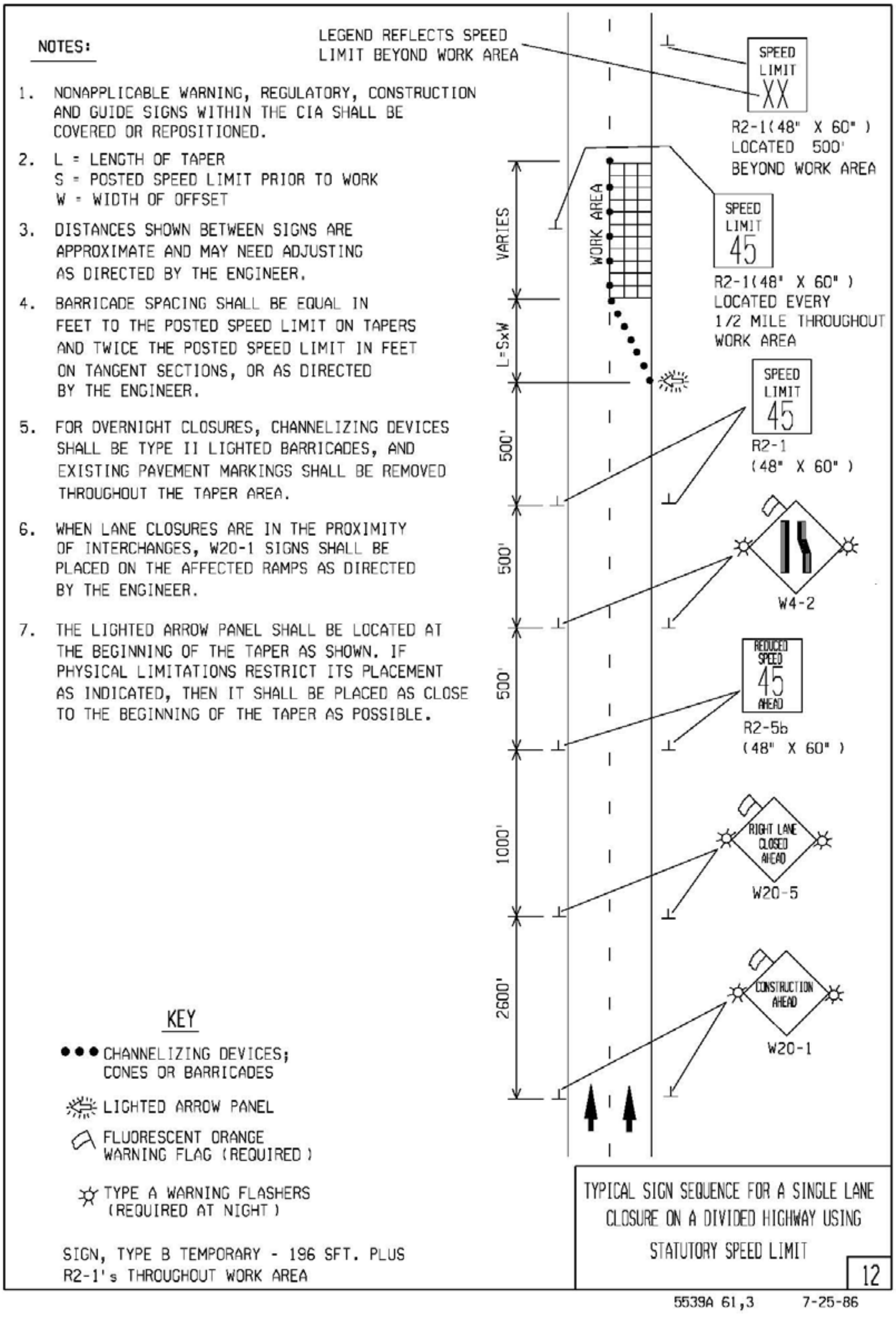


Figure 19. Typical Application of Lane Closure on a Multilane Road with a Reduced Speed Limit in Michigan.

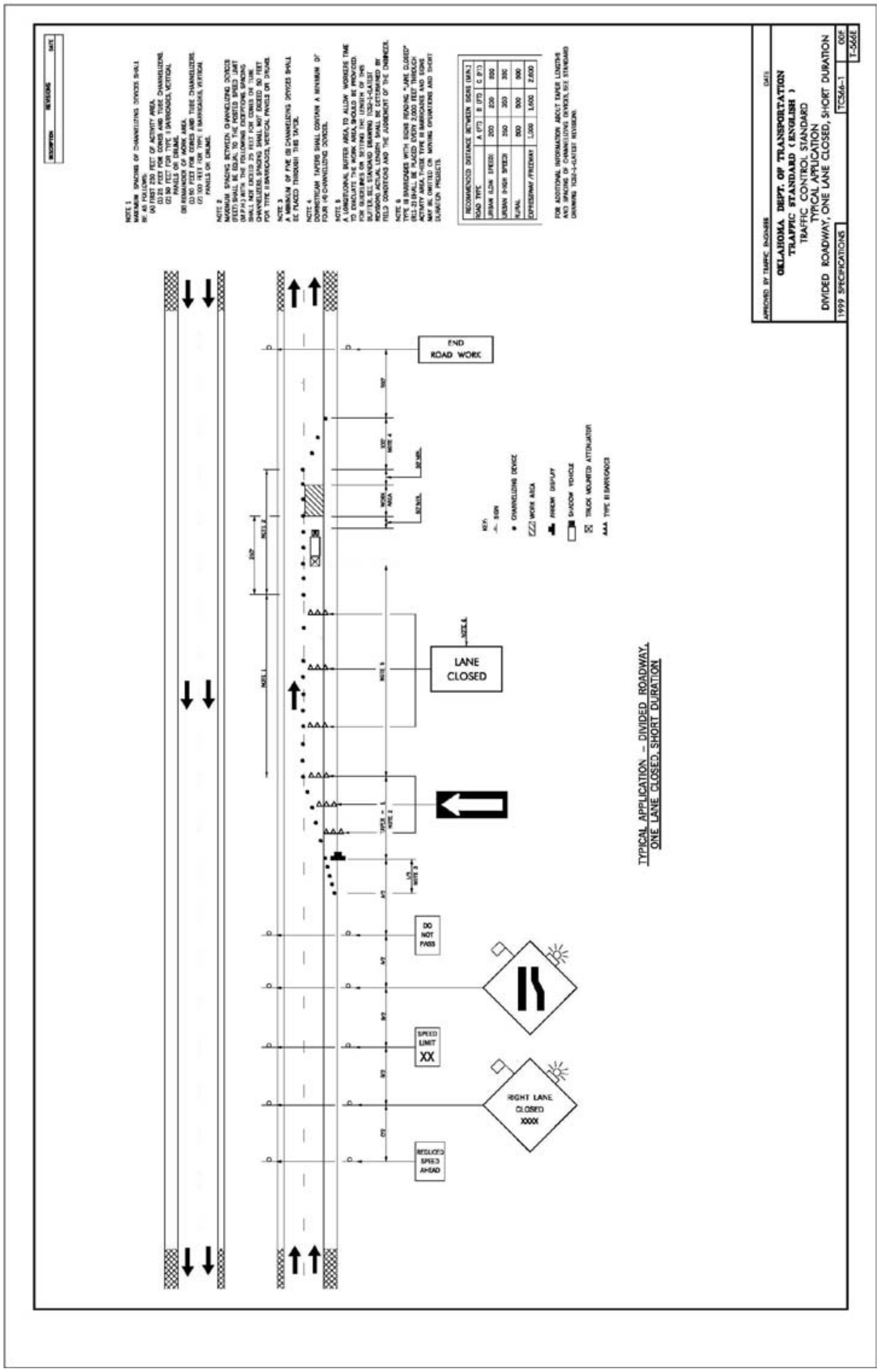


Figure 20. Typical Application of Lane Closure on a Multilane Road with a Reduced Speed Limit in Oklahoma.

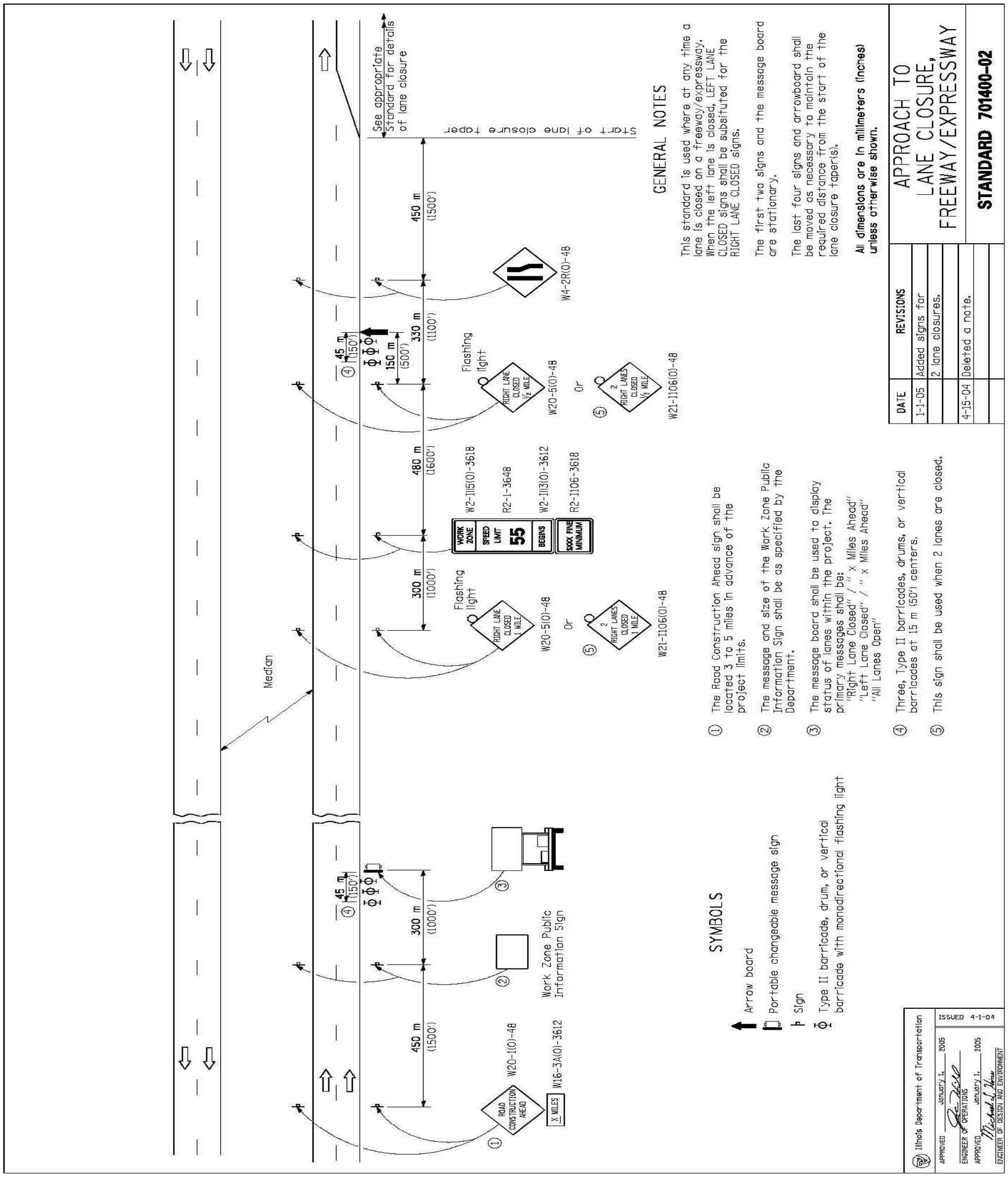


Figure 21. Typical Application of Lane Closure on a Multilane Road with a Reduced Speed Limit in Illinois.

Standard Detail Drawing 15D3-1

Reference: Part VI from the Manual on Uniform Traffic Control Devices
FDM Procedure 11-50-20

Bid items associated with this drawing:

Item #	Title
643.0100	Traffic Control (Project) (Each)
643.0900	Traffic Control Signs (Days)
643.0800	Traffic Control Arrow Boards (Days)
643.0300	Traffic Control Drums (Days)
643.0715	Traffic Control Warning Lights Type C (Days)
649.0400	Temporary Pavement Marking Removable Tape 4-inch (LF)
649.0100	Temporary Pavement Marking 4-inch (LF)
603.0500	Concrete Barrier Temporary Precast Contractor Furnished& Delivered (LF)
603.0600	Concrete Barrier Temporary Precast State-Owned Contractor Delivered (LF)
603.0801	Concrete Barrier Temporary Precast Contractor Installed (LF)
603.0900	Concrete Barrier Temporary Precast State Owned Contractor Installed (LF)
649.2100	Temporary Raised Pavement Markers (each)[optional]

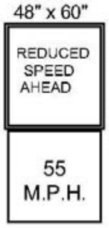
STSP	Title

Other SDD's associated with this drawing: 14B7

Design Notes:

Regulatory speed reductions in the construction work zone must be approved by the District Traffic Engineer, if a 65 MPH freeway required regulatory signing to reduce the speed to 55 MPH. The following signs should be added to the advanced warning area.

R2-5
48" x 60"



To be mounted on both sides of the roadway 500 feet beyond the "ROAD WORK 1 MILE" sign.

W13-1
36"x 36"
(BLACK & WHITE)

R2-1
48" x 60"

To be mounted on both sides of the roadway 500 feet beyond the "RIGHT LANE CLOSED 1/2 MILE" sign. The speed limit sign should also be located 1500 feet beyond the end of the acceleration lane of each entrance ramp. There should be a speed limit sign every 2 or 3 miles.

Temporary Raised Pavement Markers can be used along with Temporary Pavement Marking, Removable Tape to aid in delineation. Raised markers shall be used when the geometry is such that it is impossible to locate the lane closure with a minimum clear view 1500 feet in front of lane closure drums. Raised markers should not be used if the lane closure is in place for less than 7 continuous days and nights. Consideration should also be given to the speed of the roadway and the traffic volumes. Raised markers shall be placed at 25 foot spacing when they are used as a solid lane line and a 50 foot spacing when they are used as a broken lane line.

An overview detail specific to the project should be used in conjunction with this detail. Additional advance warning signs (beyond 1 mile in advance) should be shown on the overview sheet, if necessary.

Contact Person: Thomas Notbohm (608) 266-0982

September 30, 2004

Figure 22. Design Notes for Typical Applications with a Reduced Speed Limit in Wisconsin.

Currently, TxDOT standards (*21*,*54*) do not specifically show the exact location of work zone speed limit signing with respect to the work activity and other required work zone signing. Thus, when TxDOT maintenance contracts include the use of a short term work zone speed limits but utilize these standard plans, the actual location of the work zone speed limit signing in the field is determined by the contractor and TxDOT inspector, unless a specific traffic control plan is created by TxDOT personnel for the project. This issue has been addressed by other state DOTs, who have either (a) modified their standard sheets to integrate the speed limit signing with the work zone advance warning signing or (b) included specific guidance about the location of the speed limit signs as design notes in their standards. The researchers recommend that similar modifications be made to the TxDOT standard sheets so as to facilitate the use of short term work zone speed limits by contractors and TxDOT field personnel (when properly authorized through the Transportation Commission Minute Order process).

CHAPTER 2.4:
MOTORIST SURVEYS

Researchers used the results in Chapter 2.1, along with input from the project advisory committee, as a basis for the experimental design of the surveys discussed in this chapter. The primary objectives were to determine: 1) motorists' understanding and opinion of alternative short term work zone speed limit signs and their enforceability, 2) if the orange or white LED color used on ESL signs and PCMSs indicate to motorists that they are advisory or regulatory signs, respectively, and 3) motorist preference.

STUDY DESIGN AND PROTOCOL

Overview

Researchers used a laptop computer to administer the surveys; however, it was not necessary for the participants to have any computer experience. The survey included four categories of signs: 1) static work zone signs, 2) ESL signs, 3) "YOUR SPEED" signs, and 4) speed limits displayed on PCMSs. The motorist survey findings in Chapter 2.2 indicated that a small percent of participants mistook the ESL signs as "YOUR SPEED" signs; therefore, researchers included the "YOUR SPEED" signs in this survey to further investigate this issue.

