Evaluation of Ohio Work Zone Speed Zones Process

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16. Abstract

This report describes the methodology and results of analyses performed to determine the effectiveness of Ohio Department of Transportation processes for establishing work zone speed zones. Researchers observed motorists' speed choice upstream of and adjacent to various work zone conditions used to justify reduced speed limits in work zones. Researchers also observed speed choice upstream and within variable work zone speed zones.

Based on previous research and the results of the studies documented herein, researchers made recommendations regarding appropriate speed limit reductions for shoulder activity, lane shifts, lane closures, and median crossovers. Researchers also recommended the expanded use of variable work zone speed zones.

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EVALUATION OF OHIO WORK ZONE SPEED ZONES PROCESS

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

TABLE OF CONTENTS

Page

List of Figures ... ix
List of Tables ... x
Chapter 1: Introduction ... 1
Statement of the Problem ... 1
Research Objective ... 1
Background ... 2
Overview of Permanent Speed Zoning in Ohio ... 2
Current Speed Zoning in Ohio Work Zones ... 3
Do Slower Speeds Improve Safety? ... 10
How Do Motorists Drive in Work Zones? ... 10
Contents of This Report ... 13
Chapter 2: Motorist Reactions to Reduced Work Zone Speed Limits and Associated Work Zone Conditions ... 15
Introduction ... 15
Study Design ... 15
Study Sites ... 16
Data Reduction and Analysis ... 18
Results ... 20
Speed Characteristics Upstream of Work Zone ... 20
Speed Characteristics Downstream of First Work Zone Speed Limit Sign ... 21
Speed Characteristics at Sites with Lane Shifts ... 23
Speed Characteristics at Sites with Lane Closures ... 24
Speed Characteristics at Sites with Median Crossovers ... 26
Other Considerations ... 28
Summary ... 28
Chapter 3: Motorist Reactions to Variable Work Zone Speed Zoning and Associated Work Zone Conditions ... 31
2012 Pilot Deployments ... 31
Digital Speed Limit Sign Results ... 35
Static Speed Limit Sign Results ... 36
Law Enforcement ... 36
2013 Pilot Deployments ... 37
Study Design and Sites Characteristics ... 38
Results ... 46
Summary ... 51
Chapter 4: Recommendations ... 55
Chapter 5: References ... 61
Appendix A: Reduced Work Zone Speed Limits and Associated Work Zone Conditions Detailed Findings ... 67
Appendix B: 2012 Pilot Variable Work Zone Speed Zoning Study Sites Detailed Findings ... 75

Appendix C: 2013 Pilot Variable Work Zone Speed Zoning Study Sites Detailed Findings....79

LIST OF FIGURES

Page

Figure 1. ODOT Work Zone Speed Zoning Guidelines (*3*). 5
Figure 2. 2012 Pilot Deployment Study Sites' Digital Speed Limit Signs................................. 33
Figure 3. 2012 Pilot Deployment Study Sites' Static Speed Limit Signs................................... 34
Figure 4. Variable Work Zone Speed Zoning Speed Reduction Warning Signs......................... 38
Figure 5. Examples of the Digital Speed Limit Signs. 41
Figure 6. First Digital Speed Limit Sign Locations at Site 3... 44
Figure 7. 85th Percentile Speeds at the Digital Speed Limit Signs. 51

LIST OF TABLES

Page

Table 1. NCHRP Work Zone Regulatory Speed Limit Determination Guidelines (*22*,*23*). 9
Table 2. Findings from Texas Study (*38*). 13
Table 3. Field Study Sites and Speed Limit Characteristics. 17
Table 4. Conditions and Factors Used to Justify Speed Limit Reductions. 19
Table 5. Daytime Speed Characteristics Upstream of Work Zone. 20
Table 6. Daytime Speed Characteristics Downstream of the First Work Zone Speed Limit Sign. 22
Table 7. Daytime Speed Characteristics at Various Work Zone Conditions. 25
Table 8. 2012 Pilot Variable Work Zone Speed Zoning Study Sites and Speed Limit Characteristics. 32
Table 9. 2013 Pilot Variable Work Zone Speed Zoning Study Sites and Speed Limit Characteristics. 39
Table 10. Location of Speed Reduction Warning Signs. 40
Table 11. Location of First Digital Speed Limit Sign. 43
Table 12. Location of Other Digital Speed Limit Signs. 45
Table 13. Speed Characteristics Upstream of Work Zone. 47
Table 14. Speed Characteristics Near the Speed Reduction Warning Signs. 48
Table 15. Speed Characteristics Downstream of the First Digital Speed Limit Sign. 50
Table 16. Work Zone Speed Zoning Recommendations for Multilane Highways. 56
Table 17. Examples of Work Zone Condition Remains but Speed Limit Varies. 58
Table 18. Examples of Work Zone Condition Removed. 58

CHAPTER 1:
INTRODUCTION

STATEMENT OF THE PROBLEM

In April 2011, the Ohio Department of Transportation (ODOT) published a new process for determining work zone speed zones in an effort to enhance the safety of the traveling public and workers while providing efficient flow of traffic. This process was based upon recommendations from previous National Cooperative Highway Research Program (NCHRP) studies and ODOT internal procedures. However, this process continued to result in many work zones with continual speed limit reductions (i.e., 24 hours) even though the condition that warranted the speed limit reduction was not always present (e.g., workers present, restricted geometries, etc.). In addition, under this process many speed limit reductions were posted along the entire work zone, instead of only in the specific portion where the condition that warranted the speed limit reduction was present.

In September 2012, legislative changes to Ohio Revised Code 4511.98 enabled ODOT to establish speed limits in construction zones that vary based on criteria the agency considered appropriate. Based on this legislation, ODOT developed a pilot variable work zone speed zone process to supplement the existing work zone speed zone process. The pilot variable work zone speed zone process addressed speed limit reductions in work zones when workers were present without positive protection and within a certain distance to the travel lanes. Research was needed to evaluate the work zone speed zoning process implemented in April 2011 and the pilot use of variable work zone speed zoning.

RESEARCH OBJECTIVE

The main objective of this research was to determine the effectiveness of ODOT's two processes for establishing work zone speed zones. To accomplish this objective, the research team completed the following tasks:

- Task 1. Hold Project Start-up Meeting.
- Task 2. Identify Most Common Warranting Conditions and Factors.
- Task 3. Develop an Experimental Plan and Identify Field Study Locations.
- Task 4. Conduct Field Studies.

- Task 5. Reduce and Analyze Data.
- Task 6. Hold Project Review Session.
- Task 7. Prepare and Submit Quarterly Reports.
- Task 8. Prepare and Submit Recommendations and Reports.
- Task 9. Hold Project Wrap-up Meeting.

BACKGROUND

Most transportation professionals view the setting of appropriate regulatory speed limits on 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 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.

Overview of Permanent Speed Zoning in Ohio

Section 4511.21 of the Ohio Revised Code (ORC) (*2*) establishes statutory speed limits and dictates how statutory speed limits may be changed based on an engineering study (i.e., speed zoning). ODOT considers various factors, such as development, roadway features, crashes, and the speeds vehicles are traveling when conducting speed zoning studies (*3*).

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. Posting a speed limit at a level that most drivers consider reasonable tends to yield more uniform speeds on the roadway. ODOT primarily uses the 85^{th} percentile speed and 10 mph pace speed to determine the maximum speed considered safe and reasonable for that segment by the majority of drivers. The 85^{th} percentile speed is the speed that 85 percent of drivers travel at or below at a given point on the roadway. The 10 mph pace speed is the 10 mph range of speeds containing the greatest number of observed speeds. ODOT also conducts test runs to support the speed data collected.

Even though the posted speed limit may be based on the speeds that the majority of drivers choose to travel, many studies have reported that the posted speed limit is usually significantly lower than the 85th percentile speeds (*4,5,6,7,8,9,10,11,12*). This indicates that there is very little motorist compliance with existing posted speed limits. This may be due in part to the difficulty with predicting operating speeds (and thus the speed limit) based on the design speed for geometric elements (*12,13,14,15,16,17,18*). In addition, agencies are often influenced by political and residential pressures to lower speed limits.

Current Speed Zoning in Ohio 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. Instead, engineering judgment based on the nature of the project and other factors that affect the safety of the traveling public and construction workers must be used. To aid this decision-making process, many state highway agencies have adopted policies and procedures for determining if a reduced regulatory speed limit should be established in a construction work zone (*19*).

The Ohio Manual on Uniform Traffic Control Devices (OMUTCD) (*20*) indicates that lowering the regulatory speed limit in work zones should be avoided as much as practical because motorists will only reduce their speeds through the work zone if they clearly perceive a need to do so. When used, reduced speed limits should only be used in the specific portion of the work zone where conditions or restrictive features are present, not throughout the entire project. The OMUTCD further states that temporary traffic control plans should be designed such that the speed limit does not have to be reduced by more than 10 mph. A speed limit reduction greater than 10 mph should only be used when required by restrictive features in the work zone.

Additional details regarding the current process for speed zoning in work zones is documented in the ODOT Traffic Engineering Manual. Prior to April 2011, the ODOT process for the use and determination of work zone speed zones (*21*) stated that for construction projects on freeways, expressways, and rural highways with four or more lanes, a 10 mph reduction in the speed limit must be implemented. The speed limit for construction on any other type of facility should not be changed. The process further stated the speed limit reductions could only be implemented for projects lasting at least 30 consecutive calendar days and at locations where the roadway width or pavement conditions were reduced or restricted for work activities. The process specifically stated that speed limit reductions should not be used with bridge rehabilitation/repair work or night-only lane closures, and were generally not suitable for use on projects less than one-half mile in length. Clean-up work and other work beyond the shoulder to be performed after restoration of all full-width lanes and shoulders to traffic, such as seeding, also did not constitute a speed limit reduction. Overall, this process did not take into account the wide range of work conditions and factors that exist across construction and maintenance projects. It also restricted the use of reduced speed limits to longer-term construction projects. Therefore, this process may have resulted in speed limit reductions at projects where they were not really needed and a lack of speed limit reductions at projects where they were needed.

The current ODOT process for the use and determination of work zone speed zones (*3*), published in April 2011, states that all ODOT construction projects, and all operations/maintenance work projected to take more than three hours to complete, on a high-speed ($\geq$ 55 mph), multilane highway should be reviewed to determine if a speed limit reduction is needed. The process includes directions, figures, tables, and forms for determining if a work zone speed zone might be recommended, as well as a form to document when and where speed limit reductions were actually implemented. Figure 1 contains the current ODOT work zone speed zoning guidelines.

The work zone conditions and applicable factors used in the ODOT work zone speed zoning guidelines are similar to those recommended in NCHRP Reports 3-41 (*22*) and 3-41(2) (*23*). That research found that motorists do reduce speed in work zones, even those with no speed limit reductions. Speed limit compliance in the work zone was generally greatest when the speed limit was not reduced and decreased when the speed limit was reduced by more than 10 mph. Work zone speed limits 10 mph below the original posted limit resulted in slightly reduced speed variances through the work zone and corresponded to the smallest increase in work zone crashes. Overall, the researcher recommendations confirmed that work zone speed limit reductions should be avoided as much as possible. However, researchers also noted that motorists might not always fully comprehend all of the hazards present in a work zone. Therefore, it was proposed that speed limits in work zones *could* be reduced from their original, pre-work zone levels if any of a number of potentially hazardous site conditions were present. Table 1 contains those researchers' final recommendations. Speed limit reductions of more than 10 mph were discouraged, since previous research (*24*,*25*,*26*) had shown that motorists will not typically slow down more than 10 mph through a work zone, even if enforcement were present.

(Adapted from NCHRP Report 3-41(2))

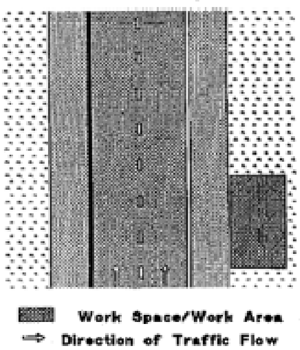
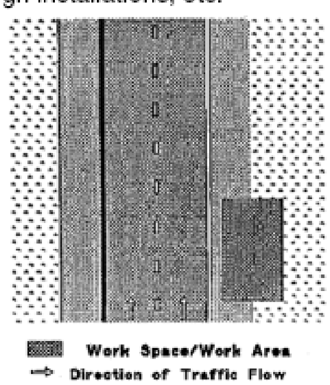
Work Zone Condition	Factors that may warrant a Speed Zone	Speed Limit Reduction?
1. ROADSIDE ACTIVITY Activities which are more than 10 feet from the edge line. Typical applications may include roadway construction, landscaping work, utility work, fencing work, cleaning drainage, structural work, reworking ditches, etc. 	Only if unexpected conditions exist.	No reduction should be used unless unusual situations create hazardous conditions for motorists, pedestrians, or workers.
2. SHOULDER ACTIVITY Activities which encroach upon the area closer than 10 feet, but not closer than 2 feet to the edge line. Typical applications may include roadway construction, culvert extensions, guardrail installation, cleaning drainage, reworking ditches, shoulder work, utility work, side slope work, landscaping work, structural work, sign installations, etc. 	• Unprotected workers present for extended periods (generally more than 3 hours) within 10 feet of the edge line. • Horizontal curvature that might increase vehicle encroachment rate (could include mainline curves, ramps, and turning roadways). • Unexpected conditions.	Where one or more of the factors exist, a Work Zone Speed Zone based on Form 1296-17 may be used.

Figure 1. ODOT Work Zone Speed Zoning Guidelines (*3*).

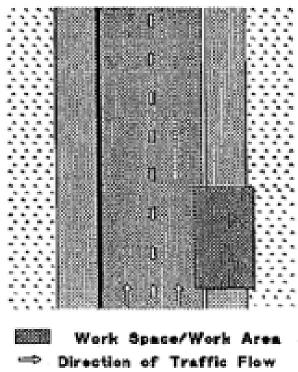
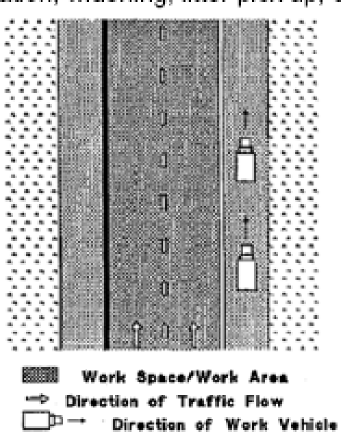
3. LANE ENCROACHMENT Activities which encroach upon the area from 2 feet beyond the edge line to inside the edge line, but maintain a lane width of no less than 10 feet. Typical applications may include roadway construction utility work, guardrail installation, shoulder work, etc. 	• Unprotected workers present for extended periods (generally more than 3 hours) within 2 feet of the edge line. • Horizontal curvature that might increase vehicle encroachment rate (could include mainline curves, ramps, and turning roadways). • Barrier or pavement edge drop off less than 1.5 feet from the edge line. • Reduced safe speed for stopping sight distance. • Unexpected conditions.	Where one or more of the factors exist, a Work Zone Speed Zone based on Form 1296-17 may be used.
4. MOBILE ACTIVITY ON SHOULDER Activities which require intermittent stops on the shoulder or an operation moving at more than 3 mph on the shoulder. For an operation moving at less than 3 mph on the shoulder, see Shoulder Activity, above. Typical applications may include roadway construction, shoulder and slope work, utility work, guardrail installation, landscape work, delineator installation, widening, litter pick up, etc. 	Only if unexpected conditions exist.	No reduction should be used unless unusual situations create hazardous conditions for motorists, pedestrians, or workers.

Figure 1. ODOT Work Zone Speed Zoning Guidelines (*3*) (Continued).