The study was divided into three parts. The first part was used to determine motorists' comprehension and opinion of short term work zone speed limit signs and their enforceability. The second part assessed whether the orange or white LED color used on ESL signs and PCMSs indicate to motorists that they are advisory or regulatory signs, respectively. The third part was administered to ascertain motorist preference. Appendix G contains an example of the motorist survey.

Survey Locations and Demographics

In the summer of 2008, researchers conducted the motorist surveys at Texas DPS offices in the following cities: Bryan, Dallas, Rosenberg, and San Antonio. These sites were chosen in order to obtain a statewide representative sample. In each city, researchers recruited 198 participants; thus, in total 792 motorists were surveyed. The only criteria of the participants recruited were that they be over the age of 18 and have a current Texas driver's license. The demographics were based on the age and gender of the Texas driving population (*38*), and the education was based on data from the U.S. Census Bureau (*39*). Table 22 summarizes the overall demographic distribution obtained. Overall, it is believed that the results obtained in this study represent Texas drivers reasonably well.

Table 22. Subject Demographics for Motorist Surveys.

	Gender		**Age**			**Education**	
	M	**F**	**18-39**	**40-54**	**55+**	**HS Diploma or Less**	**SC (2 yrs+) and More**
Survey Sample	50%	50%	43%	32%	25%	48%	52%
Texas Data (*38*,*39*)	50%	50%	44%	31%	25%	49%	51%

Treatments

Figure 23 shows the 11 signs evaluated in the motorist survey. The three static work zone speed limit signs include the standard sign assembly, the trailer-mounted sign assembly with flashing beacons activated, and the flexible roll-up sign assembly. The only difference in the two Type 1 ESL signs was the color of the LEDs used to display the speed limit (either orange or white). The two "YOUR SPEED" signs were included as distracter signs to see whether motorists would confuse the ESL signs with the "YOUR SPEED" signs. On two of the PCMSs, text was used to display the speed limit. On the other two PCMSs, graphic displays of actual speed limit signs were shown. Otherwise, the only difference between the PCMS displays was the color of the LEDs used (either orange or white).

Experimental Design and Protocol

To control for possible learning and treatment order effects, researchers developed six different versions of the survey. Thus, each of the survey versions was administered 22 times in each city. After collecting some demographic information about each subject, researchers gave a brief introduction describing the purpose of the study and the overall process for each part of the survey. Participants were then shown an example sign and asked questions to familiarize them with the survey procedure. Each participant then completed the three parts of the survey.

Static Work Zone Speed Limit Signs

Figure 23. Signs Evaluated in Motorist Survey.

Part 1 – Comprehension and Enforceability

Researchers investigated all 11 of the signs shown in Figure 23 in the comprehension part of the survey. However, due to time limitations in conducting the survey, each participant was only shown three out of the 11 signs. In order to obtain more data points on the alternative short term work zone speed limit signs, four of the signs were only viewed by 132 subjects. These signs included the two "YOUR SPEED" signs and the two advisory speed limit PCMS text signs. This enabled the remaining seven alternative short term work zone speed limit signs to be viewed by 264 subjects. The order of the sign displays was randomized to control for possible learning and treatment order effects.

Each participant was asked to assume that they were driving down a freeway where the posted speed limit had been 70 mph for some time. In addition, they were to assume that they were traveling at 70 mph and saw the sign displayed on the computer screen. Each display was shown for five seconds and then automatically turned off. This five second exposure time represented the time available to read a 48 inch by 60 inch speed limit sign on a typical highway traveling at 70 mph (based on 1 inch of letter height per 30 ft of legibility distance). Figure 24 contains an example of the display shown on the computer screen in part 1 of the survey.

After the sign display was turned off, researchers asked the following series of questions to determine if the participants comprehended the signs.

- What type of sign was just displayed on the computer screen?
- What information did the sign give you?
- What was the speed limit shown?
- What activity was the sign being used for? (Only asked for sign displays that included a work zone sign (G20-9)).

Figure 24. Example of Display Shown on Computer Screen in Part 1.

Researchers then asked the following questions to determine if the participants thought the signs were advisory or regulatory in nature (i.e., the speed limit was an advisory speed for which a speeding ticket cannot be issued or the speed limit was a regulatory speed for which a speeding ticket can be issued).

- If you continue going 70 mph past the sign, do you think you could get a speeding ticket?
- What made you think that?

For the static work zone speed limit sign with flashing beacons activated (Figure 23b), researchers also asked participants if the beacons were not flashing, did they think they could get a speeding ticket it they continued driving at 70 mph. Researchers asked this additional question to determine if participants understood that when the beacons were not flashing the reduced work zone speed limit was not in effect (i.e., they could continue to travel at the normal non-work zone speed limit).

Part 2 – Color Comparisons

Researchers conducted part 2 of the survey to further explore motorists perceptions of the meaning of orange versus white LEDs used to display work zone speed limits. While the numerals on the ESL signs may be comprised of either white or orange LEDs according to the Texas MUTCD (*14*), the discussions with law enforcement documented in Chapter 2.2 identified that police felt that the orange LED numerals indicated an advisory speed (for which a speeding ticket cannot be issued), instead of a regulatory speed limit.

Only six of the signs in Figure 23 were included in part 2 of the survey. These included the two ESL signs and all four PCMS displays. These signs were displayed in the following three groups to all participants: 1) orange and white ESL signs, 2) orange and white PCMS text messages, and 3) orange and white PCMS graphic displays. The order of the grouped sign displays was randomized to control for possible learning and treatment order effects. The three static work zone speed limit signs were not included since they did not have a LED sign component. In addition, the "YOUR SPEED" signs were not included since they were only used as distracter signs.

Before beginning part 2 of the survey, participants were reminded that they were still driving down a freeway where the posted speed limit had been 70 mph for some time and that they were still traveling at 70 mph. Each participant was then shown a group of sign displays. The group of sign displays remained on the computer screen while each participant answered the following series of questions.

- Do you know the difference in these signs? If so, please explain.
- Do these signs have the same meaning? Why or why not?
- Do you think you could get a speeding ticket if you continue going 70 mph past either of these signs? What made you think that?

The first question was asked to ensure that the participants actually noticed the LED color differences on the computer screen. The second question was used to determine if the participants felt there was a difference in the meaning (i.e., advisory versus regulatory) between the two signs. The third question was asked to determine if the participants thought the signs were advisory or regulatory in nature (i.e., the speed limit was an advisory speed for which a speeding ticket cannot be issued or the speed limit was a regulatory speed for which a speeding ticket can be issued). This process was repeated for the remaining two sign groups before continuing to part 3.

Part 3 – Preferences

Researchers conducted part 3 of the survey to determine motorists' preferences of the work zone speed limits signs. All of the signs in Figure 23, except the "YOUR SPEED" signs, were shown to all of the participants. The signs were displayed in the following groups: 1) static signs (three signs), 2) ESL signs (two signs), and 3) PCMS displays (two text signs and two graphic signs). As in part 2, the order of the sign groups was randomized to control for possible learning and treatment order effects.

At the beginning of part 3, researchers explained that three groups of signs would be displayed on the computer screen and that each group contained different sign options that could be used in the same situation. Participants were also informed that some of the signs would be signs they had already seen, but there would be additional signs that they had not seen in the previous sections of the survey. Each participant was then shown one group of sign displays. The group of sign displays remained on the computer screen while each participant answered the following questions.

- Please rate each sign shown individually on how well you think that sign is at notifying drivers that they are in a work zone and there is a reduced speed limit. (Participants used a scale from one to five, where one indicated an excellent job and five indicated a terrible job.)
- Out of the signs you just rated, overall which sign do you think would be the most effective at notifying drivers that they are in a work zone and there is a reduced speed limit? Why?

This process was repeated for the remaining two sign groups. After which, the participants selected their overall sign preference from their top choice from each of the three sign groups.

DATA ANALYSIS

First, researchers combined the participants' responses from the four survey locations. For part 1 of the survey, researchers computed the percentage of correct responses for each treatment. For the seven speed limit signs with a work zone sign, the correct responses were those that indicated the sign was a work zone speed limit sign. Participants' responses that never verbally verified that the speed limit applied to a work zone were not considered correct. For the two PCMS text messages, the correct responses were those that mentioned the sign was a speed limit sign, since there was no indication that the speed limit applied to a work zone. Signs were considered to be understood by motorists when 85 percent of the total participants correctly interpreted the treatment.

For part 2 of the survey, researchers used the first question to determine whether or not participants noticed that the two signs shown simultaneously on the computer screen had different color displays (i.e., either white or orange LEDs). Table 23 shows that less than 5 percent of the subjects for each sign group did not notice the different color displays. Since the objective of this part of the survey was to explore motorists' perceptions of the meaning of orange versus white displays, responses from participants that did not notice the color difference between signs were not included in the analysis. For the remaining part 2 questions, researchers computed the percentage of responses for each treatment.

Table 23. Different Color Display Comprehension Percentages.

Sign Groups	Percent of Participants	
	Noticed Color Difference	Did Not Notice Color Difference
Orange ESL and white ESL (n=792)	97%	3%
Orange PCMS graphic and white PCMS graphic (n=792)	99%	1%
Orange PCMS text and white PCMS text (n=792)	99%	1%

The final portion of the analysis was conducted on the preference information collected in part 3 of the survey. Researchers determined an average rating for each sign based on the cumulative data from all survey locations by adding up the rating number given by each participant and then dividing by the number of participants in the study. They also identified a percentage of participants who preferred different options within each category of signs and their overall preference.

RESULTS

Part 1 – Comprehension and Enforceability

As shown in Table 24, more than 95 percent of the participants understood that the three static signs, two ESL signs, and two PCMS graphic displays indicated a work zone speed limit. Less than 1 percent of participants thought the ESL signs were displaying their speed (i.e., confused the ESL sign with a "YOUR SPEED" sign).

Table 24. Motorist Survey Sign Comprehension Results.

Sign	Percent of Participants who Correctly Comprehended Sign Meaning
Static standard WZSL sign (n=264)	96.6%
Static WZSL sign with flashing beacons (n=264)	98.1%
Static WZSL roll-up sign (n=264)	99.6%
Orange ESL sign (n=264)	100.0%
White ESL sign (n=264)	98.1%
Orange PCMS graphic (n=264)	96.2%
White PCMS graphic (n=264)	97.3%
Orange PCMS text (n=132)	99.2%
White PCMS text (n=132)	99.2%

WZSL = Work Zone Speed Limit

Ninety-nine percent of the participants also understood that both of the PCMS text messages were speed limits. For the orange PCMS text message, 14 percent of these participants actually indicated that the sign displayed a work zone speed limit. Based on comments, these participants assumed that the speed limit applied to a work zone situation because of the orange LED color.

As shown in Table 25, at least 99 percent of the participants thought they could receive a speeding ticket for traveling over the reduced work zone speed limit posted on the standard static and roll-up work zone speed limit signs, two ESL signs, and two PCMS graphic displays. This was also true for the static work zone speed limit sign with flashing beacons when the flashing beacons were activated. However, when the flashing beacons were not activated, almost half of the participants still thought the reduced speed limit was in effect and therefore could receive a speeding ticket for traveling over the reduced work zone speed limit on the sign. Speed limit text messages on PCMSs are typically used to supplement posted regulatory speed limit signs since they are typically considered as warning signs. Interestingly, independent of LED color 98 percent of the participants thought they could get a speeding ticket for traveling over the speed limit displayed as a text message on the PCMSs.

Table 25. Participants' Perceptions of the Enforceability of the Speed Limit Posted on the Signs.

Sign	Speed Limit on Sign (mph)	Percent of Participants Who Thought They Could Receive a Speeding Ticket for Traveling Over Speed Limit on Sign
Static standard WZSL sign (n=264)	60	99.6%
Static WZSL sign with flashing beacons (n=264) - Flashing beacons activated - Flashing beacons not activated	60	 99.6% 49.2%
Static WZSL roll-up sign (n=264)	60	99.2%
Orange ESL sign (n=264)	55	99.2%
White ESL sign (n=264)	55	100.0%
Orange PCMS graphic (n=264)	50	99.6%
White PCMS graphic (n=264)	50	99.6%
Orange PCMS text (n=132)	50	97.7%
White PCMS text (n=132)	50	97.7%

Part 2 – Color Comparisons

In part 2 of the survey, all of the participants were shown the following three sign groups: 1) ESL signs, 2) PCMS text messages, and 3) PCMS graphic displays. Each group contained two signs with different color displays (i.e., either white or orange LEDs) side-by-side on the computer screen. Once it was established that participants recognized a difference in appearance between the two alternatives shown, researchers questioned them as to how this difference affected their interpretation of the sign (i.e., did they have different meanings). Table 26 shows the percentage of participants who believed that the signs did and did not have different meanings based on the change in LED color. The majority, 88 percent or more, of the participants believed that the signs had the same meaning (i.e., LED color did not change meaning of sign).

Table 26. Percentage of Responses to Question "Do These Signs Have the Same Meaning?"

Sign Group	Do the Signs have the Same Meaning?		
	Yes	No	Not Sure
Orange ESL and white ESL (n=770)	89%	10%	1%
Orange PCMS graphic and white PCMS graphic (n=783)	89%	11%	0%
Orange PCMS text and white PCMS text (n=786)	88%	12%	0%

For those participants that indicated there was a difference in the meaning between the two signs (12 percent or less), researchers asked them to explain the difference. Table 27 contains this information. For all three of the sign groups, approximately one-fourth of the participants thought the change in LED color was an indication of a regulatory versus an advisory speed sign. The most commonly identified difference in meaning (29 to 40 percent) was that the orange LED indicated something pertaining to a work zone (e.g., workers present, an indication of increased danger within the work zone, warning to use more caution in work zone area, etc.), whereas the white LED was a standard speed limit sign implying no work zone activity or less extensive work activity (e.g., no workers present, no work activity being performed, less complicated work zone set up or less dangerous work zone activity such as mowing, etc.).

Nine percent of the participants believed that the ESL sign with orange LEDs was an indication of the speed they were traveling (i.e., "YOUR SPEED" sign) and not a speed limit sign. These findings are similar to the Atlanta District motorist survey findings discussed in Chapter 2.2. It should be noted that none of the participants thought the ESL sign with white LEDs was a "YOUR SPEED" sign.

Six to 9 percent of the participants felt that the difference in LED color was an indication of daytime versus nighttime speed limits, and 3 to 7 percent stated that it was indicating when the sign was on or off. These two categories could be attributed to the participants' difficulty in perception of the colors illuminated or displayed on the computer monitor.

Table 27. Percentage of Participants that Identified Differences in Sign Meanings.

Signs Group	Regulatory vs. Advisory	Other Responses				
		Work Zone	Your Speed	Day vs. Night	Sign On vs. Off	Other
ESL (White vs. Orange) (n=79)	22%	29%	9%	6%	3%	32%
PCMS Graphic (White vs. Orange) (n=89)	25%	40%	2%	9%	7%	17%
PCMS Text (White vs. Orange) (n=94)	22%	33%	4%	7%	4%	29%

As explained earlier in this chapter, to determine if the participants thought the signs were advisory or regulatory in nature (i.e., the speed limit was an advisory speed for which a speeding ticket cannot be issued or the speed limit was a regulatory speed for which a speeding ticket can be issued), researchers asked participants to indicate if they believed they could receive a citation if they exceeded the speed indicated on the signs. Table 28 indicates the percentage of participants for each sign who believed they could or could not receive a citation based on the given sign. For all three of the sign groups, the majority of the participants (97 percent or higher) believed that both sign options (white and orange) were enforceable by law and they could get a speeding ticket if they continued going 70 mph. This group is shown as those that responded yes to both of the signs (orange and white LEDs). The shaded area indicates those participants that felt the signs with the orange LEDs were not enforceable (could not get a speeding ticket) and the signs with the white LEDs were enforceable (could get a speeding ticket). The majority of these individuals believed that the sign with the orange LEDs was an advisory sign (could not get a speeding ticket) and the signs with the white LEDs were regulatory signs (enforceable or could get a speeding ticket). The remaining 1 percent in each group represent those that believed they could get a speeding ticket with the sign with orange LEDs but could not with the sign with white LEDs. Most of these individuals believed the orange LED indicated the sign was on, while the white LED sign was off.

Table 28. Percentage of Responses to Question "Do You Think You Could Get a Speeding Ticket if You Continue Going 70 mph?"

Sign Group	Orange Response	White Response	Percent
ESL signs	Yes	Yes	98%
	Yes	No	1%
	No	Yes	1%
	No	No	0%
PCMS – text	Yes	Yes	97%
	Yes	No	1%
	No	Yes	2%
	No	No	0%
PCMS – graphic	Yes	Yes	98%
	Yes	No	1%
	No	Yes	1%
	No	No	0%

Part 3 – Preferences

The final section of the survey identified which of the sign alternatives tested were better received by the public. The first task researchers gave to the participants was to rate each sign individually based on how well they believed it notified a driver that they were in a work zone and that there was a reduced speed limit. There were three categories of signs included in this portion of the study: 1) static and roll-up signs, 2) ESL signs, and 3) PCMS signs.

Table 29 shows the average rating of each sign alternative. These ratings were based on a scale from 1 to 5, where 1 indicated that the sign was doing an excellent job of informing the motorists and 5 indicated it was doing a terrible job. The sign that had the lowest (and therefore best) average rating was the static sign with flashing beacons (1.2). Based on comments, researchers believe that this sign was rated the best due to the flashing beacons. The second lowest rating was for the orange ESL sign (1.8), followed closely by the white ESL (2.0). Researchers believe these signs were rated well due to their familiarity with the sign design (i.e., the sign looks like standard speed limit sign) and the use of new technology (i.e., changeable numerals). Overall, the PCMS sign category had the highest (and therefore worst) average ratings as a group. However, it should be noted that all of the options except the roll-up static sign had an average rating which was lower than three and therefore were favorably received by the study participants. The participants thought the static roll-up sign was ineffective because it was too low to the ground and thus could get knocked down more easily or become dirty.

Table 29. Average Rating of Work Zone Speed Limit Sign Alternatives.

Sign Category	Sign Explanation	Average Rating
Static signs	Standard	2.2
	Flashing beacons	1.2
	Roll-up	3.2
ESL signs	Orange LEDs	1.8
	White LEDs	2.0
PCMSs	Orange text	2.3
	White text	2.3
	Orange graphic	2.8
	White graphic	2.5

The final questions posed to the participants was to select their overall most effective sign at notifying drivers that they are a work zone and there is a reduced work zone speed limit. This assessment was accomplished by having each participant select one sign from each sign category and then their overall selection from these signs. Table 30 shows the participants' preference for each sign category and overall. The flashing beacon was selected as the best sign in the static sign category (91 percent) because the participants felt that the flashing beacons would gain the attention of drivers. In the ESL sign category, the orange LED sign was selected as the best (64 percent) primarily due to the visibility of the sign and that the color orange indicated to use more caution. In the PCMS group, there was a close split between the white text (32 percent), the white graphic (28 percent), and the orange text (27 percent). Most of the participants felt that their selection was bigger, clearer, or easier to see.

Overall, 72 percent of the participants preferred the flashing beacon sign. However as stated in the comprehension results (part 1 of this chapter), when the flashing beacons were not activated, almost half of the participants still thought the reduced speed limit was in effect and therefore could receive a speeding ticket for travelling over the reduced work zone speed limit on the sign. Thus, participants did not understand that the reduced speed limit was no longer in effect and that they could travel at the normal non-work zone speed limit (i.e., 70 mph). Unfortunately, there was no clear preference between the remaining signs.

Table 30. Participant Preference Percentages for Work Zone Speed Limit Sign Alternatives.

Sign Category	Sign Explanation	Participant Percentage	
		In Category	Overall
Static signs	Standard installation	8%	3%
	Flashing beacons	91%	72%
	Roll-up	1%	0%
ESL signs	Orange LEDs	64%	2%
	White LEDs	36%	2%
PCMSs	Orange Text	27%	7%
	White text	32%	9%
	Orange graphic	13%	2%
	White graphic	28%	2%

Summary

Overall, more than 95 percent of the participants understood that the static roll-up sign, ESL signs, and PCMS graphic sign displays indicated a work zone speed limit. In addition, over 99 percent of the participants felt they could get a speeding ticket if they traveled over the work zone speed limit displayed. While 98 percent of the participants understood that the static signs with flashing beacons activated signified a work zone speed limit that was enforceable with a speeding citation, almost half of the participants (49 percent) thought that the work zone speed limit was still in effect when the flashing beacons were not activated (i.e., could receive a speeding ticket for traveling over the reduce speed limit). Interestingly, 98 percent of the participants thought the PCMS text messages (which are warning signs used to supplement posted regulatory speed limit signs) were also enforceable with a speeding citation.

In color comparisons (orange versus white LED displays), the majority (88 percent or more) of the participants felt there was no difference in the meaning of the signs based on the change in LED color. In fact, there were less the 2 percent of the participants that stated the difference in the color of the signs was attributed to orange being an advisory sign and white being a regulatory sign.

All of the sign options evaluated had an average rating, with the exception of the roll-up static sign. The sign preferred by participants was the static sign with flashing beacons; however, this sign was not understood by almost half of the participants.

RECOMMENDATIONS

Accurately predicting the actual speeds at which motorists will travel within a particular work zone prior to the establishment of that work zone on the roadway is difficult. Therefore, the selection of the maximum safe speed is based on work zone conditions which are believed to affect the safety of the traveling public and construction workers. TxDOT's procedure for determining if a reduced regulatory speed limit should be established in a construction work zone came from NCHRP research recommendations from the mid 1990s. The procedure takes into consideration the type of work activity and a number of other site-specific factors; however, for most of the work zone conditions speed limit reductions up to 10 mph are allowed if any of the factors listed for each condition are present. Thus, reduced speed limits can be justified in a large majority of work zones, and while a speed limit reduction of 5 mph may be used, the one typically requested by TxDOT personnel is the maximum allowable speed reduction (10 mph).

Unfortunately the low levels of compliance with reduced work zone speed limits reported in a number of studies suggest that many conditions, factors, and combinations thereof now used to warrant lower speed limits are not perceived by motorists as justifying the need for slower speeds. Changes to the speed limit selection process that result in reduced speed limits that more closely correspond to motorist perceptions that reduced speeds are necessary should raise the credibility of TxDOT's work zone speed limit procedures with the public. In addition, the actual travel speeds through the work zone should be more closely aligned with the reduced work zone speed limit. Based on the results presented in Part 1 of this report and input from the TxDOT Project Monitoring Committee, researchers recommend the following changes to the Work Zone Speed Limit Worksheet located in the TxDOT Work Zone Standards (*16*) (see Appendix B).

- All references to conditions that do not currently warrant speed limit reductions (i.e., roadside activity and moving activity on shoulder) should be removed.
- For <u>shoulder activity</u> the maximum amount of speed reduction should be changed to 5 mph. Speed reductions should be discouraged on roadways with existing speed limits less than 65 mph.
- For <u>lane encroachment</u> the maximum speed reduction should be changed to 5 mph. Speed reductions should be discouraged on roadways with existing speed limits less than 65 mph. The following factors should be added: 1) "*lane width reduction of*

1 foot of more with a resulting lane width between 10 and 11 feet" and 2) "*traffic control devices encroaching on a lane open to traffic or within a closed lane but within 2 feet of the edge of the open lane*." The "*reduced design speed for stopping sight distance*" factor should be removed since TxDOT TRF prefers not to reduce the speed limit based solely on reduced design speeds. Instead of reducing the speed limit, advisory speeds can be used where design standards or physical conditions of the roadway restrict safe operating speeds to values less than the posted regulatory speed limit.

- For <u>lane closures</u> the maximum speed reduction should remain 10 mph. Independent of operating speed, the maximum speed reduction should be used when workers are in a closed lane unprotected by barrier and only a single travel lane remains open in the work zone; however, when more than one travel lane will remain open, speed reductions less than 10 mph should be considered. When unprotected workers are not a factor, speed limit reductions should be discouraged on roadways with existing speed limits less than 65 mph and on roadways with existing speed limits greater than or equal to 65 mph when more than one travel lane will remain open. The factors addressing reduced design speed for taper length or speed change lane length, horizontal curve, and stopping sight distance should be removed based on the reasons previously identified. The factor for "*traffic congestion created by a lane closure*" should also be removed since this can be considered an unexpected condition.
- For <u>temporary diversions</u> the maximum speed reduction should remain 10 mph. Speed limit reductions should be discouraged on roadways with existing speed limits less than 65 mph. The following factor should be added: *"barrier within 2 feet of the traveled way*."
- <u>Centerline or lane line encroachment</u> should be removed since this condition is just another type of lane closure; and thus, is addressed under the lane closure condition.
- The following statement should be removed to discourage the use of reduced speed limits based solely on reduced design speeds: "*Where work zone geometrics with reduced design speeds cannot be avoided, the work zone speed limit should not exceed the design speed, even if this requires a speed limit reduction greater than 10 mph*." Again, advisory speeds can be used where design standards or physical

conditions of the roadway restrict safe operating speeds to values less than the posted regulatory speed limit.

- The following statement should be added to allow TxDOT TRF the ability, when justified, to implement reduced speed limits greater than those recommended or for other types of work zone situations not specifically addressed: "*There should not be a reduction in the existing regulatory speed limit greater than those recommended herein or for any other work zone conditions unless unusual situations create hazardous conditions for motorists, pedestrians, or workers. Requests of this nature will be reviewed and approved by TxDOT TRF on a case-by-case basis*."

Researchers also recommend that TxDOT revise Form 1204, Request for Construction Speed Zone *(36)*. This form should include a place for TxDOT to document the work zone condition(s) and factor(s) used to justify the reduced work zone speed limit, as well as the maximum amount of speed reduction allowed for the work zone condition/factor combination. This will allow TxDOT TRF personnel to more easily determine whether the requested work zone speed limit is warranted.

Unfortunately, motorists do not always recognize the work zone hazard and thus may be driving too fast for conditions. Where the need for lower speed limits below actual travel speeds exists due to a work zone hazard that is not adequately perceived by motorists, enforcement should be targeted in order to encourage motorist compliance and to raise motorist awareness of their surroundings. Examples include: unexpected conditions (e.g., construction entrances when work is occurring, turning traffic, crash history, etc.), speed reductions greater than those recommended above, and speed reductions for other work zone conditions that result in unusual situations that create hazardous conditions for motorists, pedestrians, or workers.

Current Texas law is fairly restrictive in terms of establishing reduced speed limits in work zones. Most of the difficulties lie in the need to establish a single speed limit on a roadway segment through an order documented in the meeting minutes of the Texas Transportation Commission. Whereas current law allows TxDOT to deactivate a work zone speed limit when not needed (by removing or covering the sign that designates the lower speed limit), it does not provide TxDOT with the flexibility to easily accommodate changes in the work zone speed limit based on the existing work conditions (e.g., 5 mph for a lane encroachment condition and 10 mph when a lane is closed). Therefore, changes to the current code would be needed to provide additional flexibility to TxDOT to address changing conditions in a work zone through changes in a reduced work zone speed limit. Several other states have recognized the need for this flexibility, and have laws on their books to grant the DOT or its representative the authority to determine and post appropriate work zone speed limits. Given that a precedent has been set, researchers recommend that TxDOT consider requesting legislative action to grant authority to the Executive Director or his designee to establish work zone speed limits, rather than the Texas Transportation Commission.

Short term work zone speed limits are reduced speed limits that are posted and visible to motorists only when work activity is present. When the work activity is not present, the short term work zone speed limit signs should be removed or covered; thereby allowing the legal speed limit for that segment to revert back to the normal non-work zone speed limit. Although TxDOT has allowed short term work zone speed limits to be used for several years, recent Texas legislation *(22)* has emphasized their use.

The major challenge with short term work zone speed limits is the daily install/remove or uncover/cover process of the signs which represents an additional task for the contractor that reduces overall work productivity. In addition, the potential exists for the contractor to forget or simply choose not to cover or remove signs. In effect, the failure to cover or remove the signs turns the short term limit into a long/intermediate one. In addition, differences between TxDOT's work zone speed limit policy and law enforcement's speed limit philosophies (e.g., local law enforcement prefers the reduced speed limits always be in effect whether or not work activity is present) are hindering the implementation of short term work zone speed limits.

In this project, researchers evaluated several alternative work zone speed limit devices that could be used to better manage short term work zone speed limits. Based on the results presented in Part 2 of this report, researchers recommend the use of ESL signs and flexible roll-up static work zone speed limit signs. In order to reduce the potential confusion between ESL signs and "YOUR SPEED" signs, and ensure that the speed limit is considered a regulatory speed limit, the changeable display should be comprised of white LEDs. Prior to implementation, researchers recommend that TxDOT develop standards for both types of signs and ensure they conform to applicable TxDOT Departmental Material Specifications *(55)* and are compliant with current criteria for crashworthy work zone traffic control devices *(37)*.

Currently, TxDOT standards (*21*,*54*) do not specifically show the exact location of work zone speed limit signing with respect to the work activity and other required work zone signing. Thus, when TxDOT maintenance contracts include the use of short term work zone speed limits but utilize these standard plans, the actual location of the work zone speed limit signing in the field is determined by the contractor and TxDOT inspector, unless a specific traffic control plan is created by TxDOT personnel for the project. This issue has been addressed by other state DOTs, who have either (a) modified their standard sheets to integrate the speed limit signing with the work zone advance warning signing or (b) included specific guidance about the location of the speed limit signs as design notes in their standards. Researchers recommend that similar modifications be made to the TxDOT standard sheets so as to facilitate the use of short term work zone speed limits by contractors and TxDOT field personnel (when properly authorized through the Transportation Commission Minute Order process).

REFERENCES

1. *Synthesis of Safety Research Related to Traffic Control and Roadway Elements*. Report No. FHWA-TS-82-233. FHWA, U.S. Department of Transportation, Washington, D.C., December 1982.
2. Maximum Speed Requirement. Texas Transportation Code, Section 545.351, Available at http://tlo2.tlc.state.tx.us/statutes/tn.toc.htm. Accessed August 31, 2008.
3. Authority of Transportation Commission to Alter Speed Limits. Texas Transportation Code, Section 545.353. Available at http://tlo2.tlc.state.tx.us/statutes/tn.toc.htm. Accessed August 31, 2008.
4. *Procedures for Establishing Speed Zones*. Texas Department of Transportation, Austin, Texas, November 2006. Available at http://onlinemanuals.txdot.gov/txdotmanuals/szn/szn.pdf. Accessed August 8, 2008.
5. *Survey of Speed Zoning Practices*. Institute of Transportation Engineers, Washington, D.C., 2001.
6. McLean, J.R. Review of the Design Speed Concept. *Australian Road Research*, Vol. 8, No. 1, 1978, pp. 3-16.
7. McLean, J.R. An Alternative to the Design Speed Concept for Low Speed Alignment Design. In *Transportation Research Record: Journal of the Transportation Research Board, No. 702*, Transportation Research Board of the National Academies, Washington, D.C., 1979, pp. 55-63.
8. Glennon, J.C., J.E. Leisch, and T.R. Newman. *Safety and Operational Considerations for Design of Rural Highway Curves*. Report No. FHWA-RD-83/035. Federal Highway Administration, Washington, D.C., August 1983.
9. Lamm, R., E.M. Choueiri, J.C. Haywood, and A. Paluri. Possible Design Procedure to Promote Design Consistency in Highway Geometric Design on Two-Lane Rural Roads. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1195*, Transportation Research Board of the National Academies, Washington, D.C., 1988, pp. 111-121.
10. Islam, M.N., and P.N. Seneviratne. Evaluation of Design Consistency of Two-Lane Rural Highways. In *ITE Journal*, February 1994, pp. 28-31.
11. Anderson, I.B., R.Q. Brackett, K.M. Collins, K.L. Fink, R.A. Krammes, C.J. Messer, J.L. Ottesen, O.J. Pendleton, and M.A. Shafer. *Horizontal Alignment Design Consistency for Rural Two-Lane Highways*. Report No. FHWA-RD-94-034, Federal Highway Administration, Washington D.C., 1995.
12. Poe, C.M., J.P. Tarris, and J.M. Mason, Jr. *Relationships of Operating Speed to Roadway Geometric Design Speeds*. Report No. FHWA-RD-96-024, Federal Highway Administration, Washington, D.C., 1996.
13. Procedures for Establishing Speed Zones. Texas Administrative Code, Title 43, Part 1, Chapter 25, Subchapter B. Available at http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC?tac_view=5&ti=43&pt=1&ch=25&sch=B&rl=Y. Accessed August 31, 2008.
14. *Texas Manual on Uniform Traffic Control Devices*. Texas Department of Transportation, Austin, Texas, 2006. Available at http://www.dot.state.tx.us/publications/traffic.htm. Accessed August 31, 2008.