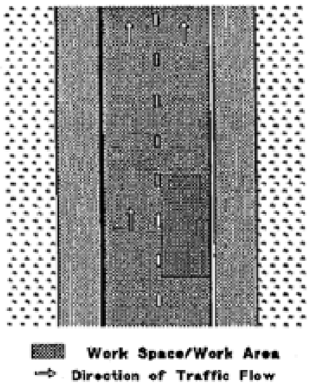
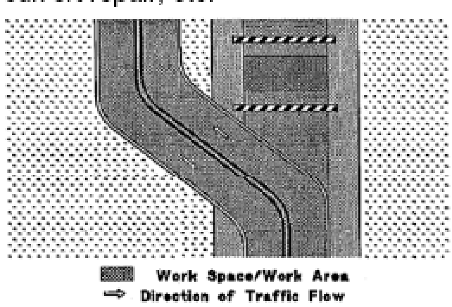
5. LANE CLOSURE Activities which encroach upon the area between the center line or lane line and the edge of the traveled way. Typical applications may include roadway construction, pavement repair, utility work, widening, pavement resurfacing, pavement marking, bridge repair, etc.  	• Unprotected workers present for extended periods (generally more than 3 hours) in the closed lane. • Lane width reduction of 1 foot or more with a resulting lane width of less than 11 feet. • Temporary 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 safe speed for taper length or speed change lane length. • Barrier or pavement edge drop off within 1.5 feet of the edge line. • Reduced safe speed of horizontal curve. • Reduced safe speed for stopping sight distance. • Traffic congestion created by lane closure (when not covered by Permitted Lane Closure Schedules (PLCSs), or when unexpected congestion occurs when covered by PLCS), or where MOT Exception Committee (MOTEC) has approved a PLCS violation. • Unexpected conditions.	Where one or more of the factors exist, a Work Zone Speed Zone based on Form 1296-17 may be used.
6. TEMPORARY DETOUR Activities requiring a temporary detour to be constructed. Detour and transition geometry with a safe speed equal to or greater than the existing regulatory speed limit should be provided whenever possible. Typical applications may include roadway construction, bridge construction, subgrade restoration, culvert repair, etc.  	• Lane width reduction of 1 foot or more with a resulting lane width of less than 11 feet. • Reduced safe speed for detour roadway or transitions (radius of curvature, superelevation, and sight distance). • Unexpected conditions.	Where one or more of the factors exist, a Work Zone Speed Zone based on Form 1296-17 may be used.

Figure 1. ODOT Work Zone Speed Zoning Guidelines (*3*) (Continued).

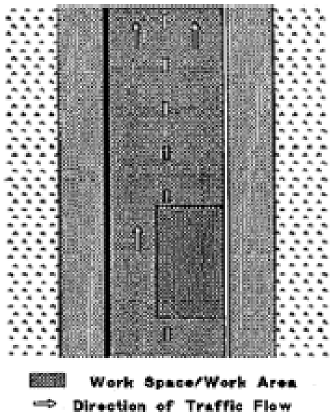
7. CENTER OR LANE LINE ENCROACHMENT Activities which encroach upon the area on both sides of the center line or lane line of a multi-lane highway. Typical applications may include roadway construction, pavement marking, crack sealing, pavement repair, widening, pavement resurfacing, bridge repair, etc.  	• Unprotected workers present in the closed area for extended periods (generally more than 3 hours). • Remaining lane plus shoulder width of less than 11 feet. • Reduced safe speed for taper length or speed change lane length. • Barrier or pavement edge drop off within 1.5 feet of the edge line. • Reduced safe speed of horizontal curve. • Reduced safe speed for stopping sight distance. • Traffic congestion created by lane closure (when not covered by Permitted Lane Closure Schedules (PLCSs), or when unexpected congestion occurs when covered by PLCS) or MOT Exception Committee (MOTEC) approved PLCS violation. • Unexpected conditions.	Where one or more of the factors exist, a Work Zone Speed Zone based on Form 1296-17 may be used.

Figure 1. ODOT Work Zone Speed Zoning Guidelines (*3*) (Continued).

In 2012, legislative changes to Ohio Revised Code 4511.98 enabled ODOT to establish speed limits in construction zones that vary based on conditions (*27*). Based on this legislation, ODOT developed a pilot variable work zone speed zone process to supplement the existing work zone speed zone process. This pilot process allowed variable work zone speed zones on multilane highways with existing speed limits of 55 mph or greater when workers are present for three or more consecutive hours, within the closed lane(s) or within 10 ft of the edge of the traveled way, and without positive protection. In the variable work zone speed zone, the speed limit could be reduced to 10 mph less than the original posted speed limit. In addition, the variable work zone speed zone is limited to only the active portion of the project and the work that justified the speed limit reduction. Beginning in September 2012, ODOT implemented pilot projects utilizing variable work zone speed zoning.

Table 1. NCHRP Work Zone Regulatory Speed Limit Determination Guidelines (*22,23*).

Condition	Maximum Speed Limit Reduction	Factors That Justify Speed Limit Reduction
Roadside Activity (greater than 10 ft from travel lanes)	None	• None
Shoulder Activity (2 to 10 ft from travel lanes)	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 travel lanes)	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 edgeline)	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.

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. For example, there are multiple anecdotal stories in the industry of large trucks blowing hard hats off workers and into active travel lanes. 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. However, several non-work zone research efforts have shown that crash rates are higher at very low speeds compared to the average speed (*28*,*29*,*30*,*31*).

Logically, crashes are likely to be more severe at higher operating speeds, simply because there is more kinetic energy that has to be dissipated during the crash. In addition, studies have shown that crash rates are higher for vehicles traveling much faster than the average speed of traffic (*28*,*29*,*30*,*31*,*32*). However, it is not clear whether the use of reduced speed limits themselves is 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 (*33*). 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) (*28*,*29*,*30*,*31*,*33*,*34*). 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 as 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 (*35*,*36*,*37*,*38*) 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. Oftentimes, throughout the work zone, most motorists are exceeding the reduced speed limit. The low levels of compliance with reduced work zone speed limits reported in a number of studies (*38*,*39*,*40*) shows the disconnect between state agency procedures for establishing regulatory work zone speed limits and actual motorist speed choice in work zones. Undoubtedly, an improved understanding of the relationship between conditions/factors used to justify reduced work zone speed limits and motorists' perceptions of the need to reduce their speed could improve the speed limit selection process.

A limited number of surveys conducted during the NCHRP 3-41 project (*22*) did find that over 90 percent of drivers believed that lane closures were locations where drivers should reduce their speed. 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 was less conclusive.

In a more recent Texas A&M Transportation Institute (TTI) study (*38*), researchers surveyed 476 drivers to obtain insight into motorists' opinions of reduced speed limits in Texas work zones. Researchers found that 66 percent of the participants thought that the speed limit was reduced in more than half of all work zones. This is not surprising since at that time, Texas Department of Transportation (TxDOT) procedures warranted reduced speed limits in a majority of work zones. When participants were asked what conditions they needed to slow down for in a work zone, only 43 percent stated they would slow down when workers were present, and only 37 percent indicated they would 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 in Ohio to justify reduced speed limits in work zones (i.e., lane closures, detours, narrow lanes, pavement edge drop off, and barrier).

As part of this same study (*38*), TTI researchers conducted field studies in Texas work zones to determine motorists' speed choice adjacent to the conditions and factors currently used by state agencies to warrant reduced speed limits. TTI researchers collected spot speed data during the day at 12 work zones. At all but one of these work zones, researchers collected data in both directions of travel, resulting in a total of 23 sites. These work zones were located on limited-access freeways, four-lane divided and undivided highways, and two-lane, two-way roadways. The majority of these work zones had work zone speed limits 10 mph below the original, non-work zone speed limit. The other sites either had a 5 mph or 15 mph speed reduction for the work zone. The study sites included three of the typical work zone conditions for which the speed limit may be reduced (i.e., lane encroachment, lane closure, and temporary diversion [crossover]). In addition, many of the factors used to warrant reduced speed limits in work zones were present.

At each work zone, researchers used handheld light detection and ranging (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 conditions 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. Data were collected in both directions, when applicable, on weekdays during non-peak periods under favorable weather conditions. Overall, researchers collected 17,683 speed measurements at 138 locations.

Consistent with previous research, the 85^{th} percentile speeds downstream of reduced work zone speed limit signs tended to decrease slightly (on average by 3 mph); however, the 85^{th} percentile 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, even though the sites included both 5 and 10 mph speed limit reductions. In other words, when no other work zone conditions were present, motorists did not utilize the amount of the speed limit reduction to judge how much they should reduce their speed.

Table 2 shows that motorists decreased their speeds in work zones when they perceived a need to; however, the amount of speed reduction appeared to be dependent upon the normal operating speed of the roadway, the imposing nature of the situation, and enforcement activities. Research has consistently shown enforcement to be the most effective method of speed control available in work zones (*24,25,38*). 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 the actual travel speeds and 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.

Table 2. Findings from Texas Study (*38*).

Work Zone Condition	Speed Reduction[a]
Reduced speed limit sign	0 to 3 mph
Barrier near inside travel lane	0 to 3 mph
Roadside work activity with barrier	2 to 3 mph
Lane encroachment	1 to 5 mph
Roadside work activity without barrier	1 to 6 mph
Lane closure	1 to 7 mph
Construction vehicle access/egress point	5 to 6 mph
Temporary crossover/diversion	4 to 9 mph
Two-lane, two-way, barrier-separated traffic	7 to 9 mph
Active enforcement	2 to 18 mph

[a] 85th percentile speeds upstream of the work zones ranged from 60 to 77 mph.

Another recent study examined speed characteristics and compliance in four work zones in Missouri (*41*). At three of the sites, the speed limit was decreased by 10 mph (70 mph down to 60 mph). At the fourth site, the speed limit was decreased by 20 mph (70 mph down to 50 mph). Researchers found that the presence of construction activity significantly decreased vehicle speeds, and that passenger cars traveled at significantly higher speeds than trucks in the work zone. However, vehicle speeds were statistically higher than the posted speed limit in all cases but one. Also, compliance at the site with a 50 mph work zone speed limit was lower than at sites with a 60 mph work zone speed limit.

Many speed reduction technologies and enforcement surrogates have been tested over the years, but most have been shown to have only a limited effect on driver behavior (*24*,*39*,*42*,*43*,*44*,*45*). Those same studies often found dismally low compliance rates with the work zone speed limits at their study sites, an indication again of the extent to which the reduced speed limits and driver perceptions of the need to slow down are incongruous.

CONTENTS OF THIS REPORT

This report describes the methodology and results of analyses conducted to determine the effectiveness of ODOT's processes for establishing work zone speed zones. Chapter 2 documents motorist reactions to work zone speed zoning and the work zone conditions/factors used to warrant reduced work zone speed limits. Chapter 3 details motorist reactions to variable work zone speed zoning and associated work zone conditions. Chapter 4 contains the recommendations based on the research findings.

CHAPTER 2:
MOTORIST REACTIONS TO REDUCED WORK ZONE SPEED LIMITS AND ASSOCIATED WORK ZONE CONDITIONS

INTRODUCTION

As discussed previously, the current ODOT process for determining work zone speed zones states that all ODOT construction projects, and all operations/maintenance work projected to take more than three hours to complete, on a high-speed (≥ 55 mph), multilane highway should be reviewed to determine if a speed limit reduction is needed. The work zone speed zoning guidelines (Figure 1) include work zone conditions and applicable factors that may warrant a work zone speed zone (i.e., reduced work zone speed limit). If certain conditions/factors will be present, an evaluation sheet (Form 1296-17) is then used to calculate a speed limit reduction value (i.e., 0, 10, or 15 mph). Further reductions may be justified based on additional considerations not included on the evaluation sheet.

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 inconsistent. An improved understanding of the relationship between conditions/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. As part of this research project, the research team conducted field studies to determine motorist reactions to several of the condition/factor combinations used to justify reduced speed limits in Ohio work zones.

STUDY DESIGN

In June 2013, researchers conducted field studies in Ohio work zones to determine motorists' reactions to the conditions, factors, and combinations thereof currently used by ODOT to warrant reduced speed limits. While it would have been desirable to collect data for every possible condition/factor combination shown in Figure 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 ODOT personnel to justify reduced speed limits in work zones.

At each work zone (or site), researchers used handheld 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 first 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 (or node), researchers attempted to collect 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, the commercial vehicle speed data were not included in the analysis. Data were collected in both directions, when applicable, during non-peak periods under favorable weather conditions. Depending on the work activity and traffic volumes at each site, data were collected during the day, at night, or both during the day and at night. At each data collection location, researchers also monitored and recorded the presence of any law enforcement in the vicinity.

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. Researchers also obtained and reviewed the construction and traffic control plans for each project.

STUDY SITES

As shown in Table 3, researchers collected data during the day at eight work zones in Ohio. All of these work zones had work zone speed limits 10 mph below the original posted speed limit for passenger cars. At all but two of these sites, researchers collected data in both directions of travel, and at one site, researchers collected data on an intersecting roadway that was also part of the work zone. At four of the sites, researchers also collected data at night; however, low traffic volumes resulted in small sample sizes at some data collection locations (i.e., nodes). Thus, night data were only analyzed where appropriate. Enforcement was only present at one site. Overall, researchers collected the speed of 14,851 passenger vehicles and 2522 commercial vehicles at 115 nodes.

Table 3. Field Study Sites and Speed Limit Characteristics.

Site No.	District	PID Number	Date	Road	Direction	Day or Night	No. of Nodes	Original Speed Limit (mph)	Work Zone Speed Limit (mph)	Speed Reduction (mph)	Enforcement Present?
1	4	76747	6/19/13	I-90	EB	Day	7	65	55	10	No
					WB	Day	6	65	55	10	No
			6/19/13	SR 11	NB	Day	3	65[a]	55	10	No
			6/20/13		SB	Day	5	65[a]	55	10	No
			6/28/13	I-90	WB	Day	5	65	55	10	No
						Night	4[b]	65	55	10	No
2	4	76411	6/20/13	I-80	WB	Day	4	65	55	10	No
3	4	82940	6/21/13	SR 11	NB	Day	6	65[a]	55	10	No
					SB	Day	5	65[a]	55	10	No
4	8	87061	6/21/13	I-71	SB	Day	5	65	55	10	No
						Night	6[b]	65	55	10	Yes
5	10	80080 & 22598	6/23/13	US 50	EB	Day	7	60[a]	50	10	No
					WB	Day	6	60[a]	50	10	No
6	10	87515	6/24/13	US 33	EB	Day	9[b]	65[a]	55	10	No
						Night	9[b]	65[a]	55	10	No
					WB	Day	7[b]	65[a]	55	10	No
						Night	3[b]	65[a]	55	10	No
7	11	78245	6/25/13	I-77	NB	Day	4	65	55	10	No
			6/26/13			Night	4	65	55	10	No
			6/25/13		SB	Day	4	65	55	10	No
8	5	81253	6/26/13	I-70	EB	Day	3	65	55	10	No
					WB	Day	3	65	55	10	No

No. = Number; PID = Project Identification; I = Interstate; SR = State Route; US = United States; EB = Eastbound; WB = Westbound; NB = Northbound; SB = Southbound; Nodes = Data Collection Locations.
[a] Commercial vehicle speed limit was 55 mph.
[b] Sample size too small at one or more nodes.

As shown in Table 4, the study sites included three work zone conditions for which the speed limit may be reduced: lane shift, lane closure, and temporary diversion. All lane shifts moved traffic by a full lane width, similar to the example shown in OMUTCD Figure 6H-36. Researchers evaluated both right and left lane closures. All lane closures were single-lane closures on four-lane highways (i.e., two lanes in each direction). Researchers also studied two types of temporary diversions: median crossovers and hybrid median crossovers. The median crossover scenarios studied included left lane closures and the routing of all traffic in one direction across the median to the opposite direction via a one-lane temporary road (MT-95.70 [*46*]). In contrast, the hybrid median crossover scenarios (also known as contraflow) studied diverted only one travel lane across the median (PIS 209572 [*47*] and PIS 209573 [*48*]). The remaining lane was maintained to the right of the median through an area of part-width construction. For the contraflow operations, the through traffic was encouraged via signing to use the median crossover. Traffic needing to exit the highway had to remain on the normal side of the road. Contraflow operations are used to mitigate traffic impacts and the cost to accommodate ramp access. In addition to these three work zone conditions, many of the factors used to warrant reduced speed limits in work zones were also 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.
- 85^{th} percentile speed.
- Percent of vehicles exceeding the speed limit.