15. Mahoney, K., R.J. Porter, D.R. Taylor, B.T. Kulakowski, and G.L. Ullman. *Design of Construction Work Zones on High-Speed Highways*. NCHRP Report 581, Transportation Research Board of the National Academies, Washington, D.C., 2007.
16. Work Zone Speed Limit Worksheet. Work Zone Standards, Traffic Operations Division, Texas Department of Transportation, Austin, Texas, March 2003. Available at http://www.dot.state.tx.us/insdtdot/orgchart/cmd/cserve/standard/toc.htm. Accessed August 31, 2008.
17. Crowther, L.R., and K.S. Opiela. *Procedure for Determining Work Zone Speed Limits.* NCHRP Research Results Digest 192. TRB, National Research Council, Washington, D.C., September 1996.
18. Ullman, G.L., and D.R. Riesland. *Catalog of Work Zone Speed Control Methods*. Research Report FHWA/TX-89/1161-2. Texas Transportation Institute, The Texas A&M University System, College Station, Texas, May 1990.
19. Richards, S.H., and C.L. Dudek. Implementation of Work Zone Speed Control Measures. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1086*, Transportation Research Board of the National Academies, Washington, D.C., 1986, pp. 36-42.
20. Benekohal, R.F., P.T.V. Resende, and R.L. Orloski. *Effects of Police Presence on Speed in a Highway Work Zone: Circulating Marked Police Car Experiment.* Report No. FHWA-IL/UI-240. University of Illinois, Urbana, Illinois, 1992.
21. Work Zone Speed Limit Standard. Barricade and Construction Work Zone Speed Limit Standard BC(3)-07. Traffic Operations Division, Texas Department of Transportation, Austin, Texas, 2007. Available at http://www.dot.state.tx.us/insdtdot/orgchart/cmd/cserve/standard/toc.htm. Accessed August 31, 2008.
22. Removing or Covering Signs in Construction or Maintenance Work Zone. Texas Transportation Code, Section 201.907. Available at http://tlo2.tlc.state.tx.us/statutes/tn.toc.htm. Accessed August 31, 2008.
23. *A Policy on Geometric Design of Highways and Streets*. American Association of State Highway and Transportation Officials, Washington, D.C., 2004.
24. Solomon, D. *Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle*. Federal Highway Administration, Washington, D.C., 1964 (reprinted in 1974).
25. Harkey, D.L., H.D. Robertson, and S.E. Davis. Assessment of Current Speed Zoning Criteria. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1281*, Transportation Research Board of the National Academies, Washington D.C., 1990, pp. 40-51.
26. Garber, N.J., and R. Gadiraju. Factors Affecting Speed Variance and Its Influence on Accidents. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1213*, Transportation Research Board of the National Academies, Washington D.C., 1989, pp. 64-71.
27. Benekohal, R.F., L. Wany, R. Orloski, and L.M. Kastel. Speed-Reduction Patterns of Vehicles in a Highway Construction Zone. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1352*, Transportation Research Board of the National Academies, Washington D.C., 1992, pp. 35-45.

28. Benekohal, R.F., and L. Wang. Speed Change Distribution of Vehicles in a Highway Work Zone. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1409*, Transportation Research Board of the National Academies, Washington D.C., 1993, pp. 42-51.
29. Benekohal, R.F., and L. Wang. Relationship Between Initial Speed and Speed Inside a Highway Work Zone. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1442*, Transportation Research Board of the National Academies, Washington, D.C., 1994, pp. 41-48.
30. Brewer, M.A., G. Pesti, and W.A. Schneider. *Identification and Testing of Measures to Improve Work Zone Speed Limit Compliance.* Report No. FHWA/TX-06/4704-1. Texas Transportation Institute, The Texas A&M University System, College Station, Texas, October 2005.
31. Ullman, G.L., P.J. Carlson, and N.D. Trout. *Work Zone-Related Traffic Legislation in Texas*. Report No. FHWA/TX-99/1720-3. Texas Transportation Institute, The Texas A&M University System, College Station, Texas, March 1999.
32. Ullman, G.L. Effect of Radar Transmissions on Traffic Operations at Highway Work Zones. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1304*, Transportation Research Board of the National Academies, Washington D.C., 1991, pp. 261-269.
33. Fontaine, M.D., P.J. Carlson, and H.G. Hawkins, Jr. *Evaluation of Traffic Control Devices for Rural High-Speed Maintenance Work Zones: Second Year Activities and Final Recommendations*. Report No. FHWA/TX-01/1879-2. Texas Transportation Institute, The Texas A&M University System, College Station, Texas, October 2000.
34. Garber, N.J., and S.T. Patel. Control of Vehicle Speeds in Temporary Traffic Control Zones (Work Zones) Using Changeable Message Signs with Radar. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1509*, Transportation Research Board of the National Academies, Washington D.C., 1995, pp. 73-81.
35. Wang, C., K.K. Dixon, and D. Jared. Evaluating Speed-Reduction Strategies for Highway Work Zones. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1824*, Transportation Research Board of the National Academies, Washington, D.C., 2003, pp. 44-56.
36. Request for Construction Speed Zone. Form 1204. Texas Department of Transportation, Austin, Texas, March 7, 2005.
37. Ross Jr., H.E., D.L. Sicking, R.A. Zimmer, and J.D. Michie. *Recommended Procedures for the Safety Performance of Highway Features.* National Cooperative Highway Research Program Report 350, Transportation Research Board of the National Academies, Washington, D.C., 1993.
38. U.S. Department of Transportation, Federal Highway Administration Statistics 2005, Table DL-22. Available at http://www.fhwa.dot.gov/policy/ohim/hs05/htm/dl22.htm. Accessed August 31, 2008.
39. U.S. Census Bureau, American Community Survey 2006, Table ACS Demographic and Housing Estimates 2006. Available at http://factfinder.census.gov/servlet/STTable?_bm=y&-geo_id=04000US48&-

qr_name=ACS_2006_EST_G00_S1501&-ds_name=ACS_2006_EST_G00. Accessed August 31, 2008.

40. *Delaware Code*. Available at http://delcode.delaware.gov/title21/c041/sc08/index.shtml#TopOfPage. Accessed August 31, 2008.

41. *Indiana Code*. Available at http://www.in.gov/legislative/ic/code/title9/ar21/ch5.html. Accessed August 31, 2008.

42. *Code of Virginia.* Available at http://leg1.state.va.us/cgi-bin/legp504.exe?000+cod+46.2-881. Accessed August 31, 2008.

43. *Revised Code of Washington.* Available at http://apps.leg.wa.gov/RCW/default.aspx?cite=46.61.400. Accessed August 31, 2008.

44. *Missouri Revised Statutes*. Available at http://www.moga.mo.gov/statutes/C300-399/3040000010.HTM. Accessed August 31, 2008.

45. *Tennessee Code*. Available at http://www.michie.com/tennessee/lpext.dll?f=templates&fn=main-h.htm&cp. Accessed August 31, 2008.

46. *Oklahoma Statutes*. Available at http://www.lsb.state.ok.us/osstatuestitle.html. Accessed August 31, 2008.

47. *Minnesota Statutes*. Available at https://www.revisor.leg.state.mn.us/statutes/?id=169.14. Accessed August 31, 2008.

48. Hall, J., and E. Wrage. *Controlling Vehicle Speeds in Highway Construction Zones*. Report No. NMSHTD-97-07. New Mexico State Highway and Transportation Department, Santa Fe, New Mexico, December 1997.

49. Letter from Regina S. McElroy (FHWA) to Jerry Britton (Varitext, Inc.), RE: HOTO-1, December 6, 2005. Available at http://www.atssa.com/galleries/default-file/12-6b-05.pdf. Accessed August 31, 2008.

50. *Manual on Uniform Traffic Control Devices*, 2003 Edition with Revisions Numbers 1 and 2 Incorporated, FHWA, U.S. Department of Transportation, December 2007. Available at http://mutcd.fhwa.dot.gov/. Accessed August 31, 2008.

51. Riffkin, M., T. McMurtry, S. Heath, and M. Saito. *Variable Speed Limit Signs Effects on Speed and Speed Variation in Work Zones*. Utah Department of Transportation, Salt Lake City, Utah, January 2008.

52. Richards, S.H., R.C. Wunderlich, and C.L Dudek. *Controlling Speeds in Highway Work Zones*. Report No. FHWA/TX-84/58+292-2. Texas Transportation Institute, The Texas A&M University System, College Station, Texas, February 1984.

53. Graham, J.L., R.J. Paulsen, and J.C. Glennon. *Accident and Speed Studies in Construction Zones*. Report No. FHWA-RD-77-80. Midwest Research Institute, Kansas City, Missouri, June 1977.

54. Traffic Control Plan Standards. Traffic Operations Division, Texas Department of Transportation, Austin, Texas. Available at http://www.dot.state.tx.us/insdtdot/orgchart/cmd/cserve/standard/toc.htm. Accessed August 31, 2008.

55. Departmental Material Specifications. Texas Department of Transportation, Austin, Texas. Available at

http://www.dot.state.tx.us/services/construction/material_specifications/. Accessed August 31, 2008.

APPENDIX A:
TXDOT FORM 1204 – REQUEST FOR CONSTRUCTION SPEED ZONE

Texas Department of Transportation

Request for Construction Speed Zone

Form 1204 (Rev. 3/7/2005)
Page 1 of 2

District: ____________________ County: ____________________

Highway No.: ____________________ Pre-Construction Posted Speed: ____________

Direction*: ____________________ Proposed Construction Speed**: ____________

Contact Person: ____________________ Contact Phone Number: ____________

* Show direction as northerly or southerly, etc., from beginning milepoint to end milepoint.
** If the work zone speed must be lowered more than 10 mph below the posted speed, attach documentation justifying the speed drop. For more information, see standard sheet for Work Zone Speed Limits.
If the work zone speed limit is lowered more than 15 mph below the posted speed, buffer zones will need to be established as well.

Net Length of Each Section Outside of Incorporated Cities:

Section 1: ____________________ Section 2: ____________________

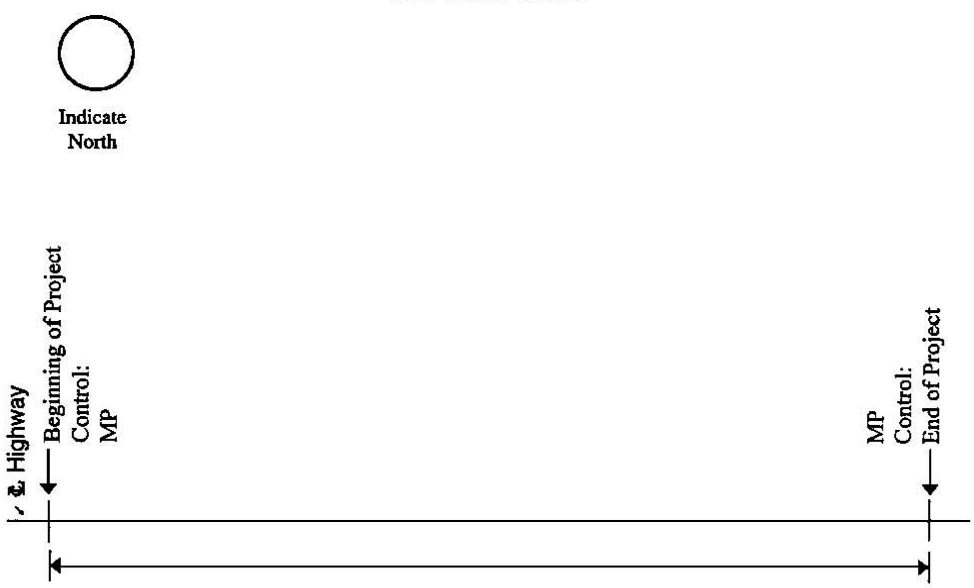
Section 3: ____________________ Section 4: ____________________

Control and Section Number at Both Beginning and End of Each Section:

	Beginning				End			
Section	Milepoint	Cont.	Sec.	Job	Milepoint	Cont.	Sec.	Job
1								
2								
3								
4								

Project No.: ____________________

Draw Sketch Below:

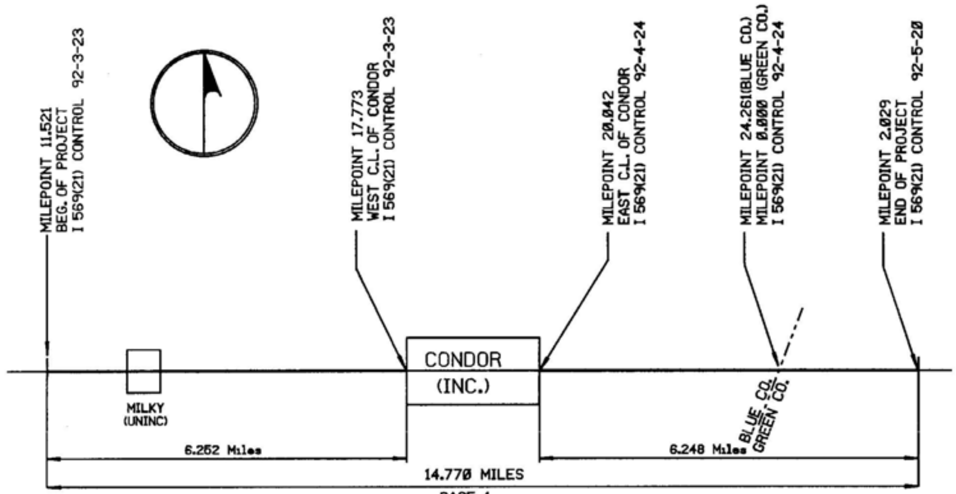


(Instructions on page 2)

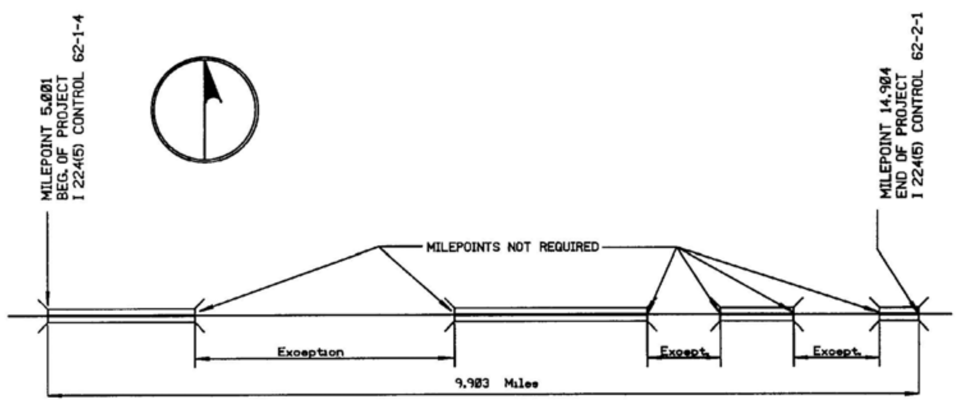
Form 1204 (Rev. 3/7/2005)
Request for Construction Speed Zone
Page 2 of 2

Instructions:

- √ Sketch each project submitted.
- √ Show city limits of all incorporated cities within limits of project, giving milepoints.
- √ Show the approximate location and name of any unincorporated areas within limits of zone.
- √ Show milepoint, project, and control numbers of any county lines that occur within zone limits.
- √ Fill out a separate sheet for each zone requested.
- √ Give net length of each section within the zone.

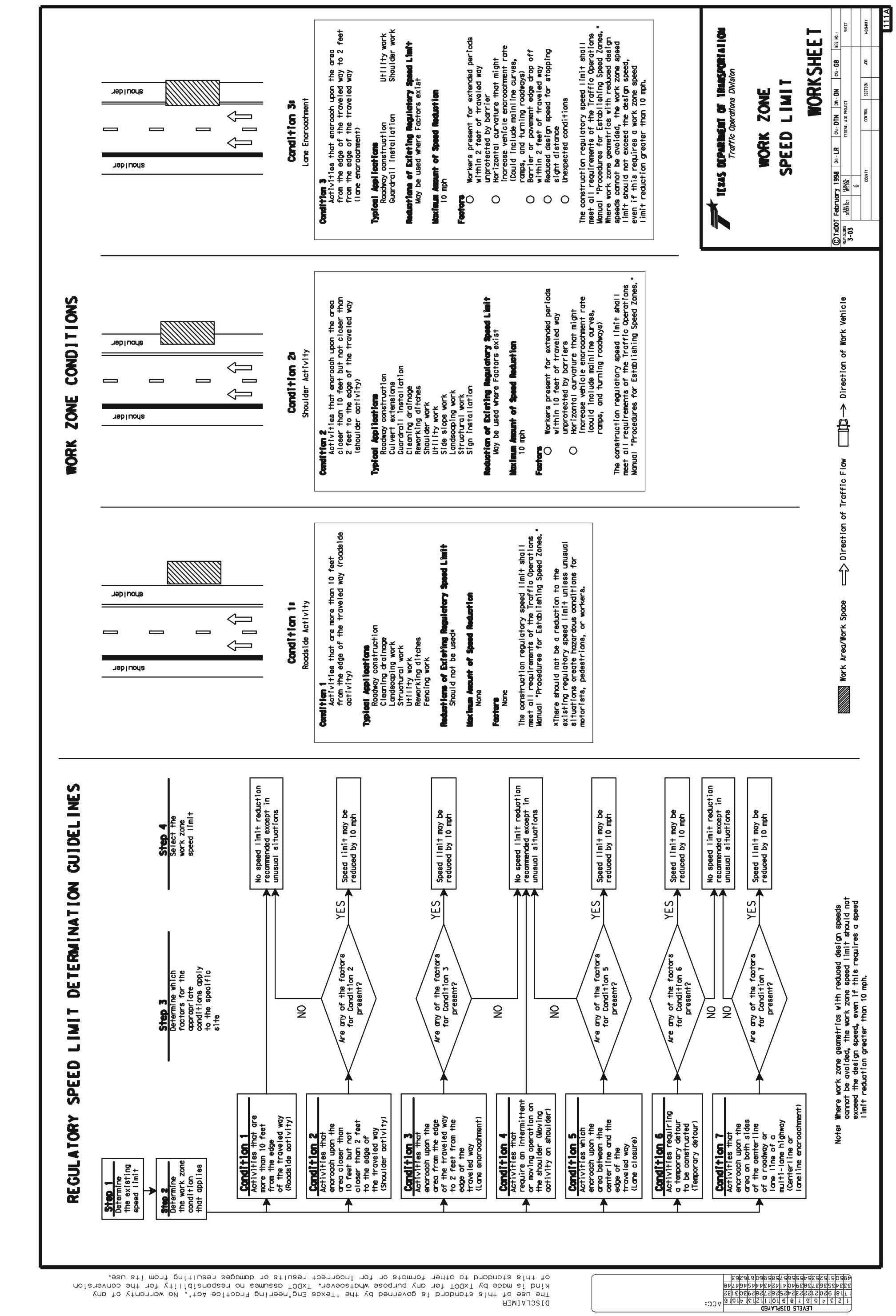


CASE 1
WHERE THERE IS AN INCORPORATED CITY WITHIN THE LIMITS OF THE PROJECT

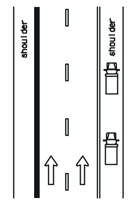


CASE II
WHERE THERE ARE EXCEPTIONS WITHIN THE LIMITS OF THE PROJECT

APPENDIX B:
TXDOT WORK ZONE SPEED LIMIT WORKSHEET



WORK ZONE CONDITIONS (CONTINUED)



Condition 4:

Moving Activity on Shoulder

Condition 4
Activities that require an intermittent or moving operation on the shoulder (moving activity on shoulder)

Typical Applications
- Roadway construction
- Widening
- Delineator installation
- Shoulder and slope work
- Utility work
- Guardrail installation
- Landscape work

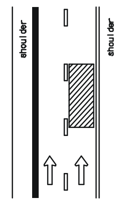
Reductions of Existing Regulatory Speed Limit
Should not be used*

Maximum Amount of Speed Reduction
None

Factors
None

The construction regulatory speed limit shall meet all requirements of the Traffic Operations Manual "Procedures for Establishing Speed Zones."

*There should not be a reduction to the existing regulatory speed limit unless unusual situations create hazardous conditions for motorists, pedestrians, or workers.



Condition 5:

Lane Closure

Condition 5
Activities that encroach upon the area between the centerline and the edge of the traveled way (lane closure)

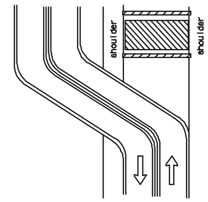
Typical Applications
- Roadway construction
- Pavement repair
- Utility work
- Widening
- Pavement resurfacing
- Pavement marking
- Bridge repair

Reductions of Existing Regulatory Speed Limit
May be used where Factors exist

Maximum Amount of Speed Reduction
10 mph

Factors
- ○ Workers present for extended periods in the closed lane unprotected by barrier
- ○ Lane width reduction of 1 foot or more with a resulting lane width less than 11 feet
- ○ Traffic control devices encroaching on a lane open to traffic or within a closed lane but within 2 feet of the edge of the open lane
- ○ Reduced design speed for taper length or speed change lane length
- ○ Barrier or pavement edge dropoff within 2 feet of the traveled way
- ○ Reduced design speed of horizontal curve
- ○ Reduced design speed for stopping sight distance
- ○ Traffic congestion created by a lane closure
- ○ Unexpected conditions

The construction regulatory speed limit shall meet all requirements of the Traffic Operations Manual "Procedures for Establishing Speed Zones." Where work zone geometrics with reduced design speeds cannot be avoided, the work zone speed limit should not exceed the design speed, even if this requires a work zone speed limit reduction greater than 10 mph.



Condition 6:

Temporary Diversion

Condition 6
Activities requiring a temporary diversion to be constructed (temporary diversion)**

Typical Applications
- Roadway construction
- Subgrade restoration
- Bridge construction
- Culvert repair

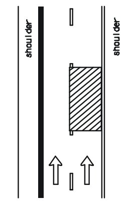
Reductions of Existing Regulatory Speed Limit
May be used where Factors exist

Maximum Amount of Speed Reduction
10 mph

Factors
- ○ Lane width reduction of 1 foot or more with a resulting lane width less than 11 feet
- ○ Reduced design speed for detour roadway or transitions (radius of curvature, superelevation, and sight distance)
- ○ Unexpected conditions

The construction regulatory speed limit shall meet all requirements of the Traffic Operations Manual "Procedures for Establishing Speed Zones." Where work zone geometrics with reduced design speeds cannot be avoided, the work zone speed limit should not exceed the design speed, even if this requires a work zone speed limit reduction greater than 10 mph.

**Detour and transition geometry with a design speed equal to or greater than the existing regulatory speed limit should be provided whenever possible.



Condition 7:

Centerline or Lane Line Encroachment

Condition 7
Activities that encroach upon the area on both sides of the centerline of a roadway or lane line of a multilane highway (centerline or lane line encroachment)

Typical Applications
- Roadway construction
- Pavement marking
- Pavement resurfacing
- Pavement repair
- Widening
- Crack sealing
- Bridge repair

Reductions of Existing Regulatory Speed Limit
May be used where Factors exist

Maximum Amount of Speed Reduction
10 mph

Factors
- ○ Workers present on foot in the traveled way or in the closed lane unprotected by barrier for extended periods
- ○ Remaining lane plus shoulder width is less than 11 feet
- ○ Reduced design speed for taper length or speed change lane length
- ○ Barrier or pavement edge drop off within 2 feet of the traveled way
- ○ Reduced design speed of horizontal curve
- ○ Reduced design speed for stopping sight distance
- ○ Traffic congestion created by lane closure
- ○ Unexpected conditions

The construction regulatory speed limit shall meet all requirements of the Traffic Operations Manual "Procedures for Establishing Speed Zones." Where work zone geometrics with reduced design speeds cannot be avoided, the work zone speed limit should not exceed the design speed, even if this requires a work zone speed limit reduction greater than 10 mph.

Work Area/Work Space ⇨ Direction of Traffic Flow → Direction of Work Vehicle

TEXAS DEPARTMENT OF TRANSPORTATION
Traffic Operations Division

WORK ZONE SPEED LIMIT

WORKSHEET

 DN: LR CK: DTN DW: DN CK: GB
REVISIONS 3-03 | 6 | COUNTY | CONTROL | SECTION | JOB | HIGHWAY | SHEET

1118

LEVELS DISPLAYED ACC:

APPENDIX C:
MOTORIST REACTION FIELD STUDY DETAILED RESULTS

Table C1. Site 1 EB Daytime (Littlefield US-84) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85^{th} Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	70	127	68.8	23.7	4.9	72	39%
Downstream of WZSL sign	60	139	63.5	24.4	4.9	69	73%
PCMS	60	138	63.1	30.7	5.5	69	64%
Right lane closure	60	132	60.0	26.5	5.1	65	42%
Temporary diversion (Main lanes) (DS = 50 mph)	60	128	54.9	38.5	6.2	61	18%
2L2W section No crossing traffic	60	125	49.8	19.8	4.4	55	0%
2L2W section Crossing traffic	60	130	48.4	26.6	5.2	54	1%
End temporary diversion End work zone	60	127	51.7	37.9	6.2	58	10%

WZSL = Work Zone Speed Limit; PCMS = Portable Changeable Message Sign; DS = Design Speed; 2L2W = Two-Lane, Two-Way

Table C2. Site 1 WB Daytime (Littlefield US-84) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85^{th} Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	70	127	69.6	12.9	3.6	73	40%
Downstream of WZSL sign	60	128	61.0	26.3	5.1	67	49%
Lane closure ½ mile ahead sign	60	127	60.3	17.4	4.2	65	44%
Left lane closure "YOUR SPEED" sign	60	132	56.5	15.5	3.9	60	8%
2L2W section Crossing traffic	60	132	49.6	38.9	6.2	57	5%
2L2W section No crossing traffic	60	141	50.8	37.4	6.1	57	7%
End work zone	60	125	60.1	25.5	5.1	65	50%

WZSL = Work Zone Speed Limit; 2L2W = Two-Lane, Two-Way

Table C3. Site 2 EB Daytime (Edmonson SH-194) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85^{th} Percentile Speed (mph)	Percent Exceeding Speed Limit
Work activity [a]	60	127	58.1	50.1	7.1	65	37%
End work zone	60	126	62.8	39.0	6.2	70	62%
Free flow	70	133	65.7	30.8	5.5	71	16%

[a] Workers unprotected near traveled way, pavement edge drop off, narrow lanes, and traffic control device encroachment.

Table C4. Site 2 WB Daytime (Edmonson SH-194) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85^{th} Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	70	126	64.7	35.8	6.0	70	14%
Downstream of WZSL sign	60	126	62.9	51.2	7.2	70	67%
Lane shift	60	126	56.4	61.1	7.8	64	27%
Work activity	60	126	57.6	48.8	7.0	65	31%

WZSL = Work Zone Speed Limit

Table C5. Site 3 EB Daytime (Amarillo I-40) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	70	129	71.8	20.0	4.5	76	65%
Downstream of WZSL sign	60	130	67.2	20.1	4.5	70	95%
Right lane closure	60	131	64.0	34.5	5.9	70	69%
Temporary diversion (Main lanes) (DS = 45 mph)	60	125	60.2	49.1	7.0	68	46%
2L2W section Barrier w/in 2 ft No work activity	60	128	62.3	23.1	4.8	67	60%
2L2W section Barrier w/in 2 ft Work activity	60	160	62.9	16.6	4.1	67	72%
End temporary diversion	60	125	57.2	24.8	5.0	62	27%

WZSL = Work Zone Speed Limit; DS = Design Speed; 2L2W = Two-Lane, Two-Way

Table C6. Site 3 WB Daytime (Amarillo I-40) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	70	126	72.3	17.5	4.2	76	70%
Downstream of WZSL sign	60	134	66.8	34.8	5.9	73	84%
Left lane closure	60	131	62.7	34.9	5.9	69	63%
2L2W section Barrier w/in 2 ft Work activity	60	131	61.4	16.9	4.1	66	53%
2L2W section Barrier w/in 2 ft No work activity	60	126	62.5	17.6	4.2	67	65%

WZSL = Work zone Speed Limit; 2L2W = Two-Lane, Two-Way

Table C7. Site 3 EB Nighttime (Amarillo I-40) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	65	127	66.6	30.0	5.5	72	57%
Downstream of WZSL sign	60	58	64.6	34.1	5.8	71	76%
Right lane closure	60	57	62.6	34.3	5.9	69	54%
2L2W section Barrier w/in 2 ft No work activity	60	106	59.5	30.2	5.5	65	38%

WZSL = Work Zone Speed Limit; 2L2W = Two-Lane, Two-Way

Table C8. Site 4 NB Daytime (College Station SH-6) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	70	138	71.0	21.4	4.6	76	53%
Downstream of WZSL sign	55	129	59.6	34.1	5.8	66	76%
"YOUR SPEED" sign	55	129	57.8	14.4	3.8	61	72%
Construction entrance	55	130	57.7	22.5	4.7	62	68%
Work activity	55	129	59.0	27.4	5.2	65	75%
Temporary diversion (Frontage road) (DS = 55 mph)	55	157	57.5	28.6	5.3	63	61%
On frontage road	55	134	57.5	17.2	4.1	62	71%
Left lane closure [a] No work activity	55	132	58.0	23.5	4.8	63	67%
Left lane closure [a] Work activity	55	142	53.9	15.3	3.9	58	31%

WZSL = Work Zone Speed Limit; DS = Design Speed

[a] Lane closure data were collected on a different day. The lane closure was located in the temporary diversion.