Appendix A contains these descriptive statistics. Changes in these descriptive statistics were computed as the difference between the statistic at the work zone condition/factor combinations of interest and the statistic measured upstream of the work zone (i.e., base condition). Thus, positive values represent increases and negative values represent decreases.

Table 4. Conditions and Factors Used to Justify Speed Limit Reductions.

Site No.	Direction	Order of Conditions and Factors Encountered by Motorists			
		First	Second	Third	Fourth
1	EB	Left lane closure[a]	Lane shift	Unexpected condition[b] Barrier w/in 2 ft of inside lane	Left lane closure[a]
	WB	Left lane closure[c] Hybrid median crossover[d] Reduce safe speed for crossover[d]	Left lane closure[c]	Barrier w/in 2 ft of lane	
	NB	Left lane closure	Barrier w/in 2 ft of lane		
	SB	Left lane closure	Median crossover Reduce safe speed for crossover	Barrier w/in 2 ft of lane	
2	WB	Lane shift	Barrier w/in 2 ft of inside lane		
3	NB	Hybrid median crossover Reduce safe speed for crossover	Barrier w/in 2 ft of lane		
	SB	Left lane closure[e]	Barrier w/in 2 ft of lane	Left lane closure[e]	Barrier w/in 2 ft of lane
4	SB	Right lane closure[f]	Unprotected workers[f]	Lane shift	Barrier w/in 2 ft of inside lane
5	EB	Left lane closure	Barrier w/in 2 ft of lane Lane closure shift	Right lane closure	Unprotected workers
	WB	Left lane closure	Median crossover Reduce safe speed for crossover	Barrier w/in 2 ft of lane	
6	EB	Right lane closure[g] Barrier w/in 2 ft of lane	Left lane closure[g] Barrier w/in 2 ft of lane	Right lane closure[g] Barrier w/in 2 ft of lane	
	WB	Left lane closure	Median crossover Reduce safe speed for crossover	Barrier w/in 2 ft of lane	
7	NB	Right lane closure	Unprotected workers		
	SB	Left lane closure	Unprotected workers		
8	EB	Lane shift	Barrier w/in 2 ft of inside lane		
	WB	Lane shift	Barrier w/in 2 ft of inside lane		

[a] Closed so construction vehicles using median turnaround could accelerate in left lane before merging with traffic.
[b] Construction vehicle access/egress.
[c] On 6/19/2013, there were two left lane closures, one near beginning of work zone and another one farther downstream. Both lanes open between two lane closures.
[d] On 6/28/2013, contraflow was used (no lane closures) but only collected data in the median crossover.
[e] Two different work zones in the same vicinity with left lane closures. Both lanes open between lane closures. There was no speed limit reduction for the first work zone.
[f] At night only.
[g] Three different work zones in the same vicinity with lane closures. Both lanes open between lane closures. There was no speed limit reduction for the first work zone. Barrier at work activity only.

In an attempt to better align work zone speed limits with actual motorist speed choice, researchers deemed it is desirable to have the 85th percentile speed within approximately 5 mph of the work zone speed limit and to minimize the change in speed variability. Researchers used standard statistical analysis methods to determine if changes in the mean speed and variance were significant. A 5 percent significance level ($\alpha = 0.05$) was used for all statistical analyses. Of course, researchers also considered worker safety. While the daytime and nighttime data were divided and analyzed separately, only the daytime data are discussed below. The nighttime data exhibited similar trends and are documented in Appendix A.

RESULTS

Speed Characteristics Upstream of Work Zone

First, researchers reviewed the speed characteristics upstream of the work zones to identify trends in the normal speeds on the facilities (Table 5). As expected, the 85th percentile speed was greater than the original posted speed limit at almost all of the sites (90 percent). However, at 82 percent of these sites, the 85th percentile speed was within 5 mph of the original posted speed limit. Only 18 percent of these sites had an 85th percentile speed that was 6 to 7 mph over the original posted speed limit. The mean speed was closely aligned with the original posted speed limit (within 1 mph) at more than half of the sites (58 percent), yielding overall mean speeds that were practically the same as the original posted speed limit (64.7 mph for 65 mph speed limit and 60.3 mph for the 60 mph speed limit). These findings are supported by previous research (*12*).

Table 5. Daytime Speed Characteristics Upstream of Work Zone.

No. of Nodes	Speed Limit (mph)	Sample Size	Metrics[a]	85th Percentile Speed (mph)	Mean Speed (mph)	Speed Variance (mph^2)	Percent Exceeding Speed Limit		
							By ≤ 5 mph	By > 5 mph	Total
2	60	257	Overall Range	65 65	60.3 60.2-60.5	21.1 21.1-21.2	42.0 41.1-43.0	9.3 9.3-9.4	51.3 50.4-52.4
19	65	2374	Overall Range	69 64-72	64.7 58.9-68.6	23.8 11.3-33.8	34.8 8.2-50.8	9.7 2.1-32.6	44.5 10.3-76.3

[a] Overall value for the entire dataset shown on top. Range across nodes shown on bottom.

As discussed previously, speed variance is closely related to the likelihood of crashes (i.e., the greater the variability in vehicle speeds, the greater the crash risk). Speed variance upstream of the work zones ranged between 11.3 and 33.8 mph^2. Overall, the speed variance was 21.1 mph^2 and 23.8 mph^2 for sites with an original posted speed limit of 60 mph and 65 mph, respectively. As mentioned earlier, lower speeds do not always equate to lower speed variance. An example of this was found at site 1SB. This site had the lowest mean and 85^{th} percentile speeds (59 and 64 mph, respectively) but the highest speed variance (33.8 mph^2). This higher speed variance was a result of motorists traveling at a broader range of speeds (40 to 77 mph).

The range of the total percent exceeding the original posted speed limit data shows the variability in compliance across the 65 mph sites. However, at all of the sites, most motorists exceeding the speed limit were doing so by 5 mph or less. Overall, for both speed limits evaluated (60 and 65 mph), about half of the motorists were exceeding the original posted speed limit upstream of the work zone.

Speed Characteristics Downstream of First Work Zone Speed Limit Sign

Next, researchers compared the speed characteristics of the roadway upstream of the work zone to the speed characteristics downstream of the first reduced work zone speed limit sign. Initially, researchers analyzed data at sites where the first work zone speed limit sign was not within view of another work zone condition (e.g., lane closure, temporary detour, etc.) in order to isolate the effects of the work zone speed limit sign itself.

Table 6 shows the overall daytime speed characteristics downstream of the first work zone speed limit sign, as well as the change in the speed characteristics from the upstream location. It does appear that motorists slightly decreased their speed downstream of the work zone speed limit. However, since the 85^{th} percentile speeds upstream of the work zones were 3 to 7 mph over the original posted speed limit, the 85^{th} percentile speeds at the first work zone speed limit sign ended up being 13 to 15 mph over the reduced work zone speed limit. In addition, the speed variance and total percent exceeding the speed limit increased (by 11.6 mph^2 and 30.7 percent, respectively). These findings are consistent with previous research (*35*,*36*,*38*) and reiterate that motorists will only reduce their speeds if they clearly perceive a need to do so. In other words, motorists need to see the reason for the reduced speed limit before they will typically lower their speed.

Table 6. Daytime Speed Characteristics Downstream of the First Work Zone Speed Limit Sign.

No. of Nodes	Original Speed Limit (mph)	Work Zone Speed Limit (mph)	Sample Size	Work Zone Condition in View	Metrics[a]	85th Percentile Speed (mph)	Mean Speed (mph)	Speed Variance (mph^2)	Percent Exceeding Speed Limit		
									By ≤ 5 mph	By > 5 mph	Total
4	65	55	573	None	Overall Range *Change*	69 68-70 *-1*	63.4 62.0-64.8 *-3.1*[b]	30.5 25.8-33.2 *11.6*[b]	23.9 15.4-30.3 *-20.1*	67.7 53.9-80.0 *50.8*	91.6 84.2-95.4 *30.7*
2	65	55	280	Lane Shift	Overall Range *Change*	63 62-64 *-6*	58.2 58.2 *-7.6*[b]	22.9 19.2-26.3 *4.0*	41.2 37.3-46.9 *-0.7*	26.8 25.4-28.0 *14.9*	68.6 65.3-72.3 *14.9*
2	60	50	261	Lane Closure	Overall Range *Change*	58 58-59 *-6*	53.4 53.5-53.9 *-6.9*[b]	23.3 19.5-26.8 *2.2*	41.0 40.8-41.2 *-1.0*	29.1 26.9-31.3 *19.8*	70.1 67.7-72.5 *18.8*
8	65	55	1108	Lane Closure	Overall Range *Change*	62 57-66 *-5*	57.0 53.0-59.9 *-6.4*[b]	28.2 18.5-33.2 *4.6*[b]	34.1 18.7-43.4 *4.1*	23.0 9.1-40.1 *18.4*	57.0 41.5-81.7 *22.4*

[a] Overall value for the entire dataset shown on top. Range across nodes shown in the middle. Change from upstream (base) nodes shown on bottom.
[b] Significantly different at a 5 percent significance level.

Researchers also looked at sites where either a lane shift or lane closure was within view of the first work zone speed limit sign (i.e., approximately 500 ft between the sign and work zone condition). The findings for these sites are also in Table 6. In general, at these sites, there was a larger decrease in the 85th percentile (5 to 6 mph) and mean speeds (6 to 8 mph) and a smaller increase in the speed variance (2.2 to 4.6 mph^2). Also, for two of three conditions (55 mph lane shift and 50 mph lane closure), the speed variance was not found to be significantly different from the upstream locations. While the speed variance for the third condition (55 mph lane closure) was found to be significantly different from the upstream locations, it was still less of an increase than found at the sites with no work zone condition in sight. The increase in the total percent exceeding the speed limit was also less at sites where a work zone condition was within view (14.9 to 22.4 percent). Overall, while the 85th percentile speeds at the first work zone speed limit sign with a work zone condition visible were still 3 to 11 mph over the reduced speed limit, the variability in speeds was less than that at the sites with only a work zone speed limit sign. This result implies that when the first work zone speed limit sign is provided within view of a lane shift or lane closure, drivers begin to reduce their speed more consistently.

Speed Characteristics at Sites with Lane Shifts

Lane shifts are used when the work space encroaches into either the right or left lane of a divided highway, but it is not desirable to close a lane for capacity reasons (*20*). Researchers analyzed speed data from three sites (2WB, 4SB, and 8EB) where both travel lanes were shifted by a full lane width from their existing alignment for bridge or overpass work. In addition, at all three sites, a barrier was used to separate the work activity from the active travel lanes (MT-102.10 [*49*]). For these work zone conditions/factors, the speed limit was reduced from 65 mph to 55 mph. Researchers were unable to collect lane shift data at sites where only drums, not barriers, were used (MT-102.20 [*50*]). However, the use of barrier is the worst-case scenario since it tends to impact motorist speed choice more than drums.

Table 7 shows the speed characteristics entering the lane shifts (i.e., where motorists go from the existing alignment to the shifted alignment). These data show that motorists decreased their speed at the entry to the lane shifts (85th percentile and mean speed decreased by 6 and 7 mph, respectively). However, the 85th percentile speed range at the entry to the lane shifts (64 to 67 mph) shows that motorists traveled at speeds closer to the original posted speed limit

(65 mph), not the reduced work zone speed limit (55 mph). In addition, across all sites, more than three-quarters of the motorists were exceeding the work zone speed limit. There was also a significant increase in the speed variance.

As discussed previously, it is desirable to have the 85th percentile speed within approximately 5 mph of the work zone speed limit and to minimize the change in speed variability. With these criteria in mind, it appears that a speed limit reduction of 5 mph may be more appropriate on multilane highways with an original posted speed limit greater than or equal to 65 mph, regardless of whether workers are present and independent of the type of temporary traffic control device used. These results are similar to those found in previous research (*38*).

Unfortunately, researches were unable to collect lane shift data at sites on multilane highways with an original posted speed limit of 60 mph or 55 mph. Previous research (*38*) did find that it may not be necessary to reduce the speed limit even by 5 mph on roadways with an original posted speed limit less than or equal to 60 mph. However, both mobility and safety must be considered, so when workers are present without positive protection, researchers still believe a 5 mph reduction in the posted speed limit is acceptable.

Speed Characteristics at Sites with Lane Closures

Lane closure activities are those that encroach upon the area between the center line or lane line and the edge of the traveled way. Researchers previously discussed a portion of the lane closure data in relationship to the first work zone speed limit sign (Table 6). Additionally, researchers analyzed speed data within lane closures at two sites (5EB and 5WB) where the speed limit was reduced from 60 mph to 50 mph and at three sites (1WB, 7NB, and 7SB) where the speed limit was reduced from 65 mph to 55 mph. Researchers also analyzed speed data within lane closures at two sites (3SB and 6EB) where there was no speed limit reduction (original posted speed limit equal to 65 mph). At all of the study nodes analyzed, the lane closure was delineated with drums, but there was no active work (i.e., workers present) in the immediate vicinity. While barriers were used near the work activity at most of these sites, researchers could not safely collect data in those areas due to constricted roadway geometries.

Table 7. Daytime Speed Characteristics at Various Work Zone Conditions.

No. of Nodes	Original Speed Limit (mph)	Work Zone Speed Limit (mph)	Sample Size	Work Zone Condition	Metrics[a]	85th Percentile Speed (mph)	Mean Speed (mph)	Speed Variance (mph^2)	Percent Exceeding Speed Limit: By ≤ 5 mph	Percent Exceeding Speed Limit: By > 5 mph	Percent Exceeding Speed Limit: Total
3	65	55	424	Entering Lane Shift	Overall	64	59.5	28.9	40.3	37.0	77.3
					Range	64-67	58.7-61.1	24.9-34.4	38.3-42.2	31.0-45.3	71.6-87.5
					Change	*-6*	*-7.1*[b]	*9.5*[b]	*-3.9*	*20.0*	*16.1*
2	60	50	264	Within Lane Closure	Overall	56	52.2	20.2	50.0	17.4	67.4
					Range	55-58	50.9-53.5	17.9-19.2	42.4-55.3	11.4-22.7	53.8-78.0
					Change	*-8*	*-8.1*[b]	*-0.9*	*8.0*	*8.1*	*16.1*
3	65	55	412	Within Lane Closure	Overall	57	54.1	13.8	31.1	2.7	33.7
					Range	58	53.3-54.4	12.6-15.3	28.6-33.8	0.8-5.6	31.0-35.6
					Change	*-12*	*-11.7*[b]	*-1.8*	*-12.6*	*-7.2*	*-19.8*
2	65	NA	258	Within Lane Closure	Overall	62	56.6	35.1	4.7	1.9	6.6
					Range	59-64	54.3-58.7	28.6-32.1	0.8-8.3	0.8-3.0	1.6-11.3
					Change	*-4*	*-5.7*[b]	*13.1*[b]	*-16.2*	*-1.2*	*-17.4*
1	60	50	125	Entering Median Crossover	Overall	49	44.8	20.3	10.4	0.8	11.2
					Range	NA[c]	NA[c]	NA[c]	NA[c]	NA[c]	NA[c]
					Change	*-15*	*-15.7*[b]	*-0.8*	*-42.9*	*-9.4*	*-52.2*
4	65	55	548	Entering Median Crossover	Overall	56	49.3	44.9	13.5	4.2	17.7
					Range	51-59	44.9-54.2	24.4-40.7	0.7-32.2	0.7-9.1	1.4-41.3
					Change	*-13*	*-14.5*[b]	*11.7*[b]	*-16.3*	*-6.7*	*-22.9*

[a] Overall value for the entire dataset shown on top. Range across nodes shown in the middle. Change from upstream (base) nodes shown on bottom.
[b] Significantly different at a 5 percent significance level.
[c] Range not an appropriate metric since data from only one node analyzed.