Table C9. Site 4 SB Daytime (College Station SH-6) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	70	132	67.9	15.5	3.9	71	27%
Downstream of WZSL sign Temporary diversion (Frontage road) (DS = 55 mph)	55	130	59.0	22.3	4.7	64	71%
On frontage road	55	133	57.4	21.1	4.6	61	59%
End temporary diversion	55	140	58.2	28.6	5.4	64	64%
"YOUR SPEED" sign	55	145	57.2	12.4	3.5	61	62%
Work activity opposite side	55	140	58.0	22.6	4.8	63	68%
Construction entrance	55	133	57.9	20.9	4.6	62	27%
Work activity	55	162	58.4	20.3	4.5	63	69%

WZSL = Work Zone Speed Limit; DS = Design Speed

Table C10. Site 4 NB Nighttime (College Station SH-6) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	65	137	67.8	23	4.8	72	71%
Downstream of WZSL sign	55	131	58.5	21	4.6	63	75%
"YOUR SPEED" sign	55	123	56.7	13	3.6	60	63%
Construction entrance	55	128	55.7	11	3.3	59	49%
Temporary diversion (Frontage road) (DS = 55 mph)	55	138	54.5	21	4.5	58	41%
On frontage road	55	130	54.6	15	3.9	59	38%

WZSL = Work Zone Speed Limit; DS = Design Speed

Table C11. Site 4 SB Nighttime (College Station SH-6) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	65	126	64.8	21.3	4.6	69	37%
Downstream of WZSL sign Temporary diversion (Frontage road) (DS = 55 mph)	55	130	57.6	23.0	4.8	63	65%
On frontage road	55	129	57.3	22.4	4.7	60	64%
End temporary diversion	55	126	54.9	27.5	5.2	59	43%
"YOUR SPEED" sign	55	124	56.5	12.2	3.5	60	58%
Construction entrance	55	111	57.3	23.8	4.9	61	64%

WZSL = Work Zone Speed Limit; DS = Design Speed

Table C12. Site 5 EB Daytime (Huntsville SH-30) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	60	135	61.9	32.7	5.7	68	60%
Downstream of WZSL sign Right lane closure	50	132	55.9	34.7	5.9	63	82%
Temporary diversion (Main lanes) (DS = 50 mph)	50	150	57.5	26.8	5.2	64	93%
2L2W section No work activity	50	130	59.1	21.6	4.6	64	95%

WZSL = Work Zone Speed Limit; DS = Design Speed; 2L2W = Two-Lane, Two-Way

Table C13. Site 6 NB Daytime (Waco SL-340) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	60	142	57.5	20.7	4.6	62	25%
Left lane closure	60	131	54.3	34.2	5.8	60	12%
Temporary diversion (Frontage road) (DS = 50 mph)	60	132	54.4	32.7	5.7	60	14%
On frontage road	45	136	55.2	48.2	6.9	61	92%
Right lane closure	45	130	54.1	37.2	6.1	60	95%
End temporary diversion	45	134	57.6	39.4	6.3	64	97%

DS = Design Speed

Table C14. Site 6 SB Daytime (Waco SL-340) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	60	139	57.9	20.9	4.6	62	32%
Temporary diversion (Frontage road) (DS = 50 mph)	60	129	57.7	33.2	5.8	63	31%
Downstream of WZSL sign On frontage road	45	151	55.0	46.7	6.8	62	93%
On frontage road	45	115	53.1	35.8	6.0	59	94%

WZSL = Work Zone Speed Limit; DS = Design Speed

Table C15. Site 7 NB Daytime (Waco I-35) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	70	134	70.1	28.3	5.3	75	46%
Downstream of WZSL Sign	60	131	66.5	25.7	5.1	72	90%
Barrier w/in 2 ft Work activity	60	130	68.2	23.2	4.8	73	98%

WZSL = Work Zone Speed Limit

Table C16. Site 7 SB Daytime (Waco I-35) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	65	138	63.1	24.3	4.9	67	32%
Downstream of WZSL Sign	60	134	67.7	28.0	5.3	74	93%
Barrier w/in 2 ft Work activity	60	147	64.6	25.7	5.1	70	82%

WZSL = Work Zone Speed Limit

Table C17. Site 8 EB Daytime (Waco LP-340) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	60	133	62.4	25.1	5.0	67	68%
Temporary diversion (Frontage road) (DS = 50 mph)	60	131	59.5	26.0	5.1	64	40%
Downstream of WZSL sign On frontage road	45	133	57.3	34.2	5.8	63	98%

WZSL = Work Zone Speed Limit; DS = Design Speed

Table C18. Site 8 WB Daytime (Waco LP-340) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	60	144	55.1	29.0	5.4	60	14%
Temporary diversion (Frontage road) (DS = 50 mph)	60	132	49.8	25.4	5.0	54	4%
Downstream of WZSL sign On frontage road	50	132	51.7	28.7	5.4	57	55%

WZSL = Work Zone Speed Limit; DS = Design Speed

Table C19. Site 9 NB Daytime (Waco FM-2113) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85^{th} Percentile Speed (mph)	Percent Exceeding Speed Limit
Work activity [a]	50	90	56.2	51.5	7.2	62	77%
Work activity	40	101	41.1	26.2	5.1	47	50%
No work activity	50	70	49.1	40.0	6.3	55	37%

[a] Workers unprotected near traveled way, pavement edge drop off, narrow lanes, and traffic control device encroachment.

Table C20. Site 9 SB Daytime (Waco FM-2113) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85^{th} Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	60	129	56.3	26.7	5.2	61	19%
Downstream of WZSL sign	50	132	50.6	28.7	5.4	56	52%
Work activity	40	134	41.7	26.8	5.2	47	58%
Work activity [a]	50	132	54.8	29.8	5.5	60	78%

WZSL = Work Zone Speed Limit
[a] Narrow lanes

Table C21. Site 10 NB Daytime (Hillsboro I-35) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85^{th} Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	70	139	72.2	18.9	4.4	77	68%
Downstream of WZSL sign [a]	60	136	65.1	19.9	4.5	70	86%
Work activity Construction entrance Barrier w/in 2 ft	60	132	65.7	26.0	5.1	71	84%
Work activity Barrier w/in 2 ft	60	138	67.8	28.5	5.3	74	96%
Lane shift	60	134	66.4	40.5	6.4	73	86%
Upstream of I-35E/ I-35W split	60	142	71.7	27.7	5.3	77	98%
I-35W ramp	60	130	61.4	21.4	4.6	67	55%
I-35E ramp	60	133	63.7	26.1	5.1	69	71%
End of work zone on I-35E	60	129	68.5	24.5	4.9	73	95%

WZSL = Work Zone Speed Limit

[a] Data collection site in horizontal curve. The angle at which speed data were collected may have produced lower speeds than actually present.

Table C22. Site 10 SB Daytime (Hillsboro I-35) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85^{th} Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow on I-35W	70	147	72.0	23.1	4.8	77	61%
Free flow on I-35E	70	130	71.3	25.1	5.0	75	57%
Downstream of WZSL sign	60	130	66.2	19.7	4.4	71	90%
Work activity Construction entrance Barrier w/in 2 ft	60	129	66.6	22.8	4.8	71	91%
End of work zone	60	129	67.7	17.8	4.2	72	95%

WZSL = Work Zone Speed Limit

Table C23. Site 10 SB Nighttime (Hillsboro I-35) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85^{th} Percentile Speed (mph)	Percent Exceeding Speed Limit
Downstream of WZSL sign	60	130	63.3	20.9	4.6	68	72%
Work activity Construction entrance Barrier w/in 2 ft	60	137	63.9	24.8	5.0	69	73%

WZSL = Work Zone Speed Limit

Table C24. Site 11 NB Daytime (Burleson I-35) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85^{th} Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	65	130	68.0	23.4	4.8	72	64%
Downstream of WZSL sign	55	135	62.3	34.0	5.8	68	85%
No work activity	55	147	66.9	35.3	5.9	73	99%
Work activity	55	131	64.5	30.0	5.5	71	96%
No presence of work zone	55	169	68.0	30.0	5.5	73	99%

WZSL = Work Zone Speed Limit

Table C25. Site 11 SB Daytime (Burleson I-35) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85^{th} Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	65	152	68.4	25.6	5.1	73	71%
Downstream of WZSL sign	55	141	64.7	23.0	4.8	70	100%
Work activity	55	146	62.2	21.6	4.7	67	92%
No work activity	55	143	64.1	26.3	5.1	69	97%
No presence of work zone	55	132	65.8	19.5	4.4	70	100%

WZSL = Work Zone Speed Limit

Table C26. Site 12 EB Daytime (Parker/Palo Pinto Co. I-20) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	70	128	73.0	14.6	3.8	76	75%
Downstream of WZSL sign	60	131	71.8	26.1	5.1	76	98%
Left lane closure	60	135	69.6	30.2	5.5	75	93%
2L2W section Barrier w/in 2 ft No work activity	60	130	64.1	21.2	4.6	69	82%
2L2W section Barrier w/in 2 ft Work activity	60	105	63.9	14.0	3.7	68	86%
End lane closure	60	109	62.4	17.8	4.2	66	67%

WZSL = Work Zone Speed Limit; 2L2W = Two-Lane, Two-Way

Table C27. Site 12 WB Daytime (Parker/Palo Pinto Co. I-20) Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Free flow	65	139	70.5	23.5	4.8	75	89%
Downstream of WZSL sign	60	129	67.9	20.9	4.6	72	95%
Right lane closure	60	129	66.9	20.8	4.6	72	92%
Temporary diversion (Main lanes) (DS = 45 mph)	60	107	60.4	24.8	5.0	66	46%
2L2W section Barrier w/in 2 ft No work activity	60	131	63.5	17.9	4.2	68	76%
2L2W section Barrier w/in 2 ft Work activity	60	135	62.2	13.5	3.7	66	67%
End temporary diversion	60	75	60.4	15.7	4.0	64	53%

WZSL = Work Zone Speed Limit; DS = Design Speed; 2L2W = Two-Lane, Two-Way

APPENDIX D:
ESL SIGN SPECIFICATION

Texas Transportation Institute
The Texas A&M University System
3135 TAMU
College Station, TX 77843-3135

979-845-7596
Fax: 979-845-6006
http://tti.tamu.edu

May 21, 2007

To Whom It May Concern:

The Texas Transportation Institute (TTI) plans to purchase two portable, solar and battery powered, trailer-mounted, changeable speed limit signs for a research project being conducted for the Texas Department of Transportation (TxDOT). Below are the purchase specification details. Please send your quotes including shipping to Melisa Finley, Associate Research Engineer, via fax (979-845-6006) or email (m-finley@tamu.edu) by May 22, 2007 at 5:00 pm CST. Questions should be addressed to Melisa Finley, 979-845-7596.

General Clauses and Conditions

1. All parts not specifically mentioned which are necessary for the unit to be complete and ready for operation or which are normally furnished as standard equipment shall be furnished by the vendor. All parts shall conform in strength, quality, and workmanship to the accepted standards of the industry.
2. The unit shall be completely assembled and adjusted, and all equipment including standard and supplemental equipment shall be installed and the unit made ready for continuous operation upon delivery.
3. The unit provided shall meet or exceed all federal and state of Texas safety, health, lighting and noise regulations and standards in effect and applicable to equipment furnished at the time of manufacture.

Specifications

1. Scope: This specification describes a portable, trailer mounted solar assisted and battery powered changeable speed limit sign with light emitting diode (LED) display panel. This unit will be used by TTI to display the regulatory speed limit to motorists in work zones.
2. Sign Panel: Sign panel shall be a R2-1 static regulatory speed limit sign 48 inches wide by 60 inches high. Sign panel shall meet the TxDOT standard sign designs which can be found in the *Standard Highway Sign Designs for Texas*. Sign panel shall meet TxDOT Typical Sign Requirements for Regulatory Signs, TSR(5)-03. Sign panel shall be equipped with a mode indicator lamp on the reverse side of the panel to indicate that the sign is operating.
3. Changeable Speed Limit Display Panel: Changeable speed limit display panel shall be LED technology which displays vehicle speeds in miles per hour from 5 to 95 mph in 5 mph increments. Changeable speed limit display panel shall:
   - 3.1. Consist of two characters, each a minimum of 18 inches in height.
   - 3.2. Consist of either white or yellow (amber) LEDs that are visible from a minimum of 600 ft and provide an apparent character stroke width of between 1.8 and 3.2 inches.
   - 3.3. Be equipped with a photocell that automatically adjusts the intensity of the display for day and night operations.

Work Zone and DMS Program

3.4. Be covered by an Ultra Violet (UV) inhibited, clear, non-fading or clouding polycarbonate resin lens, a minimum of 0.25 inch in thickness that can be opened or removed for maintenance.
3.5. Be permanently attached to the sign panel.
3.6. Receive input from a local control console that shall allow the operator to manually set the speed displayed. The ability to set the speed displayed remotely is acceptable but not required. All remote communication systems shall be in accordance with Federal Communications Commission (FCC) regulations.
3.7. At a minimum, allow the operator to program a daytime speed limit, nighttime speed limit, and construction speed limit. When the construction speed limit is not displayed, the display panel shall automatically change between the daytime and nighttime speed limits based on ambient conditions.
3.8. In the case of a controller failure, the display panel shall display the operator set construction speed limit.

4. Sign Panel Mounting: Mounting height in the raised position shall be a minimum of 7 feet above the roadway as measured from the road surface to the bottom of the sign panel. In the upright position, top of the sign panel shall be 12 feet from the ground level, and withstand winds up to 60 miles per hour from any direction without overturning. The sign panel shall be equipped with the following as a minimum:
   4.1. A locking device, which shall lock the panel in both the upright operating position and the horizontal facedown stowed position.
   4.2. A manual device to raise and lower the sign panel. One person shall easily accomplish the raising and lowering of the sign panel. A powered raising and lowering device is acceptable but not required.
5. Circuitry and Controls: Unit shall have a controller box or panel completely solid state and properly fused and enclosed in a weatherproof, lockable, protective box.
6. Data Logging: Unit shall be equipped with the capability to data log the date, time, and speed limit displayed every time the speed limit is changed. The data shall be capable of being downloaded to a standard PC laptop.
7. Power: Unit shall be designed so that the batteries operate the display panel and the solar panel(s) recharge the batteries.
   7.1. Batteries: Unit shall be equipped with manufacturer's recommended number of batteries, providing enough voltage to meet all previous requirements, including but not limited to visibility. Batteries shall have the capacity to power the unit with no sunlight, 24 hours per day, for a minimum of 30 days. A lighted battery condition indicator gauge, to monitor the battery bank voltage or condition shall be provided. Batteries shall be housed in a lockable enclosure. The design of the enclosure shall allow batteries to be easily removed and replaced.
   7.2. Solar Panel(s): Unit shall be equipped with a solar panel(s) which generates sufficient power to enable the system to continually recharge the batteries. The solar panel(s) shall be positioned on top of the unit.
   7.3. Charger: Unit shall be equipped with a charger to recharge the batteries from a standard 120-volt AC source.
8. Trailer: Unit shall be equipped with a single axle trailer, designed to support the entire operating system for the changeable speed limit sign, including sign and changeable speed

limit display panels support system, power supply unit, controls and housings. Trailer shall be designed for towing at highway speeds of up to 70 mph.

8.1. Lighting: Trailer shall be equipped with tail, stop, and directional lights all conforming to Texas and Federal standards. A license plate holder with a white lamp for illuminating the license plate shall be provided at the center or left side of the rear of the trailer.

8.2. Safety Chains and Hooks: Trailer tongue shall be equipped with two safety chains, complete with safety hooks, each of sufficient length for the coupled towing truck and trailer to make full turns without binding.

8.3. Stabilizing System: Shall consist of a minimum of three top screw swing away lockable adjustable or sliding type leveling jacks, in locations as normally furnished by the manufacturer to stabilize and level the trailer when stationary during operation.

9. Construction: All external components shall be of weather resistance materials. All welding shall comply with American Welding Society Standards.
10. Painting: Unit shall be painted an approved manufacturer's standard lead free, graffiti resistant, white color, except for glass, rubber, and those metallic accessories or fixtures constructed of rust resistant or plated material not normally painted.
11. Manual(s): One copy each of an illustrated parts book, operator's manual, and service manual shall be delivered with each unit. These shall include, at minimum, all appropriate manuals for the speed limit display panel, controls, and electrical system.
12. Safety Plaques or Decals: Product safety plaques or decals shall be furnished and affixed at the operator's station and at any hazardous area. The safety plaques or decals shall describe the nature of the hazard, level of hazard seriousness, how to avoid the hazard, and the consequence of human interaction with the hazard. Permanent plaques are preferred to decals. Type, size and location of product safety plaques or decals shall be in accordance with the latest revision of ANSI 535.4.
13. Warranty: The unit shall be warranted against defects in material and workmanship for a period of not less than 12 months and shall cover 100% parts and labor for the unit. If the manufacturer's standard warranty period exceeds 12 months, then the standard warranty period shall be in effect. The vendor shall furnish the manufacturer's warranty to TTI at time of delivery. The vendor shall be ultimately responsible for the warranty. The warranty begins on the date the unit is determined to meet specifications and accepted by TTI.
14. Delivery Requirements: Delivery of all equipment on this order to the Texas A&M University Riverside Campus, Texas Transportation Institute, Attn: Cheryl Burt and Melisa Finley, 3100 State Highway 47, Building 7091, Bryan, Texas 77807, shall be completed by July 13, 2007. Any unit(s) not delivered by this date may be canceled from the order.
15. Acceptance Inspection: All equipment ordered will be subject to acceptance inspection and performance testing upon receipt. Acceptance inspection and performance testing will not take more than five working days, weather permitting. The vendor will be notified within this time frame of any units not delivered in full compliance with the purchase order specifications.
16. Payment: Payment will be made within 30 days after the acceptance inspection has been completed and TTI determines the equipment delivered meets specifications or the day on which a correct invoice for the goods or materials was received, whichever is later.
17. Working Day: A working day is defined as a calendar day, not including Saturdays, Sundays, or regularly observed state and federal holidays.

APPENDIX E:
LONG TERM FIELD STUDY DETAILED RESULTS

Table E1. Northbound US-59 Daytime Vehicle Speed "Before" Data Descriptive Statistics.

Site No.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
1	Free flow	70	Static	201	67.2	27.4	5.2	27%
2	South 1 zone	60	Static	197	65.9	27.0	5.2	83%
3	South 1 zone	60	Static	299	63.6	32.8	5.7	71%
4	South 2 zone	60	Static	234	64.8	32.8	5.7	76%
5	South 2 zone	60	Static	189	63.8	25.5	5.1	73%
6	South 2 zone	60	Static	219	63.9	31.6	5.6	75%
7	South 2 zone	60	Static	189	65.8	27.7	5.3	81%
8	South 2 zone	60	Static	215	65.1	29.6	5.4	80%
9	Detour	60	Static	220	59.5	33.3	5.8	41%
10	Detour	60	Static	207	64.2	34.3	5.9	73%
11	North zone	60	Static	167	62.2	23.9	4.9	61%
12	North zone	60	Static	228	63.1	28.3	5.3	70%
13	Entering Linden	50	Static	243	56.4	33.1	5.8	86%
14	Entering Linden	50	Static	195	48.8	30.0	5.5	37%

No. = Number; Trt = Treatment

Table E2. Northbound US-59 Daytime Vehicle Speed First "After" Data Descriptive Statistics with South Zone Speed Limit Reduction Only.

Site No.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
1	Free flow	70	Static	185	67.7	31.0	5.6	32%
2	South 1 zone	60	ESL	177	63.0	22.9	4.8	67%
3	South 1 zone	60	ESL	205	62.4	20.8	4.6	66%
4	South 2 zone	60	ESL	196	62.2	21.9	4.7	60%
5	South 2 zone	60	ESL	175	64.0	33.4	5.8	75%
6	South 2 zone	60	ESL	197	64.5	25.2	5.0	78%
7	South 2 zone	60	ESL	183	65.1	26.6	5.2	85%
8	South 2 zone	60	ESL	162	64.3	26.5	5.2	79%
9	Detour	60	Static	173	58.7	33.2	5.8	35%
10	Detour	60	Static	206	62.1	37.0	6.1	63%
11	North zone	70	ESL	186	64.6	26.5	5.2	10%
12	North zone	70	ESL	193	66.3	36.3	6.0	24%
13	North zone	70	ESL	166	60.5	46.9	6.9	9%
14	Entering Linden	50	Static	216	50.5	31.7	5.6	45%

No. = Number; Trt = Treatment

Table E3. Northbound US-59 Daytime Vehicle Speed First "After" Data Descriptive Statistics with South and North Zone Speed Limit Reductions.

Site No.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
1	Free flow	70	Static					
2	South 1 zone	60	ESL					
3	South 1 zone	60	ESL					
4	South 2 zone	60	ESL					
5	South 2 zone	60	ESL					
6	South 2 zone	60	ESL					
7	South 2 zone	60	ESL					
8	South 2 zone	60	ESL					
9	Detour	60	Static	192	58.8	32.9	5.7	41%
10	Detour	60	Static	201	62.0	29.0	5.4	60%
11	North zone	60	ESL	165	62.2	22.6	4.8	59%
12	North zone	60	ESL	208	64.3	29.8	5.5	74%
13	North zone	60	ESL	175	60.1	33.7	5.8	49%
14	Entering Linden	50	Static	232	50.7	23.7	4.9	51%

No. = Number; Trt = Treatment
Blank spaces indicate that no data were collected.

Table E4. Northbound US-59 Daytime Vehicle Speed Second "After" Data Descriptive Statistics with Middle Zone Speed Limit Reduction Only.

Site No.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
15	Free flow	70	Static	131	66.2	23.1	4.8	18%
1	South 1 zone	70	ESL	130	66.2	27.2	5.2	21%
2	South 1 zone	70	ESL	131	67.2	22.5	4.7	24%
3	South 1 zone	70	ESL	124	67.3	20.0	4.5	25%
4	Middle zone	60	ESL	124	64.9	14.8	3.8	89%
5	Middle zone	60	ESL	127	65.6	24.7	5.0	85%
6	Middle zone	60	ESL	138	65.4	24.7	5.0	85%
7	Middle zone	60	ESL	126	64.2	29.9	5.5	75%
8	Middle zone	60	ESL	133	64.9	21.4	4.6	84%
9	Detour	60	Static	131	59.3	31.6	5.6	43%
10	Detour	60	Static	131	64.7	25.4	5.0	85%
11	North zone	70	ESL	128	63.8	22.0	4.7	8%
12	North zone	70	ESL	130	67.7	24.9	5.0	26%
13	North zone	70	ESL	130	60.8	25.8	5.1	4%
14	Entering Linden	50	Static	131	52.8	22.4	4.7	66%

No. = Number; Trt = Treatment

Table E5. Northbound US-59 Daytime Vehicle Speed Second "After" Data Descriptive Statistics with Middle and North Zone Speed Limit Reductions.

Site No.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
15	Free flow	70	Static					
1	South 1 zone	70	ESL					
2	South 1 zone	70	ESL					
3	South 1 zone	70	ESL					
4	Middle zone	60	ESL					
5	Middle zone	60	ESL					
6	Middle zone	60	ESL					
7	Middle zone	60	ESL					
8	Middle zone	60	ESL					
9	Detour	60	Static	126	57.5	29.5	5.4	29%
10	Detour	60	Static	131	63.3	26.0	5.1	73%
11	North zone	60	ESL	132	60.9	22.1	4.7	55%
12	North zone	60	ESL	129	64.1	25.4	5.0	79%
13	North zone	60	ESL	133	58.7	28.0	5.3	37%
14	Entering Linden	50	Static	123	51.6	24.1	4.9	59%

No. = Number; Trt = Treatment
Blank spaces indicate that no data were collected.

Table E6. Northbound US-59 Daytime Vehicle Speed Second "After" Data Descriptive Statistics with South and Middle Zone Speed Limit Reductions.

Site No.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
15	Free flow	70	Static	133	66.0	25.3	5.0	18%
1	South 1 zone	60	ESL	130	66.0	26.4	5.1	88%
2	South 1 zone	60	ESL	118	63.4	17.0	4.1	76%
3	South 1 zone	60	ESL	125	64.2	19.7	4.4	81%
4	Middle zone	60	ESL	126	62.5	23.6	4.9	60%
5	Middle zone	60	ESL					
6	Middle zone	60	ESL					
7	Middle zone	60	ESL					
8	Middle zone	60	ESL					
9	Detour	60	Static					
10	Detour	60	Static					
11	North zone	60/70 [a]	ESL					
12	North zone	60/70 [a]	ESL					
13	North zone	60/70 [a]	ESL					
14	Entering Linden	50	Static					

No. = Number; Trt = Treatment
Blank spaces indicate that no data were collected.
[a] For a short period of time, the speed limit in the north zone was reduced.

Table E7. Southbound US-59 Daytime Vehicle Speed "Before" Data Descriptive Statistics.

Site No.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
14	Leaving Linden	50	Static	192	49.4	17.5	4.2	35%
13	Leaving Linden	50	Static	249	55.4	23.9	4.9	86%
12	North zone	60	Static	207	58.0	22.3	4.7	28%
11	North zone	60	Static	203	60.7	25.0	5.0	49%
10	North zone	60	Static	238	62.5	29.4	5.4	59%
9	Detour	60	Static	194	57.6	26.7	5.2	25%
8	South 2 zone	60	Static	196	61.1	25.8	5.1	52%
7	South 2 zone	60	Static	165	61.8	23.1	4.8	58%
6	South 2 zone	60	Static	210	62.3	22.2	4.7	66%
5	South 2 zone	60	Static	168	62.0	23.9	4.9	69%
4	South 2 zone	60	Static	221	62.7	26.8	5.2	68%
3	South 1 zone	60	Static	293	62.7	32.4	5.7	65%
2	South 1 zone	60	Static	134	63.0	21.0	4.6	70%
1	Free flow	60	Static	227	66.2	22.2	4.7	90%

No. = Number; Trt = Treatment

Table E8. Southbound US-59 Daytime Vehicle Speed First "After" Data Descriptive Statistics with South Zone Speed Limit Reduction Only.

Site No.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
14	Leaving Linden	50	Static	191	50.6	19.5	4.4	48%
13	North zone	70	ESL	168	58.5	31.9	5.6	1%
12	North zone	70	ESL	195	62.2	37.6	6.1	6%
11	North zone	70	ESL	178	62.4	34.1	5.8	7%
10	North zone	70	ESL	224	60.7	28.3	5.3	3%
9	Detour	60	Static	174	59.5	33.9	5.8	45%
8	South 2 zone	60	Static	155	61.6	27.9	5.3	57%
7	South 2 zone	60	Static	172	63.3	31.5	5.5	67%
6	South 2 zone	60	Static	158	64.0	40.1	6.3	72%
5	South 2 zone	60	Static	152	63.4	29.2	5.4	69%
4	South 2 zone	60	Static	183	65.2	25.7	5.1	81%
3	South 1 zone	60	ESL	191	62.1	18.3	4.3	66%
2	South 1 zone	60	ESL	166	64.1	23.8	4.9	75%
1	Free flow	70	Static	187	67.3	20.3	4.5	27%

No. = Number; Trt = Treatment

Table E9. Southbound US-59 Daytime Vehicle Speed First "After" Data Descriptive Statistics with South and North Zone Speed Limit Reductions.

Site No.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
14	Leaving Linden	50	Static	212	52.8	22.9	4.8	69%
13	North zone	60	ESL	177	57.1	23.7	4.8	25%
12	North zone	60	ESL	218	59.2	23.9	4.9	39%
11	North zone	60	ESL	196	61.2	20.2	4.5	52%
10	North zone	60	ESL	232	60.1	20.6	4.5	40%
9	Detour	60	Static	169	59.1	21.2	4.6	40%
8	South 2 zone	60	Static					
7	South 2 zone	60	Static					
6	South 2 zone	60	Static					
5	South 2 zone	60	Static					
4	South 2 zone	60	Static					
3	South 1 zone	60	ESL					
2	South 1 zone	60	ESL					
1	Free flow	70	Static					

No. = Number; Trt = Treatment

Blank spaces indicate that no data were collected.

Table E10. Southbound US-59 Daytime Vehicle Speed Second "After" Data Descriptive Statistics with Middle Zone Speed Limit Reduction Only.

Site No.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
14	Leaving Linden	50	Static	126	50.7	18.7	4.3	50%
13	North zone	70	ESL	139	57.1	29.8	5.5	0%
12	North zone	70	ESL	132	62.6	28.1	5.3	7%
11	North zone	70	ESL	127	62.4	28.1	5.3	6%
10	North zone	70	ESL	133	63.0	26.7	5.2	7%
9	Detour	60	Static	122	60.0	26.4	5.1	49%
8	Middle zone	60	ESL	133	62.7	23.8	4.9	65%
7	Middle zone	60	ESL	124	61.6	16.1	4.0	60%
6	Middle zone	60	ESL	131	62.1	22.2	4.7	64%
5	Middle zone	60	ESL	128	62.3	15.7	4.0	66%
4	Middle zone	60	ESL	126	64.7	15.8	4.0	87%
3	South 1 zone	70	ESL	133	66.9	19.3	4.4	17%
2	South 1 zone	70	ESL	129	67.7	15.6	4.0	20%
1	South 1 zone	70	ESL	123	68.7	19.7	4.4	32%
15	Free flow	70	Static	132	64.5	22.8	4.8	11%

No. = Number; Trt = Treatment

Table E11. Southbound US-59 Daytime Vehicle Speed Second "After" Data Descriptive Statistics with Middle and North Zone Speed Limit Reductions.

Site No.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
14	Leaving Linden	50	Static	132	49.1	4.1	16.8	33%
13	North zone	60	ESL	134	56.2	4.1	16.8	13%
12	North zone	60	ESL	132	61.0	4.8	22.7	52%
11	North zone	60	ESL	127	60.4	4.8	22.5	54%
10	North zone	60	ESL	128	60.6	5.5	30.1	46%
9	Detour	60	Static	125	57.9	4.2	17.4	22%
8	Middle zone	60	ESL					
7	Middle zone	60	ESL					
6	Middle zone	60	ESL					
5	Middle zone	60	ESL					
4	Middle zone	60	ESL					
3	South 1 zone	70	ESL					
2	South 1 zone	70	ESL					
1	South 1 zone	70	ESL					
15	Free flow	70	Static					

No. = Number; Trt = Treatment
Blank spaces indicate that no data were collected.

Table E12. Southbound US-59 Daytime Vehicle Speed Second "After" Data Descriptive Statistics with South and Middle Zone Speed Limit Reductions.

Site No.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
14	Leaving Linden	50	Static					
13	North zone	60/70 [a]	ESL					
12	North zone	60/70 [a]	ESL					
11	North zone	60/70 [a]	ESL					
10	North zone	60/70 [a]	ESL					
9	Detour	60	Static					
8	Middle zone	60	ESL					
7	Middle zone	60	ESL					
6	Middle zone	60	ESL					
5	Middle zone	60	ESL					
4	Middle zone	60	ESL	124	63.1	18.7	4.3	69%
3	South 1 zone	60	ESL	130	63.6	14.7	4.0	73%
2	South 1 zone	60	ESL	134	65.6	26.7	5.2	81%
1	South 1 zone	60	ESL	129	65.5	24.0	4.9	82%
15	Free flow	70	Static	131	63.8	25.1	5.0	8%

No. = Number; Trt = Treatment
Blank spaces indicate that no data were collected.
[a] For a short period of time, the speed limit in the north zone was reduced.

Table E13. Northbound US-59 Daytime Vehicle Speed "Before" Data Descriptive Statistics by Zone.

Site Nos.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
1	Free flow	70	Static	201	67.2	27.4	5.2	27%
2-3	South 1 zone	60	Static	496	64.5	31.7	5.6	76%
4-7	South 2 zone	60	Static	831	64.6	30.2	5.5	76%
9	Detour	60	Static	220	59.5	33.3	5.8	41%
11-12	North zone	60	Static	395	62.7	26.6	5.2	66%

Nos. = Numbers; Trt = Treatment

Table E14. Northbound US-59 Daytime Vehicle Speed First "After" Data Descriptive Statistics by Zone with South Zone Speed Limit Reduction Only.

Site Nos.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
1	Free flow	70	Static	185	67.7	31.0	5.6	32%
2-3	South 1 zone	60	ESL	382	62.7	21.8	4.7	66%
4-7	South 2 zone	60	ESL	751	63.9	27.7	5.3	74%
9	Detour	60	Static	173	58.7	33.2	5.8	35%
11-12	North zone	70	ESL	379	65.5	32.2	5.7	17%

Nos. = Numbers; Trt = Treatment

Table E15. Northbound US-59 Daytime Vehicle Speed First "After" Data Descriptive Statistics by Zone with South and North Zone Speed Limit Reductions.

Site Nos.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
1	Free flow	70						
2-3	South 1 zone	60						
4-7	South 2 zone	60						
9	Detour	60	Static	192	58.8	32.9	5.7	41%
11-12	North zone	60	ESL	373	63.4	27.7	5.3	68%

Nos. = Numbers; Trt = Treatment
Blank spaces indicate that no data were collected.

Table E16. Northbound US-59 Daytime Vehicle Speed Second "After" Data Descriptive Statistics by Zone with Middle Zone Speed Limit Reduction Only.

Site Nos.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
15	Free flow	70	Static	131	66.2	23.1	4.8	18%
2-3	South 1 zone	70	ESL	255	67.2	21.2	4.6	25%
4-7	Middle zone	60	ESL	517	64.4	27.1	5.2	77%
9	Detour	60	Static	131	59.3	31.6	5.6	43%
11-12	North zone	70	ESL	258	65.8	27.3	5.2	17%

Nos. = Numbers; Trt = Treatment

Table E17. Northbound US-59 Daytime Vehicle Speed Second "After" Data Descriptive Statistics by Zone with Middle and North Zone Speed Limit Reductions.

Site Nos.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
15	Free flow	70	Static	131	66.2	23.1	4.8	18%
2-3	South 1 zone	60	ESL	259	65.0	23.7	4.9	81%
4-7	Middle zone	60	ESL	517	64.4	27.1	5.2	77%
9	Detour	60	Static	126	57.5	29.5	5.4	29%
11-12	North zone	60	ESL	261	62.5	26.3	5.2	67%

Nos. = Numbers; Trt = Treatment

Table E18. Northbound US-59 Daytime Vehicle Speed Second "After" Data Descriptive Statistics by Zone with South and Middle Zone Speed Limit Reductions.