Table 7 shows the speed characteristics within these lane closures (i.e., one travel lane open and one travel lane closed). For both speed limit conditions, there was a reduction in the 85^{th} percentile and mean speeds (8 to 12 mph), which yielded 85^{th} percentile speeds between 55 and 58 mph. In addition, the speed variance for both conditions was not significantly different from the speed variance upstream of the work zone. These results show that motorists drive at comparable speeds within lane closures independent of the posted speed limit.

For the two sites without a speed limit reduction, the decreases in the 85^{th} percentile and mean speeds (4 and 5.7 mph, respectively) were less than for the sites with a lane closure and reduced work zone speed limit. In addition, at these two sites, there was an increase in speed variance (13.1 mph^2). These results are supported by previous research (*22*) and show that work zone speed zoning for lane closures (whether or not workers are present) does reduce vehicle speeds and the variability in those speeds, both of which have been shown to improve safety.

Unfortunately, researchers were unable to collect speed data in the lane closures near the work activity when workers were not protected by a barrier. However, previous research (*38*) recommended a 10 mph speed limit reduction anytime workers are in a closed lane unprotected by a barrier.

Based on these findings, for multilane highways with an original posted speed limit greater than or equal to 65 mph, a 10 mph speed limit reduction for lane closures appears to be justified regardless of whether workers are present and independent of the type of temporary traffic control device used. A 10 mph speed limit reduction is also suitable for lane closures on multilane highways with an original posted speed limit equal to 60 mph or 55 mph when workers are present and a barrier is not used. However, a 5 mph speed limit reduction is more appropriate for lane closures on multilane highways with an original posted speed limit equal to 60 mph or 55 mph when workers are not present or when workers are present but protected by a barrier.

Speed Characteristics at Sites with Median Crossovers

Median crossovers are primarily used when construction requires one direction of travel to be closed. The traffic in the closed direction is routed across the median to the opposite direction via a temporary road. This was the scenario at three study sites (1SB, 5WB, and 6WB). At two other sites (1WB and 3NB), a hybrid median crossover design (i.e., contraflow) was used (i.e., only a portion of traffic was routed across the median). Four of these sites (1WB, 1SB, 3NB, and 6WB) were on roadways where the speed limit was reduced from 65 to 55 mph, and one of these sites (5WB) was on a roadway where the speed limit was reduced from 60 to 50 mph. Since all of the 65 to 55 mph temporary median crossovers (standard and hybrid designs) had only one lane, and all of the speed data were measured at a similar location (entering the crossover), researchers combined their data for analysis.

Table 7 shows the speed characteristics entering the crossover (i.e., in the reverse curve). For both speed limit conditions, there was a reduction in the 85^{th} percentile (13 to 15 mph) and mean speeds (15 to 16 mph), which yielded 85^{th} percentile speeds within 5 mph of the work zone speed limit. In addition, the percent exceeding the speed limit was less than 20 percent (the lowest for all the work zone conditions studied with a reduced speed limit). However, while the speed variance at the site with the 50 mph work zone speed limit did not significantly change from the upstream location, the speed variance at the sites with a 55 mph work zone speed limit experienced an 11.7 mph^2 increase (significantly different from the upstream locations). While it was not readily apparent why this difference occurred, researchers hypothesize that it may be attributed to differences in the construction of the median crossovers (i.e., design speed), slight changes in data collection locations, and the fact that only one site was analyzed for the 50 mph work zone speed limit. Speed characteristics exiting the crossover (i.e., out of the reverse curve) showed that motorists had essentially maintained similar speeds throughout the median crossover section.

Based on these findings, a 10 mph speed limit reduction for median crossovers appears to be valid on multilane highways with an original posted speed limit greater than or equal to 60 mph. Unfortunately, researchers were unable to collect median crossover data at sites on multilane highways with an original posted speed limit of 55 mph and a work zone speed limit of 45 mph, so they were unable to validate a 10 mph speed limit reduction at such sites. However, based on previous NCHRP research (*22*,*23*), the speed limit reduction should not be more than 10 mph.

Other Considerations

While this research study did not include observations adjacent to shoulder activity (within 2 to 10 ft of the edge line) or lane encroachment activity (inside the edge line to within 2 ft of the edge line), previous research (*38*) found:

- A 1 to 6 mph speed reduction for roadside activity without positive protection.
- A 2 to 3 mph speed reduction for roadside activity with positive protection.

Therefore, the research team recommends only a 5 mph speed limit reduction for shoulder activities when workers are present without a barrier.

At three sites (1EB, 3NB, and 3SB), researchers noticed that a speed limit sign indicating the resumption of the original posted speed limit at the end of the work zone was not in place. Thus, the reduced work zone speed limit (55 mph) was still the legal speed limit even though the work zone had ended. The 85th percentile speeds in this area ranged from 65 to 69 mph (10 to 14 mph over the speed limit in place). In addition, over 90 percent of motorists were exceeding the speed limit. Leaving reduced work zone speed limits in place when conditions do not warrant leads to high levels of non-compliance. In order to maintain the credibility of work zone speed limit signs and other devices used to reduce speeds, the proper signs restoring the original posted speed limit must be installed immediately downstream of the end of the work zone condition that warranted the speed zone.

SUMMARY

Researchers observed motorists' driving behavior (i.e., speed choice) upstream of and 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.

- Motorists will only reduce their speed if they clearly perceive a need to do so. When the first work zone speed limit sign was within view of the work zone condition used to warrant the reduced speed limit, the decrease in speeds was more and the increase in the speed variance was less. Therefore, whenever possible, the first work zone speed limit sign should be installed within view of a work zone condition. However, sometimes this is not possible due to site conditions. If speed decreases are desired in this area to prepare motorists for the downstream work zone condition, law enforcement should be used since motorists are less likely to reduce their speeds voluntarily.

- A 5 mph speed limit reduction is suitable for shoulder activity when workers are present without a barrier on multilane highways with an original posted speed limit greater than or equal to 55 mph. However, it is not necessary to reduce the speed limit when workers are not present or when workers are present but protected by a barrier.
- A 5 mph speed limit reduction is more appropriate for lane shift conditions on multilane highways with an original posted speed limit greater than or equal to 65 mph, regardless of whether workers are present and independent of the type of temporary traffic control device used. A 5 mph speed limit reduction is also acceptable on multilane highways with an original posted speed limit equal to 60 mph or 55 mph when workers are present and a barrier is not used. However, it is not necessary to reduce the speed limit on multilane highways with an original posted speed limit of 60 mph or 55 mph when workers are not present or when workers are present but protected by a barrier.
- A 10 mph speed limit reduction is justified for lane closures on multilane highways with an original posted speed limit greater than or equal to 65 mph regardless of whether workers are present and independent of the type of temporary traffic control device used. A 10 mph speed limit reduction is also suitable for lane closures on multilane highways with an original posted speed limit equal to 60 mph or 55 mph when workers are present and a barrier is not used. However, a 5 mph speed limit reduction is more appropriate for lane closures on multilane highways with an original posted speed limit equal to 60 mph or 55 mph when workers are not present or when workers are present but protected by a barrier.
- A 10 mph speed reduction for median crossovers as currently designed by ODOT appears to be valid on multilane highways with an original posted speed limit greater than or equal to 55 mph.
- In order to maintain the credibility of work zone speed limit signs and other devices used to reduce speeds, the proper signs restoring the original posted speed limit must

be installed immediately downstream of the end of the work zone condition that warranted the speed zone.

CHAPTER 3:
MOTORIST REACTIONS TO VARIABLE WORK ZONE SPEED ZONING AND ASSOCIATED WORK ZONE CONDITIONS

As previously discussed, in September 2012, legislative changes enabled ODOT to establish speed limits in construction zones that vary based on whatever criteria the agency deemed appropriate. ODOT decided to pilot variable work zone speed zones on multilane highways with existing speed limits greater than or equal to 55 mph when workers are present for three hours or more without positive protection (i.e., a barrier) and in the closed lane(s) or within 10 ft of the edge of the traveled way. In the variable work zone speed zone, the speed limit can be reduced to 10 mph less than the original posted speed limit when work activities meet the above criteria. The speed limit reduction is limited to the active portion of the project and the work that justified the variable work zone speed zone. When conditions do not warrant a reduced speed limit, the original posted speed limit must be displayed.

In September 2012, ODOT piloted the use of variable work zone speed zones on five projects. Based on the findings at these sites, ODOT refined the variable work zone speed zone process and implemented additional pilot variable work zone speed zones in the 2013 construction season. As part of this research project, the research team conducted field studies to determine motorist reactions to the variable speed zoning and associated work zone conditions.

2012 PILOT DEPLOYMENTS

In October 2012, the research team collected data at the five work zones described in Table 8. At all of the sites except one, the work zone speed limit was 10 mph below the original posted speed limit for passenger cars. At all of the work zones, the speed limit reduction was warranted based on the variable work zone speed zone criteria described above (i.e., workers present for three hours or more in the closed lane without positive protection). Enforcement was present at three of the five sites. Overall, researchers measured the speed of 9215 passenger vehicles and 1695 commercial vehicles at 56 nodes.

Table 8. 2012 Pilot Variable Work Zone Speed Zoning Study Sites and Speed Limit Characteristics.

Site No.	District	PID Number	Date	Road	Direction	Day or Night	No. of Nodes	Original Speed Limit (mph)	Work Zone Speed Limit (mph)	Speed Reduction (mph)	Enforcement Present?
DSL1	12	92652	10/13/12	SR 2	WB	Day	7	60[a]	50	10	No
			10/14/12				7	60[a]	50	10	No
DSL2	6	76355	10/17/12	I-71	NB	Night	5[b]	65	55	10	Yes
DSL3	2	92730	10/20/12	I-75	NB	Day	4[b]	60[a]	50	10	No
						Night	4[b]	60[a]	50	10	No
					SB	Day	3	60[a]	50	10	No
						Night	3	60[a]	50	10	No
SSL1	8	22950	10/16/12	I-71	NB	Day	6	65	55	10	Yes
SSL2	2	85240	10/18/12	I-475	NB	Night	6[c]	65[a]	55	10	Yes
					WB	Night	4[c]	60[a]	55	5	No
			10/21/12	US 23	NB	Day	7	65[a]	55	10	Yes

No. = Number; PID = Project Identification; I = Interstate; SR = State Route; US = United States; EB = Eastbound; WB = Westbound; NB = Northbound; SB = Southbound; Nodes = Data Collection Locations; DSL = Digital Speed Limit; SSL = Static Speed Limit.

[a] Commercial vehicle speed limit was 55 mph.

[b] Speed data could not be measured upstream of the work zone.

[c] Sample size too small at one or more nodes.

At three work zones, variable work zone speed zoning was implemented with standard static R2-1 signs with a digital inset that could display various speed limits (Figure 2). For the 2012 pilot deployments, the illuminated numerals were amber. All of the digital signs were supposed to have a WORK ZONE plaque; however, one digital sign had a WORKERS PRESENT WHEN FLASHING plaque. All of the digital signs had alternating flashing beacons, but the location of the beacons varied (i.e., either on each side of the supplemental plaque or above and below the sign assembly). When conditions warranted, the reduced work zone speed limit was displayed and the alternating flashing beacons were activated. At all other times, the original posted speed limit was displayed and the alternating flashing beacons were deactivated.

a) DSL1

b) DSL2

c) DSL3

Figure 2. 2012 Pilot Deployment Study Sites' Digital Speed Limit Signs.

At the other two work zones, variable work zone speed zoning was implemented with standard static R2-1 signs (no digital inset) and alternating flashing beacons (Figure 3). When conditions warranted, the alternating flashing beacons were to be activated, which indicated that the reduced work zone speed limit was in effect. At all other times, the alternating flashing beacons were to be deactivated, which signified that the work zone speed limit displayed was not in effect. Again, the beacons were located either on each side of the supplemental plaque or above and below the sign assembly. Also, both static sign assemblies should have had a WHEN FLASHING plaque. Without this plaque, the speed limit displayed was always in effect, and thus the sign assembly did not function as intended.

a) SSL1

b) SSL2

Figure 3. 2012 Pilot Deployment Study Sites' Static Speed Limit Signs.

The study design for these field studies was identical to the study design documented in Chapter 2. However, a number of issues arose in the field that hindered the research team's ability to conduct an analysis similar to that documented in Chapter 2.

- All of the digital speed limit (DSL) sign assemblies were not designed and operated similarly.
- All of the static speed limit (SSL) sign assemblies were not designed and operated similarly.
- At several sites, the research team could not collect baseline data upstream of the work zone of interest due to the presence of another separate work zone immediately upstream.
- At several sites, law enforcement was present. Since law enforcement is known to reduce speeds in work zones, data from these sites could not be used to assess the impact of the variable work zone speed zones.

Aware of these limitations, researchers reviewed the data and identified trends to determine the preliminary effectiveness of variable work zone speed zones. A 5 percent significance level ($\alpha = 0.05$) was used for all statistical analyses. As mentioned previously, the research team did collect some commercial vehicle speed data. However, small sample sizes within a site and inconsistent sample sizes across sites did not enable researchers to include the commercial vehicle data in the analysis. Select passenger car data and associated trends are discussed below. Appendix B contains the 2012 pilot deployment descriptive statistics for each data collection location at each site.

Digital Speed Limit Sign Results

First, researchers reviewed the speed characteristics near the first DSL sign when no enforcement was present. At one site (DSL1WB), the 85th percentile speed, mean speed, and speed variance at the first DSL sign were essentially the same as upstream of the work zone (-1 mph, -1.1 mph, and -0.7 mph^2 change, respectively), even though motorists could see a left lane closure downstream (distance unknown due to equipment malfunction). Within the left lane closure at the second DSL sign, researchers found about an 8 mph significant decrease in the 85th percentile and mean speeds and only a 2.3 mph^2 increase in the speed variance (not statistically significant). An additional 2 mph decrease in the 85th percentile and mean speeds was seen in the lane closure next to the work activity (i.e., unprotected workers), yielding an 85th percentile speed within 4 mph of the reduced work zone speed limit (54 and 50 mph, respectively). Also, the speed variance next to the work activity was significantly reduced from the variance upstream of the work zone (-8.5 mph^2).

Researchers hypothesized that a separate work zone upstream of this site may have negatively influenced the effect of the first DSL sign. Within this adjacent work zone, there were multiple static 50 mph speed limit signs that were posted 24 hours a day 7 days a week. However, in several locations, there was no apparent need for the continual speed limit reduction (i.e., no workers/work activity present, no lane closure, no geometric alignment changes, etc.). This may have led motorists to mistrust the first DSL sign. Even so, these data show that motorists reacted as desired near the work area where there were unprotected workers.

At another site (DSL3SB), the first DSL sign was located 800 ft upstream of a right lane closure. Researchers did find that motorists decreased their speed at the first DSL sign (-9 mph and -12.1 mph change in the 85th percentile speed and mean speed, respectively). However, the speed variance significantly increased by 31.1 mph^2. Thus, while the decrease in the 85th percentile and mean speeds was larger than those reported in Chapter 2 for similar conditions (i.e., first work zone speed limit sign with a lane closure within view), the increase in the speed variance was greater. Unfortunately, at this site, the research team was unable to collect data within the lane closure near the work activity since there was no safe location to position the data collection vehicle.

Static Speed Limit Sign Results

Next, researchers reviewed the speed characteristics near the SSL signs when no enforcement was present. At one site (SSL1NB), the first SSL sign was about 3200 ft upstream of the lane closure, so motorists could not see the reason for the reduced speed limit (65 to 55 mph). As expected, at this site, there was no change in the 85th percentile speed (65 mph) and the speed variance significantly increased (12.0 mph^2). Unfortunately, all of the data collected at other nodes were influenced by the presence of law enforcement.

At two other sites (SSL2WB and SSL2NB), the first SSL sign encountered by motorists was within view of a left lane closure (i.e., approximately 500 ft between the sign and the lane closure). At site SSL2WB, the 85th percentile and mean speeds were reduced by approximately 5 mph. In addition, the speed variance was reduced by 6.1 mph^2. These findings are similar to those reported in Chapter 2. At this site, researchers were also able to review data collected within the left lane closure. As expected, the 85th percentile and mean speeds decreased by about 11 mph, and the speed variance decreased by 2.1 mph^2. These data again show that motorists reacted as desired within the lane closure.

At site SSL2NB, the 85th percentile and mean speeds were reduced by 13 and 15.4 mph, respectively. While these reductions were again larger than those reported in Chapter 2, the speed variance did significantly increase (19.5 mph^2). Recall that the sign assembly at this site did not include a WHEN FLASHING plaque. Thus, in effect, the beacons remained active 24 hours a day and only the first numeral was changed (see Figure 3) based on conditions. Researchers hypothesized that this incorrect design and use of the SSL sign may have confused motorists and thus led to the increase in speed variance.

Law Enforcement

Since several of the 2012 pilot deployment study sites used law enforcement upstream of and/or near the work activity, researchers reviewed its impact on speed characteristics. In the vicinity of the law enforcement vehicle, the 85th percentile and mean speeds decreased by approximately 14 mph at all sites. At two sites, the change in the speed variance was not significantly different from the upstream location, but at the other site, the speed variance significantly increased by 8.2 mph^2. As expected, there was a large decrease in the percent of vehicles exceeding the speed limit (61.8 to 37.1 percent). These findings are consistent with previous research (*38*).

2013 PILOT DEPLOYMENTS

Findings from the 2012 pilot deployments confirmed that motorists did reduce their speed near the first variable work zone speed zoning sign when it was within view of the work zone condition used to warrant the speed limit reduction (i.e., lane closure or work activity). In addition, motorists further reduced their speed as they traveled into the lane closure and near the work activity. However, the influence of the variable work zone speed zoning sign on the speed variance was mixed, yielding some decreases and some higher-than-expected increases.

To further evaluate variable work zone speed zoning, additional pilot deployments occurred in the 2013 construction season. Due to concerns regarding potential motorist misunderstanding (*51*) and the ability to provide law enforcement agencies with accurate and timely documentation of the posted speed limit, ODOT decided not to further utilize the SSL signs with flashing alternating beacons. All of the pilot variable work zone speed zoning deployed and evaluated in 2013 used DSL signs.

To promote consistency in the design, deployment, and operation of the DSL signs, ODOT developed two proposal notes (PN 655 and PN 656). These proposal notes covered the following information:

- Criteria for use.
- Process for requesting a variable work zone speed zone.
- Requirements for furnishing, installing, maintaining, coordinating, operating, tracking, monitoring, and removing digital speed limit sign assemblies.
- Disincentives for operating digital speed limit sign assemblies without justification (e.g., without proper approval, when not warranted, etc.).
- Materials for digital sign assembly (i.e., signs, beacons, mounting, power supply, controls, and software).
- Materials for supplemental signs.
- Plan of detailed drawings.

The only difference between the two proposal notes was the speed reduction warning sign used in advance of the DSL signs to inform motorists of the potential for a reduced speed limit ahead. In non-variable work zone speed zones, a speed reduction warning sign (W3-5 on an orange background) must be placed in advance of the work zone speed zone (*20,21*). However, this sign cannot be used with variable work zone speed zoning since the speed limit displayed on the warning sign must be identical to the speed limit on the subsequent speed limit sign. Figure 4 shows the two alternative speed reduction warning signs developed by ODOT. The VARIABLE SPEED LIMIT AHEAD (W3-SPECIAL) sign was included in PN 655, while the ACTIVE WORK ZONE WHEN FLASHING (W3-SPECIAL[a]) sign was included in PN 656. The latter sign included a Type B warning light that was to be activated any time the DSL sign displayed the reduced speed limit.

a) W3-SPECIAL (PN 655) **b) W3-SPECIAL(a) (PN 656)**

Figure 4. Variable Work Zone Speed Zoning Speed Reduction Warning Signs.

Study Design and Sites Characteristics

The study design for the 2013 studies was identical to the study design documented in Chapter 2. In August and September 2013, the research team collected data at the eight work zones described in Table 9. At all of these work zones except one, the original posted speed limit was reduced by 10 mph when workers were present for three hours or more in the closed lane without positive protection. At one work zone, a recent legislative change in the original posted speed limit (increased from 65 to 70 mph) resulted in a 15 mph reduction in the speed limit for the same conditions. Enforcement was present at three of the eight sites.

Table 9. 2013 Pilot Variable Work Zone Speed Zoning Study Sites and Speed Limit Characteristics.

Site No.	District	PID Number	Date	Road	Direction	Day or Night	No. of Nodes	Original Speed Limit (mph)	Work Zone Speed Limit (mph)	Speed Reduction (mph)	Enforcement Present?	Proposal Note Used
1	2	25529	9/9/13	US 24	EB	Day	8	65[a]	55	10	No	655
						Night	7[b]	65[a]	55	10	No	655
					WB	Day	4	65[a]	55[c]	10	No	NA
2	6	95379	9/11/13	I-70	WB	Day	7	65/70	NA	0	No	656[d]
						Night	9[b]	65	55	10	No	656
3	9	80020	9/12/13	US 23	NB	Day	5	55	45	10	No	655
					SB	Day	5	55	45	10	No	655
4	7	75940	9/13/13	US 35	EB	Day	6	50	NA	0	No	655[d]
					WB	Day	5	55	45	10	No	655
5	12	84021	9/15/13	US 422	WB	Day	5	60[a]	50	10	Yes	655[e]
			9/14/13		WB	Night	5	60[a]	50	10	Yes	655[e]
6	7	89559	9/16/13	I-75	SB	Night	7[b]	70	60	10	Yes	655
7	4	92543	9/17/13	I-76	EB	Night	6	70	60	10	No	656
			9/16/13		WB	Night	5[b]	70	60	10	Yes	656
8	5	87595	8/20/13	I-70	WB	Night	5	70	55	15	No	655

No. = Number; PID = Project Identification; I = Interstate; SR = State Route; US = United States; EB = Eastbound; WB = Westbound; NB = Northbound; SB = Southbound; Nodes = Data Collection Locations; NA = Not Applicable.

[a] Commercial vehicle speed limit was 55 mph.

[b] Sample size too small at one or more nodes.

[c] Work zone speed zoning in this direction was not variable. Standard R2-1 signs used to reduce the speed limit.

[d] Beacons were not activated since the speed limit was not reduced.

[e] W3-SPECIAL signs were not installed.

Data collection times included daytime and nighttime hours. However, again, low traffic volumes resulted in small sample sizes at some nighttime data collection locations (i.e., nodes). In addition, similar commercial vehicle sample sizes could not be obtained at all of the data collection nodes across the sites, so the commercial vehicle data were not included in the analysis. Overall, researchers collected the speed of 11,401 passenger vehicles and 3597 commercial vehicles at 89 nodes.

Speed Reduction Warning Sign Implementation

The VARIABLE SPEED LIMIT AHEAD (W3-SPECIAL) sign was used at five of the sites, while the ACTIVE WORK ZONE WHEN FLASHING sign (W3-SPECIAL[a]) was used at only two sites. At Site 5, the contractor failed to install the VARIABLE SPEED LIMIT AHEAD signs as instructed.

According to the plan drawings in the proposal notes, the speed reduction warning signs were to be located a minimum of 1250 ft upstream of the first DSL sign on freeways and expressways and a minimum of 500 ft upstream of the first DSL sign on major conventional roadways. The maximum spacing could not be greater than 1.5 times the minimum distances (1875 ft and 750 ft, respectively). Table 10 shows the approximate distances between the speed reduction warning signs and the first DSL signs.

Table 10. Location of Speed Reduction Warning Signs.

Site	Roadway Designation	Approximate Distance Between Speed Reduction Warning Sign and 1st Digital Speed Limit Sign (ft)
1EB	US	1520
2WB	Interstate	1230
3NB	US	610[a]
3SB		690[a]
5WB	US	NA[b]
4EB	US	1320
4WB		1830
6SB	Interstate	1200
7EB	Interstate	670
7WB		650
8WB	Interstate	Unknown[c]

[a] The speed reduction warning signs were located in the middle of the merging taper for the lane closure.
[b] Not applicable since speed reduction warning signs not posted.
[c] Due to malfunction in data collection equipment.

DSL Sign Implementation

Figure 5 contains examples of the DSL signs used at five of the sites. Photos of the DSL signs used at night at Site 6, Site 7, and Site 8 were not available, but the research team utilized video and the site notes to verify that the sign assemblies complied with the appropriate proposal note. All of the digital signs except those at Site 2 and Site 3 met the design requirements set forth in the proposal notes. At Site 2, the plaque above the speed limit sign said WORKSITE instead of WORK ZONE. At Site 3, the top beacon was not 12 inches above the WORK ZONE plaque. All of the other components of the Site 2 and Site 3 sign assemblies were correct. Researchers also verified in the field that all of the digital numerals were white, legible from each lane, and had no halo effect present around the numerals at night. The beacons, when activated, could also be seen from each lane.

a) Site 1

b) Site 2

c) Site 3

d) Site 4

e) Site 5

Figure 5. Examples of the Digital Speed Limit Signs.

At all of the sites except one, the research team verified that the DSL signs were used only when conditions warranted, on the dates evaluated. At night at Site 1 when no workers were present, the reduced speed limit was still displayed because the contractor forgot to change all the DSL signs. Also, at this site, the contractor never activated the beacons on the DSL signs. Thus, during the day (work active) and at night (work not active), the digital speed limit signs displayed a reduced speed limit and the beacons were deactivated.

According to the plan notes, within three calendar days of the close of each sign month, the contractor was to furnish the ODOT engineer and applicable law enforcement agencies an electronic spreadsheet file per Form CA-T-20 containing the history of activity and location data downloaded from the software contained in each DSL sign assembly used at any point during the most recently ended month. ODOT required that the software document the following for each activity entry:

- Time/date stamp.
- Description of digital display legend on the R2-1 sign.
- Unique DSL sign assembly name/code.
- Status of speed limit sign beacons.
- GPS position (latitude and longitude) of the DSL sign assembly.
- Unique user name/code showing who implemented each change.

ODOT also required the software to automatically log the GPS position of the DSL sign assembly every two minutes or sooner. With each automatic log, items one through four above were to be included.

Unfortunately, these data were not properly documented by the software and readily provided in a consistent manner to the ODOT engineer or law enforcement agencies, although they are a critical element to the viability of using variable work zone speed zones and provide supporting documentation of the posted speed limit needed to aid enforcement. First, the technical capability of the software needs to be further developed to accurately and consistently track the desired information above for each DSL sign assembly (i.e., location and status). Second, the software needs to automatically produce the desired data in the format prescribed by ODOT. This removes the ability of the contractor to modify the data before submission and reduces the need for the contractor and/or ODOT personnel to manually reduce the raw data into the desired format.

According to the plan drawings in the proposal notes, the first DSL sign was to be located a minimum of 500 ft upstream of the beginning of the merging taper on freeways and expressways and a minimum of 250 ft upstream of the beginning of the merging taper on major conventional roadways. The maximum spacing could not be greater than 1.5 times the minimum distances (750 ft and 375 ft, respectively). Table 11 shows the approximate distances between the first DSL signs and the beginning of the merging taper.

Table 11. Location of First Digital Speed Limit Sign.

Site	Roadway Designation	Approximate Distance Between 1st Digital Speed Limit Sign and Beginning of Merging Taper (ft)
1EB	US	820
2WB	Interstate	480
3NB	US	-710[a]
3SB		-960[a]
4EB	US	2660
4WB		2890
5WB	US	9150
6SB	Interstate	550
7EB	Interstate	550
7WB		660

[a] The first digital speed limit sign was located after the merging taper for the lane closure.

At three of the sites, the first DSL sign was placed well outside of the stipulated distances. Figure 6 shows that at Site 3, the first DSL sign was immediately downstream of the merging taper. This figure also shows that the speed reduction warning signs were within the merging taper. At Site 4, the first DSL sign was located over 2000 ft upstream of the beginning of the merging taper. Researchers noted that the first digital DSL signs were placed upstream of all the advance warning signs that denoted the upcoming lane closure. At Site 5, the first DSL sign was located over 1.5 mile upstream of the beginning of the merging taper. Before and after this digital sign, there was a portable changeable message sign (PCMS) warning about the potential for stopped traffic and the right lane closure ahead. Researchers believe that the first DSL sign was placed farther upstream of the actual lane closure due to the possibility of queuing. However, when queuing is not present, this placement can lead to mistrust of the reduced speed limit and other associated work zone signs and devices since motorists do not perceive a need to slow down. While some queue warning systems do utilize DSL signs to post speed limits that vary based on real-time conditions, that was not the intent of the digital signs used on this project (nor the intent of the pilot variable work zone speed zoning process). It should be noted that the second DSL sign was located approximately 860 ft upstream of the lane closure. This second sign was used in the analysis since it was appropriately positioned.

a) Northbound **b) Southbound**

Figure 6. First Digital Speed Limit Sign Locations at Site 3.

According to the plan drawings in the proposal notes, the DSL signs were required to be placed:

- Every mile, independent of the type of roadway.
- Immediately after each open entrance ramp or intersection.
- For divided highways, on the side of the roadway opposite the work area, unless space prohibited, but all digital signs at a site had to be on the same side of the roadway.

Table 12 shows the location of each DSL sign (i.e., the side of the road on which the sign was placed), the distance between DSL signs, and which lanes were closed at each site. In most cases, the DSL signs were spaced less than or equal to 1 mile. A review of the site documentation found that the longer spacing (over 1 mile) was typically used to accommodate an open entrance ramp. In other words, instead of placing a DSL sign on the main lanes at the 1 mile spacing, the spacing was extended so that the sign could be placed after an upcoming entrance ramp.

At two of the sites (4WB and 6SB), the contractor was able to place the DSL signs on the side of the road opposite the work area (i.e., lane closure). At three other sites (1EB, 2WB, and 3NB), the digital signs had to be placed on the same side of the road as the work area. The location of the DSL signs varied on each side of the road at the remaining sites (3SB, 4EB, 5WB, 7EB, and 7WB). Researchers did note that when a DSL sign was on the same side as the work area and immediately downstream from the work activity, work vehicles would occasionally block the view of the DSL sign. Researchers also noted that sometimes commercial vehicles traveling in the main lanes would block the view of a DSL sign from the other travel lanes. Placing DSL signs on both sides of the road would reduce these occurrences. Researchers did not note any instances where a DSL sign was blocking the view of another work zone sign or device (e.g., arrow panel).

Table 12. Location of Other Digital Speed Limit Signs.

Site	Lane(s) Closed	Location of the Sign[a] and Approximate Distance Between the Digital Sign and the Previous Digital Sign (ft)					
		Sign 1	Sign 2	Sign 3	Sign 4	Sign 5	Sign 6
1EB	Right	Right NA	Right 5340	Right 6830	Right 8410	Right 5010	Right 4280
2WB	Right	Right NA	Right 4950	Right 5330	Right 5180	NA	NA
3NB	Left	Left NA	Left 6050	NA	NA	NA	NA
3SB	Left	Right NA	Left 6570	NA	NA	NA	NA
4EB	Left	Left NA	Left 3390	Right 4490	NA	NA	NA
4WB	Left	Right NA	Right 3660	Right 3850	NA	NA	NA
5WB	Right	Right NA	Left 8290	NA	NA	NA	NA
6SB	Right	Left NA	Left 3460	Left 4410	Left 6000	Left 3800	NA
7EB	Left	Left NA	Right 5390	NA	NA	NA	NA
7WB	Left	Left NA	Right 5530	NA	NA	NA	NA
8WB		Unknown[b]					

NA = Not Applicable.
[a] The side of the road on which the digital speed limit sign was located.
[b] Due to malfunction in data collection equipment.