Site Nos.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
15	Free flow	70	Static	133	66.0	25.3	5.0	18%
2-3	South 1 zone	60	ESL	259	65.0	23.7	4.9	81%
4	Middle zone	60	ESL	126	62.5	23.6	4.9	60%
9	Detour	60	Static					
11-12	North zone	60/70 [a]	ESL					

Nos. = Numbers; Trt = Treatment
Blank spaces indicate that no data were collected.
[a] For a short period of time, the speed limit in the north zone was reduced.

Table E19. Southbound US-59 Daytime Vehicle Speed "Before" Data Descriptive Statistics by Zone.

Site Nos.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
14	Free flow	50	Static	192	49.4	17.5	4.2	35%
11-12	North zone	60	Static	410	59.4	25.4	5.0	38%
9	Detour	60	Static	194	57.6	26.7	5.2	25%
4-7	South 2 zone	60	Static	764	62.3	24.1	4.9	64%
2-3	South 1 zone	60	Static	427	62.8	28.8	5.4	66%

Nos. = Numbers; Trt = Treatment

Table E20. Southbound US-59 Daytime Vehicle Speed First "After" Data Descriptive Statistics by Zone with South Zone Speed Limit Reduction Only.

Site Nos.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
14	Free flow	50	Static	191	50.6	19.5	4.4	48%
11-12	North zone	70	ESL	373	62.3	35.8	6.0	6%
9	Detour	60	Static	174	59.5	33.9	5.8	45%
4-7	South 2 zone	60	Static	665	64.0	31.7	5.6	72%
2-3	South 1 zone	60	ESL	357	63.0	21.9	4.7	70%

Nos. = Numbers; Trt = Treatment

Table E21. Southbound US-59 Daytime Vehicle Speed First "After" Data Descriptive Statistics by Zone with South and North Zone Speed Limit Reductions.

Site Nos.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
14	Free flow	50	Static	212	52.8	22.9	4.8	69%
11-12	North zone	60	ESL	414	60.1	23.1	4.8	45%
9	Detour	60	Static	169	59.1	21.2	4.6	40%
4-7	South 2 zone	60	Static					
2-3	South 1 zone	60	ESL					

Nos. = Numbers; Trt = Treatment
Blank spaces indicate that no data were collected.

Table E22. Southbound US-59 Daytime Vehicle Speed Second "After" Data Descriptive Statistics by Zone with Middle Zone Speed Limit Reduction Only.

Site Nos.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
14	Free flow	50	Static	126	50.7	18.7	4.3	52%
11-12	North zone	70	ESL	259	62.5	28.0	5.3	6%
9	Detour	60	Static	122	60.0	26.4	5.1	49%
4-7	Middle zone	60	ESL	507	62.3	18.4	4.3	65%
2-3	South 1 zone	70	ESL	262	67.3	17.5	4.2	18%

Nos. = Numbers; Trt = Treatment

Table E23. Southbound US-59 Daytime Vehicle Speed Second "After" Data Descriptive Statistics by Zone with Middle and North Zone Speed Limit Reductions.

Site Nos.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
14	Free flow	50	Static	132	49.1	16.7	4.1	33%
11-12	North zone	60	ESL	259	60.7	22.6	4.8	53%
9	Detour	60	Static	125	57.9	17.4	4.2	22%
4-7	Middle zone	60	ESL					
2-3	South 1 zone	70	ESL					

Nos. = Numbers; Trt = Treatment
Blank spaces indicate that no data were collected.

Table E24. Southbound US-59 Daytime Vehicle Speed Second "After" Data Descriptive Statistics by Zone with South and Middle Zone Speed Limit Reductions.

Site Nos.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
14	Free flow	50	Static					
11-12	North zone	60/70 [a]	ESL					
9	Detour	60	Static					
4	Middle zone	60	ESL	124	63.1	4.3	18.7	69%
2-3	South 1 zone	60	ESL	248	63.5	16.3	4.0	75%

Nos. = Numbers; Trt = Treatment
Blank spaces indicate that no data were collected.
[a] For a short period of time, the speed limit in the north zone was reduced.

Table E25. Northbound US-59 Nighttime Vehicle Speed "Before" Data Descriptive Statistics.

Site No.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
1	Free flow	65	Static	128	64.3	30.2	5.5	44%
3	South 1 zone	60	Static	124	63.2	23.3	4.8	73%
6	South 2 zone	60	Static	201	63.8	26.5	5.1	72%
12	North zone	60	Static	168	62.6	27.2	5.2	62%

No. = Number; Trt = Treatment

Table E26. Northbound US-59 Nighttime Vehicle Speed First "After" Data Descriptive Statistics.

Site No.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
1	Free flow	65	Static	154	64.2	22.9	4.8	42%
3	South 1 zone	65	ESL	158	63.2	24.0	4.9	28%
6	South 2 zone	65	ESL	168	63.3	19.6	4.4	30%
12	North zone	65	ESL	190	62.2	25.4	5.0	26%

No. = Number; Trt = Treatment

Table E27. Northbound US-59 Nighttime Vehicle Speed Second "After" Data Descriptive Statistics.

Site No.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
1	South 1 zone	65	ESL	132	64.2	20.3	4.5	35%
3	South 1 zone	65	ESL	133	63.5	18.3	4.3	31%
6	Middle zone	65	ESL	136	64.2	21.3	4.6	37%
12	North zone	65	ESL	139	62.3	21.3	4.6	24%

No. = Number; Trt = Treatment

Table E28. Southbound US-59 Nighttime Vehicle Speed "Before" Data Descriptive Statistics.

Site No.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
12	North zone	60	Static	128	56.8	29.9	5.5	26%
6	South 2 zone	60	Static	168	59.6	25.7	5.1	42%
3	South 1 zone	60	Static	113	63.5	19.5	4.4	75%
1	Free flow	60	Static	121	63.3	33.3	5.8	76%

No. = Number; Trt = Treatment

Table E29. Southbound US-59 Nighttime Vehicle Speed First "After" Data Descriptive Statistics.

Site No.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
12	North zone	65	ESL	161	57.9	34.3	5.9	10%
6	South 2 zone	65	Static	151	61.4	33.4	5.8	58%
3	South 1 zone	65	ESL	160	65.0	22.1	4.7	48%
1	Free flow	65	Static	165	64.5	23.8	4.9	44%

No. = Number; Trt = Treatment

Table E30. Southbound US-59 Nighttime Vehicle Speed Second "After" Data Descriptive Statistics.

Site No.	Site Description	Speed Limit (mph)	Trt	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
12	North zone	65	ESL	124	58.5	22.7	4.8	6%
6	Middle zone	65	ESL	132	61.3	20.1	4.5	15%
3	South 1 zone	65	ESL	132	64.9	17.8	4.2	45%
1	South 1 zone	65	ESL	124	66.3	13.7	3.7	58%

No. = Number; Trt = Treatment

APPENDIX F:
SHORT TERM FIELD STUDY DETAILED RESULTS

Table F1. I-30 Vehicle Speed Data Descriptive Statistics.

Treatment	Data Collection Location [a]	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
Standard signs	Free flow	149	70.0	14.9	3.9	45%
	Downstream of treatment	160	65.7	28.7	5.4	81%
ESL signs	Free flow	150	69.9	14.3	3.8	41%
	Downstream of treatment	158	62.8	27.3	5.2	64%
Roll-up signs	Free flow	159	70.2	14.2	3.8	43%
	Downstream of treatment	157	63.8	24.3	4.9	71%

[a] Free flow vehicle speeds were measured one to two miles upstream of the work zone. Downstream of treatment vehicle speeds were measured approximately 1000 ft downstream of the treatment.

Table F2. US-59 Vehicle Speed Data Descriptive Statistics.

Treatment	Data Collection Location [a]	Sample Size (n)	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	Percent Exceeding Speed Limit
ESL signs	Free flow	154	69.1	16.0	4.0	36%
	Downstream of treatment	154	59.7	11.8	3.4	36%
Roll-up signs	Free flow	163	68.4	15.5	3.9	25%
	Downstream of treatment	156	60.3	14.4	3.8	46%

[a] Free flow vehicle speeds were measured one to two miles upstream of the work zone. Downstream of treatment vehicle speeds were measured approximately 1000 ft downstream of the treatment.

APPENDIX G:
EXAMPLE OF MOTORIST SURVEY

Project 5561 *Revised 4/22/08*

Survey Administrator Use Only		*Administrator Initials:_______*
Date: ___________	*Subject #:_______*	*Location:______________*

ANSWER FROM
SURVEY #3

This survey is being conducted by the Texas Transportation Institute, which is part of the Texas A&M University System. It is being sponsored by the Texas Department of Transportation. The purpose of the survey is to determine drivers' understanding and comprehension of signs used on roadways. The signs will be displayed on a computer screen but you do not need to know how to use a computer. I will be the only person that will operate the computer; you will only have to look at the display being shown on the screen. Now, before we get started we have a few demographic questions, which will be used for statistical purposes only.

BACKGROUND INFORMATION *(Circle Response)*

Age Category:	**18-39 40-54 55+**	Gender:	**Male**	**Female**	
Education:	**High School Diploma or Less**	**Some College (2 years plus) and More**			

The survey will be conducted in three parts. In the first part, you will see three signs. Each sign will be displayed on the computer screen for a few seconds and then it will automatically turn off. At that time I will ask you a few questions about the sign that you just saw. Do you have any questions at this point?

EXAMPLE

Now, we are going to do an example to familiarize you with the survey. Remember the sign will be displayed on the computer screen for a few seconds and then it will automatically turn off.

Sign – Pedestrian Crossing Sign

1. a. What type of sign was just displayed on the computer screen? ____________________________
____
____

Now, we are ready to begin Part 1. I want you to assume that you are driving down a freeway where the posted speed limit has been 70 mph for some time. You are traveling at 70 mph and you see the sign displayed on the computer screen.

PART 1 – COMPREHENSION

Sign 11 – PCMS #2 Orange Text

1. a. What type of sign was just displayed on the computer screen? ____________________________
____
____

b. What information is this sign giving you? ______________________________

c. What was the Speed Limit shown? **50 55 60 65 70 Other______________**

2. a. If you continue going 70 mph past the sign, do you think you could get a speeding ticket?
Yes No Don't Know

b. What made you think that? ______________________________

Sign 5 – ESL Number White

1. a. What type of sign was just displayed on the computer screen? ______________________________

b. What information is this sign giving you? ______________________________

c. What was the Speed Limit shown? **50 55 60 65 70 Other______________**

d. What activity was this sign being used for? ______________________________

2. a. If you continue going 70 mph past the sign, do you think you could get a speeding ticket?
Yes No Don't Know

b. What made you think that? ______________________________

Sign 2 – WZ Flashing

1. a. What type of sign was just displayed on the computer screen? ______________________________

b. What information is this sign giving you? ______________________________

c. What was the Speed Limit shown? **50 55 60 65 70 Other______________**

d. What activity was this sign being used for? ______________________________

2. a. If you continue going 70 mph past the sign, do you think you could get a speeding ticket?
   Yes **No** **Don't Know**

   b. What made you think that? ______________________________

3. a. If the beacons were not flashing, do you think you could get a speeding ticket if you continue driving at 70 mph? **Yes** **No** **Don't Know**

   b. What made you think that? ______________________________

In the next part of the survey you are going to see three groups of signs. Each display will stay on the computer screen while you answer some questions. Remember you are driving down a freeway where the posted speed limit has been 70 mph for some time and you are traveling at 70 mph. Okay, if you are ready we will begin.

PART 2 – COLOR COMPARISONS

Sign 11. PCMS #2 Orange Text vs. Sign 12. PCMS #2 White Text

1. a. Do you know the difference in these signs? **Yes** **No** **Don't Know**

   b. What is the difference? ______________________________

2. a. Do these signs have the same meaning? **Yes** **No** **Don't Know**

   b. Why or Why not? ______________________________

3. a. Do you think you could get a speeding ticket if you continue going 70 mph past either of these signs?

Sign A (11. PCMS #2 Orange Text)	**Yes**	**No**
Sign B (12. PCMS #2 White Text)	**Yes**	**No**

   b. What made you think that?

   Sign A: ______________________________

   Sign B: ______________________________

Sign 9. PCMS #1 Graphic White/Orange vs. Sign 10. PCMS #1 Graphic Orange

1. a. Do you know the difference in these signs? **Yes** **No** **Don't Know**

   b. What is the difference? ____

   ____

   ____

2. a. Do these signs have the same meaning? **Yes** **No** **Don't Know**

   b. Why or Why not? ____

   ____

   ____

3. a. Do you think you could get a speeding ticket if you continue going 70 mph past either of these signs?

   Sign A (9. PCMS #1 Graphic White/Orange) **Yes** **No**
   Sign B (10. PCMS #1 Graphic Orange) **Yes** **No**

   b. What made you think that?

   Sign A: ____

   ____

   ____

   Sign B: ____

   ____

   ____

Sign 6. ESL Numbers Orange vs. Sign 5. ESL Numbers White

1. a. Do you know the difference in these signs? **Yes** **No** **Don't Know**

   b. What is the difference? ____

   ____

   ____

2. a. Do these signs have the same meaning? **Yes** **No** **Don't Know**

   b. Why or Why not? ____

   ____

   ____

3. a. Do you think you could get a speeding ticket if you continue going 70 mph past either of these signs?

   Sign A (6. ESL Numbers Orange) **Yes** **No**
   Sign B (5. ESL Numbers White) **Yes** **No**

b. What made you think that?
   Sign A: ______________________________

   Sign B: ______________________________

We are about to begin the final part of the survey during which you are going to see four groups of signs. These groups of signs are different options that could be used in the same situation. Some of the signs you have already seen, however there will be additional signs you may not have seen. You are going to rate each of the signs using the following scale: 1 doing an excellent job in informing you, 2 doing a good job, 3 doing and OK job, 4 doing a bad job and 5 doing a terrible job. Again, the display will stay on the computer screen while you answer some questions. If you are ready, I will show you the first group of signs.

PART 3 – PREFERENCES

Category 3: PCMS SL Signs

1. Please rate each sign shown individually on how well you think that sign is at notifying drivers that they are in a work zone and there is a reduced speed limit.

Sign A (12. White Text)	1	2	3	4	5
Sign B (10. Orange Graphic)	1	2	3	4	5
Sign C (9. White Graphic)	1	2	3	4	5
Sign D (11. Orange Text)	1	2	3	4	5

2. Out of the signs you just rated, overall which sign do you think would be the BEST at notifying drivers that they are in a work zone and there is a reduced speed limit?

   Sign: ________ Why? ______________________________

Category 2: ESL Signs

1. Please rate each sign shown individually on how well you think that sign is at notifying drivers that they are in a work zone and there is a reduced speed limit.

Sign A (5. ESL SL Sign White Numbers)	1	2	3	4	5
Sign B (6. ESL SL Sign Orange Numbers)	1	2	3	4	5

2. Out of the signs you just rated, overall which sign do you think would be the BEST at notifying drivers that they are in a work zone and there is a reduced speed limit?

   Sign: ________ Why? ______________________________

Category 1: Static Signs & Rollup

1. Please rate each sign shown individually on how well you think that sign is at notifying drivers that they are in a work zone and there is a reduced speed limit.

Sign A (2. WZSL Sign w/Flashing Beacon)	1	2	3	4	5
Sign B (4. WZSL Rollup Sign)	1	2	3	4	5
Sign C (1. WZSL Sign)	1	2	3	4	5

2. Out of the signs you just rated, overall which sign do you think would be the BEST at notifying drivers that they are in a work zone and there is a reduced speed limit?

   Sign: ________ Why? ______________________________

Overall Preference

(Circle each sign that was selected in the Part 3 questions above.)

Category 3: PCMS	**Category 2: ESL**	**Category 1: WZSL**
Sign 12. White Text	***Sign 5. White Numbers***	***Sign 2. Flashing Beacon***
Sign 10. Orange Graphic	***Sign 6. Orange Numbers***	***Sign 4. Rollup Sign***
Sign 9. White Graphic		***Sign 1. WZSL Sign***
Sign 11. Orange Text		

1. a. You selected signs ___, ____, and ___ as the best in each of the categories previously shown. Out of these three signs, which do you feel is the overall **BEST** at notifying drivers that they are in a work zone and there is a reduced speed limit?

   Sign: ______________

   b. Why? ______________________________

That completes our survey. Do you have any additional comments about speed limit signing in work zones? If not, thank you and here is your new Texas map for helping us.

General Comments:______________________________