At three sites, researchers noticed that a speed limit sign indicating the resumption of the original posted speed limit was not in place, although this was required in the proposal notes. In order to maintain the credibility of variable work zone speed zoning, the proper signs restoring the original posted speed limit must be installed as soon as conditions no longer warrant a reduced speed limit. This can be accomplished with standard static signs or DSL signs.

Results

The data reduction and analysis of the 2013 pilot variable work zone speed zone study data were identical to the processes described in Chapter 2. Appendix C contains the descriptive statistics for each data collection location at each site. Daytime and nighttime findings are discussed below since some of the sites were only active at night.

Speed Characteristics Upstream of Work Zone

Table 13 shows the speed characteristics upstream of the variable work zone speed zones. As expected, the 85th percentile speed was greater than the original posted speed limit at all of the sites. However, at 64 percent of these sites, the 85th percentile speed was within 5 mph of the original posted speed limit. At the remaining sites, the 85th percentile speed was 6 to 9 mph over the original posted speed limit. As seen before, the mean speed was more closely aligned with the original posted speed limit (typically within a few miles per hour). The speed variance ranged between 10.5 and 26.2 mph^2. The percent exceeding the original posted speed limit again shows the variability in compliance across sites, and shows that most motorists are exceeding the original posted speed limit by 5 mph or less. These data also show there is no practical difference between the daytime and nighttime speed characteristics on roadways with the same original posted speed limit. Overall, these findings are supported by previous research (*12*) and are similar to the results in Chapter 2.

Speed Characteristics near the Speed Reduction Warning Signs

Table 14 shows the speed characteristics near the two speed reduction warning signs used to inform motorists of the need to comply with the posted speed limit downstream. A very limited dataset was available due to the presence of law enforcement and other work zone conditions. Even so, slight changes were found in the 85th percentile and mean speeds (less than 5 mph). The speed variance significantly increased at two sites (12.5 and 14.1 mph^2), showing that while some motorists were beginning to reduce their speed, others were not. In contrast, at the other two sites, the change in the speed variance was not significant. At a speed reduction warning sign, there is no requirement (or need) for motorists to adjust their speed, so the little to no change in the speed characteristics was expected.

Table 13. Speed Characteristics Upstream of Work Zone.

Time Of Day	No. of Nodes	Speed Limit (mph)	Sample Size	Metrics[a]	85^{th} Percentile Speed (mph)	Mean Speed (mph)	Speed Variance (mph^2)	Percent Exceeding Speed Limit		
								By ≤ 5 mph	By > 5 mph	Total
Day	1	50	135	Overall Range[b]	55 NA	50.1 NA	21.7 NA	29.6 NA	14.8 NA	44.4 NA
Day	3	55	432	Overall Range	62 61-64	58.2 56.7-59.6	19.0 10.5-24.8	46.8 41.8-57.2	27.3 19.4-38.8	74.1 61.2-83.3
Day	1	60	133	Overall Range[b]	65 NA	60.7 NA	18.1 NA	36.1 NA	12.0 NA	48.1 NA
Night	1	60	132	Overall Range[b]	65 NA	60.2 NA	18.3 NA	31.8 NA	12.1 NA	43.9 NA
Day	3	65	402	Overall Range	70 70-71	67.5 66.9-68.1	14.4 11.9-17.2	54.5 52.3-57.9	18.7 15.2-25.4	73.2 67.4-78.5
Night	1	65	126	Overall Range[b]	70 NA	66.3 NA	14.7 NA	50.0 NA	11.1 NA	61.1 NA
Night	4	70	526	Overall Range	72 72-74	68.3 67.2-69.0	22.5 18.5-26.2	28.1 22.6-33.3	5.1 2.2-8.8	33.3 27.1-39.2

NA = Not Applicable.
[a] Overall value for the entire dataset shown on top. Range across nodes shown on bottom.
[b] Range not an appropriate metric since data from only one node analyzed.

Table 14. Speed Characteristics Near the Speed Reduction Warning Signs.

PN	Time of Day	Site	Speed Limit (mph)	Sample Size	Metrics[a]	85th Percentile Speed (mph)	Mean Speed (mph)	Speed Variance (mph^2)	Percent Exceeding Speed Limit		
									By ≤ 5 mph	By > 5 mph	Total
655	Day	4EB	50	135	Overall *Change*	59 *4*	54.2 *4.1*[b]	17.9 *-3.8*	43.0 *13.3*	37.0 *22.2*	80.0 *35.6*
655	Day	1EB	65	131	Overall *Change*	69 *-1*	64.2 *-2.7*[b]	31.4 *14.1*[b]	40.5 *-11.8*	8.4 *-6.8*	48.9 *-18.6*
655	Night	1EB	65	140	Overall *Change*	69 *-1*	63.4 *-2.9*[b]	27.3 *12.5*[b]	30.7 *-19.3*	6.4 *-4.7*	37.1 *-24.0*
656	Night	7EB	70	124	Overall *Change*	69 *-3*	63.0 *-4.2*[b]	36.6 *10.5*	6.5 *-16.1*	2.4 *-2.1*	8.9 *-18.2*

PN = Proposal Note.
[a] Overall value for the entire dataset shown on top. Change from upstream (base) nodes shown on bottom.
[b] Significantly different at a 5 percent significance level.

Neither previous research nor this research project has investigated motorist understanding of these signs; however, researchers believe that the word ACTIVE on the ACTIVE WORK ZONE WHEN FLASHING sign (PN 656) may not be consistently interpreted by motorists. While the word ACTIVE was meant to imply that workers were present and work activity was ongoing, motorists may also consider a work zone to be ACTIVE when a lane is closed but no workers are present. Also, this may suggest that motorists do not have to exercise as much caution or pay as much attention to work zone related signs and devices when the beacons are not flashing. In contrast, the VARIABLE SPEED LIMIT AHEAD sign (PN 655) is more closely aligned to the W3-5a sign (i.e., 55 MPH SPEED ZONE AHEAD) (*20*). Out of these two signs, the research team believes that the VARIABLE SPEED LIMIT AHEAD sign better conveys the intended message.

Speed Characteristics Downstream of the Digital Speed Limit Signs

Table 15 shows the speed characteristics downstream of the first DSL sign with a reduced speed limit displayed, as well as the change in the speed characteristics from the upstream location, for sites with no law enforcement present. The first row in this table shows the speed characteristics when a lane closure is not within view. As expected, motorists only slightly decreased their speed (less than 5 mph), and the speed variance significantly increased by 10.2 mph^2.

Generally, when a lane closure was within view, a decrease in the 85^{th} percentile and mean speeds occurred. At most sites, the change in the speed variance was not significantly different. Interestingly, the decreases in the 85^{th} percentile and mean speeds were less at the lower work zone speed zone sites. In addition, the increases in the speed variance were higher (and found to be significant) at the lower work zone speed zone sites.

Figure 7 shows the 85^{th} percentile speed at the DSL signs as encountered by motorists at five sites. The general trend shows motorists further decreased their speed inside the lane closure (Sign 2) and continued to travel at reduced speeds near the remaining DSL signs. It is important to note that this was where workers were present in the closed lane without positive protection (i.e., a barrier).

Table 15. Speed Characteristics Downstream of the First Digital Speed Limit Sign.

Time of Day	Site	Original Speed Limit (mph)	Work Zone Speed Limit (mph)	Sample Size	Work Zone Condition in View	Metrics[a]	85th Percentile Speed (mph)	Mean Speed (mph)	Speed Variance (mph²)	Percent Exceeding Speed Limit: By ≤ 5 mph	Percent Exceeding Speed Limit: By > 5 mph	Percent Exceeding Speed Limit: Total
Day	4WB	55	45	137	None	Overall *Change*	61 *-3*	55.1 *-4.5*[b]	35.1 *10.2*[b]	12.4 *-29.5*	82.5 *43.7*	94.9 *14.2*
Day	5WB	60	50	135	Lane Closure	Overall *Change*	68 *3*	61.1 *0.4*	33.9 *15.8*[b]	9.6 *-26.5*	86.7 *74.6*	96.3 *48.1*
Night	5WB	60	50	135	Lane Closure	Overall *Change*	60 *-5*	55.5 *-4.7*[b]	29.0 *10.7*[b]	25.2 *-6.6*	54.8 *42.7*	80.0 *36.1*
Day	1EB	65	55	131	Lane Closure	Overall *Change*	62 *-8*	56.0 *-10.8*[b]	22.3 *5.0*	29.0 *-23.3*	18.3 *3.2*	47.3 *-20.1*
Night	8WB	70	55	134	Lane Closure	Overall *Change*	63 *-11*	57.7 *-11.3*[b]	26.5 *2.7*	32.8 *2.4*	28.4 *19.6*	61.2 *22.0*
Night	6SB	70	60	135	Lane Closure	Overall *Change*	70 *-3*	63.8 *-4.8*[b]	26.8 *6.6*	40.7 *7.4*	33.3 *31.2*	74.1 *38.6*
Night	7EB	70	60	140	Lane Closure	Overall *Change*	61 *-11*	56.3 *-10.9*[b]	26.5 *0.3*	15.7 *-6.8*	2.9 *-1.7*	18.6 *-8.5*

[a] Overall value for the entire dataset shown on top. Change from upstream (base) nodes shown on bottom.
[b] Significantly different at a 5 percent significance level.

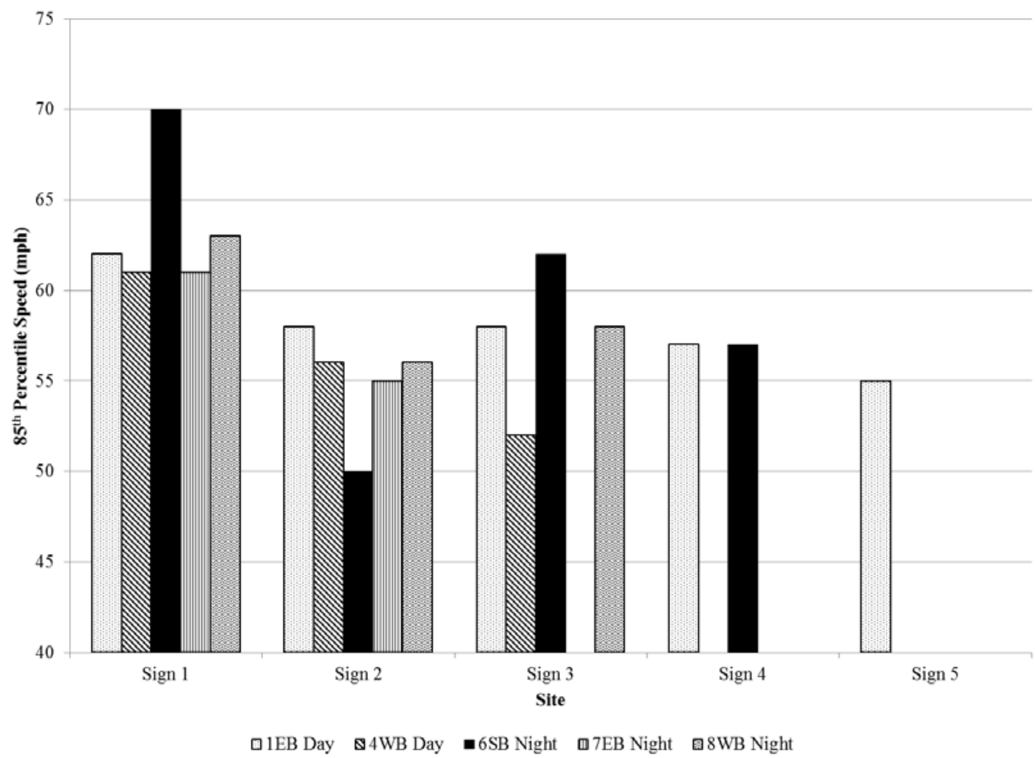


Figure 7. 85th Percentile Speeds at the Digital Speed Limit Signs.

As seen in a previous study (*38*) and in Chapter 2, the 85th percentile speed within the lane closure was generally between 55 and 60 mph independent of the work zone speed limit. While this appears to suggest that a 5 mph decrease in the speed limit may be more appropriate on multilane highways with an original posted speed limit equal to 60 mph or 55 mph, both mobility and safety must be considered. Thus, for the conditions studied (i.e., workers present in a closed lane without positive protection), researchers still believe a 10 mph reduction in the posted speed limit is acceptable. This is also consistent with previous research (*22*,*23*,*38*). However, sites that result in work zone speed zones less than 55 mph are the ones in most need of enforcement since motorists are less likely to reduce their speeds voluntarily.

SUMMARY

Researchers observed motorists' driving behavior (i.e., speed choice) upstream of and within variable work zone speed zones. Based on the results of the 2012 and 2013 pilot deployments, researchers concluded the following:

- While the development of the two proposal notes improved the consistency of the design, installation, and operation of the DSL signs, some issues were still identified in the field. Training regarding the implementation and documentation of variable work zone speed zoning should be developed for ODOT personnel and contractors so that they understand the requirements for use. Contractors should check the operation of the variable work zone speed zoning on a daily/nightly basis.

- Based on observations in the field and discussions with ODOT personnel, all of the provisions in the proposal notes for DSL sign assembly materials and supplemental sign materials were adequate, except for the DSL sign assembly software. The technical capability of the software needs to be further developed to accurately and consistently track the information specified in the proposal notes for each DSL sign assembly. The software also needs to automatically produce the desired data in the format prescribed by ODOT. This removes the ability of the contractor to modify the data before submission and reduces the need for the contractor and/or ODOT personnel to manually reduce the data into the desired format.
- There was little to no change in the speed characteristics at the two alternative speed reduction warning signs designed by ODOT to inform motorists of the need to comply with the posted speed limit downstream. While motorist understanding of the two signs was not assessed as part of this research, the research team believes that the VARIABLE SPEED LIMIT AHEAD (W3-SPECIAL) sign better conveys the intended message.
- Motorists did reduce their speed near the first DSL sign assembly when it was within view of the upcoming lane closure. Thus, the research team recommends that whenever possible, the first DSL sign assembly be installed within view of the upcoming lane closure. Motorists further decreased their speed inside the lane closure and continued to travel at reduced speeds near the remaining DSL sign assemblies and where workers were present in the closed lane without positive protection. Based on these findings, the DSL sign assembly spacing specified in the provision plan drawings (i.e., every mile and immediately after each open entrance ramp or intersection) appears to be adequate to maintain comparable reduced speeds throughout the lane closure.
- The influence of the variable work zone speed zoning sign on the speed variance was mixed. Researchers believe the novelty of the work zone speed limit signs may have

impacted the speed variance. Further use of the signs and motorist education regarding their purpose should lead to more consistent motorist reactions and thus less variability in speeds.

- A 10 mph speed limit reduction is justified for lane closures on multilane highways with an original posted speed limit greater than or equal to 55 mph when workers are present in the closed lane without positive protection (i.e., a barrier). However, work zone speed zones less than 55 mph are not recommended unless significant enforcement is used, since motorists are less likely to voluntarily reduce their speeds.

CHAPTER 4: RECOMMENDATIONS

The main objective of this research was to determine the effectiveness of the ODOT processes for establishing work zone speed zones and variable work zone speed zones. Researchers observed motorists' driving behavior (i.e., speed choice) upstream of and adjacent to several work zone condition/factor combinations used to justify reduced speed limits in work zones. Researchers also observed motorists' driving behavior upstream of and within pilot variable work zone speed zones.

Based on previous research (*22*,*23*,*38*) and the results of the studies documented herein, the research team made the recommendations shown in Table 16 for multilane highways with original posted speed limits greater than or equal to 55 mph. The following descriptions apply to this table.

- Shoulder activity—activities within 10 ft of the edge of the traveled way.
- Lane shift—activities that require the active travel lanes to be shifted laterally by a full lane width.
- Lane closure—activities that require at least one travel lane to be closed.
- Median crossover—activities that require the use of a temporary road to route all or part of one direction of travel across the median to the opposite direction of travel.
- Positive protection—a portable barrier that separates workers from the active travel lanes.

In most cases, the work zone conditions themselves justify a speed limit reduction whether or not workers are present. Thus, the recommended speed limit reductions are applicable for the entire length of the warranting work zone condition (but not the entire length of the work zone). For example, the speed limit reduction for a median crossover applies to the transition area approaching the median crossover, along the temporary road, and exiting the median crossover. Likewise, the speed limit reduction for a lane shift or lane closure pertains to the transition areas approaching these conditions and along the entire length of the lane shift or lane closure.

Table 16. Work Zone Speed Zoning Recommendations for Multilane Highways.

Work Zone Condition	Original Posted Speed Limit (mph)	Recommended Speed Limit Reduction (mph)	Provisions
Shoulder Activity	≥ 55	5	With workers present. Without positive protection.
		0	With workers present. With positive protection.
		0	Without workers present. With and without positive protection.
Lane Shift	≥ 65	5	With and without workers present. With and without positive protection.
	60 or 55	5	With workers present. Without positive protection.
		0	With workers present. With positive protection.
		0	Without workers present. With and without positive protection.
Lane Closure	≥ 65	10	With and without workers present. With and without positive protection.
	60 or 55	10	With workers present. Without positive protection.
		5	With workers present. With positive protection.
		5	Without workers present. With and without positive protection.
Median Crossover	≥ 55	10	With and without workers present. As currently designed by ODOT. Includes hybrid design.

When a work zone contains more than one condition, the highest individual speed limit reduction applies (i.e., worst-case scenario). Speed limit reductions for multiple work zone conditions should never be added together. For example, on a multilane highway with an original posted speed limit of 65 mph, a median crossover with upstream lane closures to reduce the number of lanes in each direction would warrant only a 10 mph speed limit reduction (i.e., 55 mph). Since the work zone conditions themselves justify the speed limit reduction, the speed limit reduction would remain in place until the work zone conditions were removed (whether or not workers were present). If this scenario were on a multilane highway with an original posted speed limit of 60 mph, the 10 mph speed limit reduction would still be appropriate as long as the median crossover (worst case) were in place.

If only a lane closure is present on a multilane highway with an original posted speed limit of 60 mph, then the speed limit reduction depends on whether or not workers are present and whether or not positive protection is used. This is also true for lane shifts. Thus, the work zone speed limit at a site might need to be changed on a daily/nightly basis to reflect existing conditions. This same need occurs on all multilane highways with an original posted speed limit greater than or equal to 55 mph at work zones where the lane closure is only in place during active work (i.e., removed from the roadway when no work is occurring).

The results of the pilot variable work zone speed zone study showed that motorists reduced their speed near the first variable work zone speed zoning sign when it was within view of the work zone condition that warranted the speed limit reduction. In addition, motorists further decreased their speed inside the lane closure and continued to travel at reduced speeds near the remaining DSL sign assemblies and where workers were present. Based on these findings, the research team recommends the expanded use of variable work zone speed zoning in Ohio. Variable work zone speed zoning should be considered on multilane highways with an original posted speed limit greater than or equal to 55 mph when positive protection is not used and the speed limit reduction will vary within a 24 hour period in order to accurately reflect the work zone conditions present. Typically, this need arises for two reasons:

- The work zone condition (i.e., shoulder activity without positive protection, lane shift without positive protection, or lane closure without positive protection) remains in place 24 hours a day but the speed limit reduction varies based on whether or not workers are present. See example situations in Table 17.
- The work zone condition (i.e., shoulder activity without positive protection, lane shift without positive protection, or lane closure without positive protection) is removed when workers are not present. See example situations in Table 18.

For both of these situations, the use of DSL sign assemblies allows the contractor to more easily change the speed limit to reflect the work zone conditions present. It also does not require the contractor to install/remove or uncover/cover existing and temporary speed limit signs on a daily/nightly basis. Overall, it is hoped that consistent use of DSL sign assemblies to display speed limits that accurately represent the work zone conditions present will lead to improved speed limit credibility and thus better motorist compliance for work zone speed zoning.

Table 17. Examples of Work Zone Condition Remains but Speed Limit Varies.

Work Zone Condition	Original Posted Speed Limit (mph)	Recommended Speed Limit Reduction (mph)	Provisions (Without Positive Protection)
Shoulder Activity	≥ 55	5	With workers present.
		0	Without workers present.
Lane Shift	60 or 55	5	With workers present.
		0	Without workers present.
Lane Closure	60 or 55	10	With workers present.
		5	Without workers present.

Table 18. Examples of Work Zone Condition Removed.

Work Zone Condition	Original Posted Speed Limit (mph)	Recommended Speed Limit Reduction (mph)	Provisions (Without Positive Protection)
Lane Shift	≥ 65	10	With workers and lane shift present.
		0	Without workers and lane shift.
Lane Closure	≥ 65	10	With workers and lane closure present.
		0	Without workers and lane closure.

Other recommendations regarding the use of variable work zone speed zones include:

- Training regarding the implementation and documentation of variable work zone speed zoning should be developed for ODOT personnel and contractors so that they understand the requirements for use. Contractors should check the operation of the variable work zone speed zoning on a daily/nightly basis.
- The technical capability of the DSL sign assembly software needs to be further developed to accurately and consistently track the information specified in the proposal notes for each DSL sign assembly. The software also needs to automatically produce the desired data in the format prescribed by ODOT. This removes the ability of the contractor to modify the data before submission and reduces the need for the contractor and/or ODOT personnel to manually reduce the data into the desired format.
- The VARIABLE SPEED LIMIT AHEAD (W3-SPECIAL) speed reduction warning sign should be used.

- Maintain the DSL sign assembly spacing currently specified in the provision plan drawings (i.e., every mile and immediately after each open entrance ramp or intersection).

Other work zone speed zone recommendations include:

- Sites with work zone speed zones less than 55 mph for workers present within a closed lane without positive protection are not recommended unless significant enforcement is used since motorists are less likely to voluntarily reduce their speeds compared to the same situation in a work zone speed zone greater than or equal to 55 mph.
- It is important to remember that motorists will only reduce their speed if they clearly perceive a need to do so. Therefore, whenever possible, the first work zone speed limit sign should be installed within view of the work zone condition used to warrant the reduced speed limit. Sometimes this is not possible due to site conditions, but speed decreases in the area downstream of the first work zone speed limit sign are desired to prepare motorists for the upcoming work zone condition. In this case, law enforcement should be used in the area to control speeds since motorists are not expected to voluntarily reduce their speed.
- In order to maintain the credibility of work zone speed limit signs and other devices used to reduce speeds, the proper signs restoring the original posted speed limit must be installed immediately downstream of the end of the work zone condition that warranted the speed zone.

To implement the above recommendations, changes to the ODOT Traffic Engineering Manual and the provisions for variable work zone speed zoning will be needed. Specifically, the research team recommends the following:

- Discontinue the use of Table 1297-7, Work Zone Speed Zoning Guidelines.
- Combine and revise Forms 1296-16 and 1296-17 into one form that reflects the work zone conditions and factors in Table 16, as well as any additional factors ODOT deems appropriate (e.g., unexpected conditions, crash history, traffic congestion, etc.). ODOT should also include questions to determine if variable work zone speed zoning should be considered. This one form would be used to determine and document the need for a speed limit reduction for construction projects in the design

phase, for construction projects during construction, and for operations/maintenance work.

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APPENDIX A:
REDUCED WORK ZONE SPEED LIMITS AND ASSOCIATED WORK ZONE CONDITIONS DETAILED FINDINGS

Table A1. Site 1 EB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	129	65.0	12.8	3.6	69	47.3
Reduced WZSL sign and left lane closure	55	132	55.0	20.9	4.6	60	42.4
Near work activity	55	125	61.5	18.3	4.3	66	92.8
End of lane shift	55	147	61.7	19.7	4.4	66	91.2
Begin left lane closure	55	157	57.4	31.2	5.6	63	63.1
End left lane closure	55	158	61.2	18.7	4.3	65	91.8
End work zone	65	125	66.5	16.3	4.0	71	60.0

WZSL = Work Zone Speed Limit.

Table A2. Site 1 WB Daytime_1 Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	126	67.3	15.0	3.9	71	69.8
Reduced WZSL sign	55	152	63.2	29.5	5.4	69	93.4
Within left lane closure	55	160	54.4	12.6	3.5	58	35.6
End left lane closure	55	126	60.0	14.8	3.9	64	85.7
Within left lane closure	55	130	58.4	21.7	4.7	63	71.5
End work zone	65	152	64.9	25.4	5.0	70	51.3

WZSL = Work Zone Speed Limit.

Table A3. Site 1 WB Daytime_2 Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	124	68.4	15.5	3.9	72	75.8
Reduced WZSL sign	55	130	64.8	25.8	5.1	70	95.4
Begin crossover	55	143	54.2	24.4	4.9	59	41.3
End crossover	55	140	56.2	26.5	5.2	62	55.7
End work zone	65	126	65.9	19.4	4.4	71	48.4

WZSL = Work Zone Speed Limit.

Table A4. Site 1 WB Nighttime_2 Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	127	68.0	17.3	4.2	72	72.4
Reduced WZSL sign	55	48[a]	63.5	30.0	5.5	69	89.6
Begin crossover	55	139	23.9	33.9	5.8	59	37.4
End crossover	55	13[a]	55.2	25.8	5.1	59	46.2

WZSL = Work Zone Speed Limit.
[a] Sample size too small due to inclement weather.

Table A5. Site 1 NB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	129	65.5	22.6	4.8	70	53.5
Reduced WZSL sign and left lane closure	55	131	55.4	21.3	4.6	60	42.0
End work zone	65	130	61.3	21.8	4.7	66	16.9

WZSL = Work Zone Speed Limit.

Table A6. Site 1 SB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	145	58.9	33.8	5.8	64	10.3
Reduced WZSL sign and left lane closure	55	159	58.2	24.8	5.0	63	69.8
Begin crossover	55	135	48.5	36.3	6.0	55	11.1
End crossover	55	133	54.9	33.4	5.8	60	46.6
End work zone	65	137	61.4	31.2	5.6	67	24.8

WZSL = Work Zone Speed Limit.

Table A7. Site 2 WB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	126	64.7	23.3	4.8	70	46.0
Reduced WZSL sign and lane shift	55	150	58.2	26.3	5.1	64	65.3
Begin lane shift	55	141	58.8	25.3	5.0	64	74.5
End work zone	65	130	61.4	20.3	4.5	66	17.7

WZSL = Work Zone Speed Limit.

Table A8. Site 3 NB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	134	64.1	21.1	4.6	69	38.8
Reduced WZSL sign	55	152	62.0	33.2	5.8	68	84.2
Begin crossover	55	124	49.5	40.7	6.4	56	16.9
End crossover	55	140	50.9	31.0	5.6	56	16.4
No work activity	55	127	65.3	25.2	5.0	70	96.1
End work zone	55	132	63.7	21.1	4.6	69	95.5

WZSL = Work Zone Speed Limit.

Table A9. Site 3 SB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	137	63.8	19.1	4.4	68	35.0
Begin left lane closure	65	132	58.7	32.1	5.7	64	11.4
No work activity	65	132	64.6	18.6	4.3	69	35.6
Reduced WZSL sign and left lane closure	55	153	59.6	19.6	4.4	64	81.7
End work zone	55	160	61.7	21.2	4.6	66	93.8

WZSL = Work Zone Speed Limit.

Table A10. Site 4 SB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	155	66.3	15.5	3.9	70	60.3
Reduced WZSL sign	55	139	64.0	29.3	5.4	70	94.2
Begin lane shift	55	128	61.1	34.4	5.9	67	87.5
End lane shift	55	128	59.1	22.6	4.8	64	79.7
End work zone	65	130	64.6	15.4	3.9	69	44.6

WZSL = Work Zone Speed Limit.

Table A11. Site 4 SB Nighttime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	118[a]	66.8	18.2	4.3	71	65.3
Begin right lane closure	55	129	60.3	24.6	5.0	66	84.5
Within right lane closure near work activity[b]	55	102[a]	37.9	32.9	5.7	43	0.0
Begin lane shift[b]	55	128	51.6	38.4	6.2	58	30.5
End lane shift[b]	55	133	53.6	35.0	5.9	59	39.8
End work zone[b]	65	132	64.5	24.1	4.9	69	45.5

[a] Sample size too small due to low traffic volume.
[b] Law enforcement present.

Table A12. Site 5 EB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	60	129	60.2	21.2	4.6	65	50.4
Reduced WZSL sign and left lane closure	50	131	53.9	26.8	5.2	59	72.5
Within left lane closure	50	132	53.5	19.2	4.4	58	78.0
Begin lane closure shift	50	128	53.9	13.1	3.6	58	80.5
Within right lane closure	50	126	52.6	14.4	3.8	56	67.5
Within right lane closure	50	125	51.1	18.4	4.3	55	54.4
End work zone	60	135	53.1	16.1	4.0	57	5.2

WZSL = Work Zone Speed Limit.

Table A13. Site 5 WB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	60	128	60.5	21.1	4.6	65	52.3
Reduced WZSL sign and left lane closure	50	130	53.0	19.5	4.4	57	67.7
Within left lane closure	50	132	50.9	17.9	4.2	55	53.8
Begin crossover	50	125	44.8	20.3	4.5	49	11.2
End crossover	50	129	46.3	17.0	4.1	50	11.6
End work zone	60	134	60.3	21.3	4.6	65	44.8

WZSL = Work Zone Speed Limit.

Table A14. Site 6 EB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	155	61.0	21.2	4.6	65	14.2
Begin right lane closure	65	126	54.3	28.6	5.4	59	1.6
End right lane closure	65	130	57.2	27.3	5.2	62	6.2
Baseline free flow	65	179	62.7	15.1	3.9	66	22.9
Reduced WZSL sign and left lane closure	55	130	55.0	18.5	4.3	60	41.5
End left lane closure	55	117[a]	58.9	17.8	4.2	63	4.3
Baseline free flow	65	131	62.5	19.5	4.4	67	24.4
Reduced WZSL sign and right lane closure	55	149	57.3	24.2	4.9	62	59.1
End right lane closure	65	129	56.7	25.3	5.0	63	3.9

WZSL = Work Zone Speed Limit.
[a] Sample size too small.

Table A15. Site 6 EB Nighttime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	125	60.8	24.2	4.9	65	15.2
Begin right lane closure	65	142	57.4	29.9	5.5	63	8.5
End right lane closure	65	127	57.0	31.8	5.6	63	7.9
Baseline free flow	65	129	61.4	18.3	4.3	66	16.3
Reduced WZSL sign and left lane closure	55	126	55.7	18.0	4.2	59	48.4
End left lane closure	55	133	57.7	23.2	4.8	63	64.7
Baseline free flow	65	125	61.7	26.9	5.2	67	26.4
Reduced WZSL sign and right lane closure	55	108[a]	57.7	28.6	5.3	64	58.3
End right lane closure	65	75[a]	58.1	24.0	4.9	63	5.3

WZSL = Work Zone Speed Limit.
[a] Sample size too small due to low traffic volume.

Table A16. Site 6 WB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	131	64.5	14.9	3.9	68	42.7
Reduced WZSL sign and left lane closure	55	107[a]	53.5	27.1	5.2	58	29.0
Begin crossover	55	146	44.9	31.3	5.6	51	1.4
End crossover	65	127	48.9	30.9	5.6	54	0.0
Within lane closure	65	114[a]	55.3	22.7	4.8	60	1.8
End work zone	65	150	61.9	21.9	4.7	66	19.3

WZSL = Work Zone Speed Limit.
[a] Sample size too small.

Table A17. Site 6 WB Nighttime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	37[a]	63.8	23.2	4.8	69	40.5
Reduced WZSL sign and left lane closure	55	23[a]	55.9	29.9	5.5	60	52.2
Begin crossover	55	14[a]	47.6	20.7	4.6	52	0.0

WZSL = Work Zone Speed Limit.
[a] Sample size too small due to low traffic volume.

Table A18. Site 7 NB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	137	64.9	11.3	3.4	68	44.5
Within right lane closure	55	144	58.3	23.2	4.8	63	69.4
Within right lane closure	55	126	54.4	13.2	3.6	58	34.1
End work zone	65	130	63.5	25.7	5.1	69	33.1

Table A19. Site 7 NB Nighttime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	144	66.6	21.4	4.6	71	63.9
Within right lane closure	55	130	57.2	29.6	5.4	62	66.9
Within right lane closure	55	125	55.5	19.6	4.4	59	49.6
End work zone	65	134	62.9	29.2	5.4	68	35.1

Table A20. Site 7 SB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	133	65.3	17.6	4.2	69	47.4
Reduced WZSL sign and left lane closure	55	147	59.9	33.2	5.8	66	76.2
Within left lane closure	55	126	53.3	15.3	3.9	58	31.0
End lane closure	65	127	55.4	12.5	3.5	59	0.0

WZSL = Work Zone Speed Limit.

Table A21. Site 8 EB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	135	68.6	13.4	3.7	72	76.3
Begin lane shift	55	155	58.7	24.9	5.0	64	71.6
End work zone	55	132	60.8	19.4	4.4	65	87.1

Table A22. Site 8 WB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	168	66.6	14.0	3.7	70	59.5
Reduced WZSL sign	55	130	58.2	19.2	4.4	62	72.3
End lane shift	55	127	59.7	17.0	4.1	64	83.5

WZSL = Work Zone Speed Limit.

APPENDIX B:
2012 PILOT VARIABLE WORK ZONE SPEED ZONING STUDY SITES DETAILED FINDINGS

Table B1. Site DSL1 WB Daytime_1 Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	60	130	59.8	28.2	5.3	64	41.5
1st digital VSL sign	50	135	58.8	27.6	5.3	63	93.3
2nd digital VSL sign	50	135	52.5	30.5	5.5	56	65.9
Within left lane closure near work area	50	129	50.1	19.7	4.4	54	43.4
3rd digital VSL sign	50	137	48.0	25.5	51	52	31.4
4th digital VSL sign	50	125	58.0	25.6	5.1	63	96.0
End work zone	60	130	61.1	17.7	4.2	65	58.5

VSL = Variable Speed Limit.

Table B2. Site DSL1 WB Daytime_2 Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	60	128	60.3	32.1	5.7	66	49.2
1st digital VSL sign	50	133	58.3	24.6	5.0	62	93.2
2nd digital VSL sign	50	134	51.5	23.2	4.8	56	56.7
Within left lane closure near work area	50	128	56.3	16.3	4.0	60	95.3
3rd digital VSL sign	50	148	56.9	26.1	5.1	61	89.2
4th digital VSL sign	50	133	57.4	20.2	4.5	61	93.2
End work zone	60	131	60.7	17.3	4.2	64	52.7

VSL = Variable Speed Limit.

Table B3. Site DSL2 NB Nighttime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
1st digital VSL sign	55	129	51.5	34.2	5.8	57	24.8
Within first lane closure (right lane) near work activity[a]	55	131	39.4	26.9	5.2	44	0.0
Within second lane closure (middle lane) near work activity[a]	55	131	47.3	25.0	5.0	51	6.9
End work zone	55	130	60.3	33.9	5.8	66	79.2
Speed limit back to normal	65	130	63.2	38.7	6.2	68	36.2

VSL = Variable Speed Limit.
[a] Law enforcement present.

Table B4. Site DSL3 NB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
1st digital VSL sign	50	128	53.4	31.9	5.6	58	68.0
Within left lane closure	50	126	49.7	19.4	4.4	54	39.7
End work zone	50	129	62.8	28.3	5.3	68	100.0
Speed limit back to normal	60	130	64.5	31.9	5.3	69	76.9

VSL = Variable Speed Limit.

Table B5. Site DSL3 NB Nighttime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
1st digital VSL sign	50	133	52.3	48.0	6.9	59	60.2
Within left lane closure	50	133	48.2	35.7	6.0	54	34.6
End work zone	50	139	62.3	35.4	5.9	67	97.8
Speed limit back to normal	60	135	63.6	32.2	5.7	69	69.6

VSL = Variable Speed Limit.

Table B6. Site DSL3 SB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	60	126	66.1	17.0	4.1	69	91.3
1st digital VSL sign	50	152	54.0	48.0	7.4	60	75.8
End work zone	50	133	52.8	25.5	5.1	57	66.2

VSL = Variable Speed Limit.

Table B7. Site DSL3 SB Nighttime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	60	134	63.9	21.8	4.7	68	74.6
1st digital VSL sign	50	138	55.8	38.2	6.2	61	81.9
End work zone	50	137	53.6	23.3	4.8	57	75.9

VSL = Variable Speed Limit.

Table B8. Site SSL1 NB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	140	67.0	17.3	4.2	65	66.4
1st digital VSL sign	55	128	60.0	29.2	5.4	65	80.5
2nd digital VSL sign[a]	55	129	46.9	25.4	5.0	51	4.7
End lane closure	55	140	64.5	19.9	4.5	68	97.1
End work zone	55	131	66.8	18.8	4.3	71	100.0
Speed limit back to normal	65	141	69.1	16.7	4.1	72	82.3

VSL = Variable Speed Limit.
[a] Law enforcement present.

Table B9. Site SSL2 NB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	140	67.6	17.4	4.2	71	68.1
1st digital VSL sign	55	134	52.2	36.9	6.1	58	25.4
2nd digital VSL sign	55	128	53.8	23.1	4.8	58	40.6
3rd digital VSL sign	55	132	55.3	26.9	5.2	61	50.8
Within left lane closure near work activity[a]	55	132	53.5	22.3	4.7	58	31.8
End left lane closure	65	129	63.3	22.4	4.7	68	35.7
End work zone	65	133	65.9	25.1	5.0	71	55.6

VSL = Variable Speed Limit.
[a] Law enforcement present.

Table B10. Site SSL2 NB Nighttime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	129	66.3	19.8	4.5	70	61.2
1st digital VSL sign[a]	55	67[b]	49.9	31.4	5.6	56	38.8
Near work activity	55	128	53.2	33.5	5.8	59	28.9
2nd digital VSL sign	55	53[b]	52.8	32.5	5.7	59	64.2
End right lane closure	65	50[b]	53.3	32.4	5.7	58	4.0
End work zone	65	75[b]	66.0	47.3	6.9	73	56.0

VSL = Variable Speed Limit.
[a] Law enforcement present.
[b] Sample size too small due to low traffic volume.

Table B11. Site SSL2 WB Nighttime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	60	133	64.5	31.5	5.6	70	75.9
1st digital VSL sign	55	140	59.9	25.4	5.0	65	78.6
Within right lane closure	55	127	53.7	29.4	5.4	59	33.9
End work zone	65	73[a]	65.4	17.6	4.2	69	42.5

VSL = Variable Speed Limit.

[a] Sample size too small due to low traffic volume.

APPENDIX C:
2013 PILOT VARIABLE WORK ZONE SPEED ZONING STUDY SITES DETAILED FINDINGS

Table C1. Site 1 EB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	132	66.9	17.2	4.2	70	67.4
VSLA sign	65	131	64.2	31.4	5.6	69	48.9
Within right lane closure	55	131	56.0	22.3	4.7	62	47.3
2nd digital VSL sign	55	132	54.2	13.6	3.7	58	31.8
3rd digital VSL sign	55	128	54.1	14.9	3.9	58	28.1
4th digital VSL sign	55	137	54.0	17.7	4.2	57	30.7
5th digital VSL sign	55	132	51.2	23.7	4.9	55	15.2
End right lane closure	55	138	59.7	20.0	4.5	65	81.9

VSLA = Variable Speed Limit Ahead; VSL = Variable Speed Limit.

Table C2. Site 1 EB Nighttime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	126	66.3	14.7	3.8	70	61.1
VSLA sign	65	140	63.4	27.3	5.2	69	37.1
Within right lane closure	55	127	58.8	24.9	5.0	64	71.7
2nd digital VSL sign	55	125	55.6	26.6	5.2	59	47.2
3rd digital VSL sign	55	68[a]	56.0	32.8	5.7	61	58.8
4th digital VSL sign	55	97[a]	55.7	14.5	3.8	58	54.6
5th digital VSL sign	55	51[a]	53.5	24.9	5.0	58	33.3

VSLA = Variable Speed Limit Ahead; VSL = Variable Speed Limit.
[a] Sample size too small due to low traffic volume.

Table C3. Site 1 WB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	140	67.4	12.6	3.6	71	73.6
Within right lane closure	55	136	54.4	19.0	4.4	59	38.2
Reduced WZSL sign	55	131	54.1	12.2	3.5	58	35.9
End right lane closure	55	143	57.7	13.9	3.7	62	70.6

WZSL = Work Zone Speed Limit.

Table C4. Site 2 WB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	130	68.1	11.9	3.4	71	78.5
AWZWF sign	65	135	69.0	14.8	3.8	73	80.0
1st digital VSL sign	65	130	68.2	21.9	4.7	73	71.5
2nd digital VSL sign	70	131	63.2	23.5	4.8	68	5.3
Within right lane closure	70	135	62.8	25.4	5.0	68	5.2
3rd digital VSL sign	70	136	66.4	15.7	4.0	70	14.0
End right lane closure	70	151	66.9	16.1	4.0	71	19.9

AWZWF = Active Work Zone When Flashing; VSL = Variable Speed Limit.

Table C5. Site 2 WB Nighttime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	65	65[a]	66.2	20.6	4.5	70	53.8
AWZWF sign	65	56[a]	67.4	12.9	3.6	71	53.8
1st digital VSL sign	55	50[a]	63.0	32.9	5.7	69	94.0
2nd digital VSL sign	55	57[a]	55.9	23.2	4.8	60	47.4
Within right lane closure near work activity	55	49[a]	51.3	23.3	4.8	57	20.4
3rd digital VSL sign	55	46[a]	52.5	19.3	4.4	58	26.1
4th digital VSL sign	55	50[a]	54.2	10.9	3.3	57	34.0
End right lane closure	55	81[a]	65.0	31.9	5.7	70	93.8
Speed limit back to normal	70	49[a]	66.6	31.1	5.6	72	24.5

AWZWF = Active Work Zone When Flashing; VSL = Variable Speed Limit.
[a] Sample size too small due to low traffic volume.

Table C6. Site 3 NB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	55	165	56.7	17.9	4.2	61	61.2
Begin left lane closure and VSLA sign	45	136	51.6	22.7	4.8	56	91.2
Within left lane closure near work activity	45	132	44.8	16.5	4.1	49	43.2
2nd digital VSL sign	55	130	43.6	17.5	4.2	47	0.0
End left lane closure	55	136	49.9	18.0	4.2	55	8.8

VSLA = Variable Speed Limit Ahead; VSL = Variable Speed Limit.

Table C7. Site 3 SB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	55	138	58.7	10.5	3.2	62	83.3
Begin left lane closure and VSLA sign	55	135	55.6	14.9	3.9	60	50.4
1st digital VSL sign	45	162	45.5	20.2	4.5	50	50.6
Within left lane closure near work activity	45	143	43.9	17.7	4.2	48	35.0
End left lane closure	55	136	50.1	17.4	4.2	55	9.6

VSLA = Variable Speed Limit Ahead; VSL = Variable Speed Limit.

Table C8. Site 4 EB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	50	135	501	21.7	4.7	55	44.4
VSLA sign	50	135	54.2	17.9	4.2	59	80.0
1st digital VSL sign	50	130	56.4	29.0	5.4	61	89.2
2nd digital VSL sign	50	131	49.0	23.9	4.9	53	36.6
3rd digital VSL sign	50	135	53.3	25.1	5.0	58	69.6
End left lane closure	55	162	58.7	27.8	5.3	58	78.4

VSLA = Variable Speed Limit Ahead; VSL = Variable Speed Limit.

Table C9. Site 4 WB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	55	132	59.6	24.8	5.0	64	80.6
1st digital VSL sign	45	129	55.1	35.1	5.9	61	94.9
2nd digital VSL sign	45	135	49.8	32.1	5.7	56	76.9
Within left lane closure near work activity	45	137	48.8	19.5	4.4	53	78.4
3rd digital VSL sign	45	126	47.3	17.8	4.2	52	65.2

VSL = Variable Speed Limit.

Table C10. Site 5 WB Daytime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	60	133	60.7	18.1	4.3	65	48.1
1st digital VSL sign	60	130	61.2	36.3	6.0	68	53.1
2nd digital VSL sign	50	135	61.1	33.9	5.8	68	96.3
Begin right lane closure	50	131	54.4	23.5	4.8	60	77.9
End lane closure[a]	60	131	54.7	25.4	5.0	60	10.7

VSL = Variable Speed Limit.
[a] Law enforcement present.

Table C11. Site 5 WB Nighttime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	60	132	60.2	18.3	4.3	65	43.9
1st digital VSL sign	60	129	59.3	23.8	4.9	64	41.1
2nd digital VSL sign	50	135	55.5	29.0	5.4	60	80.0
Begin right lane closure	50	137	52.2	22.2	4.7	56	62.8
End right lane closure[a]	60	126	51.5	29.9	5.5	57	7.1

VSL = Variable Speed Limit.
[a] Law enforcement present.

Table C12. Site 6 SB Nighttime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	70	138	68.6	20.2	4.5	73	35.5
1st digital VSL sign	60	135	63.8	26.8	5.2	70	74.1
2nd digital VSL sign[a]	60	133	42.7	38.0	6.2	50	0.0
3rd digital VSL sign	60	102	57.3	24.2	4.9	62	24.5
4th digital VSL sign[b]	60	128	50.9	26.6	5.2	57	0.0
5th digital VSL sign	60	66[c]	55.6	19.3	4.4	60	13.6
End right lane closure	60	68[c]	61.3	23.9	4.9	67	53.4

VSL = Variable Speed Limit.
[a] Not free flow due to queuing.
[b] Law enforcement present.
[c] Sample size too small due to low traffic volume.

Table C13. Site 7 EB Nighttime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	70	133	67.2	26.2	5.1	72	27.1
AWZWF sign	70	124	63.0	36.6	6.1	69	8.9
1st digital VSL sign	60	140	56.3	26.5	5.1	61	18.6
Begin left lane closure	60	128	51.0	36.0	6.0	57	4.7
2nd digital VSL sign	60	135	49.7	25.8	5.1	55	1.5
End left lane closure	60	128	59.8	26.5	5.1	65	45.3

AWZWF = Active Work Zone When Flashing; VSL = Variable Speed Limit.

Table C14. Site 7 WB Nighttime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	70	130	68.5	18.5	4.3	73	31.5
AWZWF sign[a]	70	131	58.6	53.1	7.3	66	4.6
1st digital VSL sign[a]	60	129	47.9	34.6	5.9	55	1.6
2nd digital VSL sign	60	114[b]	50.6	32.3	5.7	57	3.5
End left lane closure	70	130	68.5	18.5	4.3	73	31.5

AWZWF = Active Work Zone When Flashing; VSL = Variable Speed Limit.
[a] Law enforcement present.
[b] Sample size too small due to low traffic volume.

Table C15. Site 8 WB Nighttime Passenger Vehicle Speed Data Descriptive Statistics.

Data Collection Location Description	Speed Limit (mph)	Sample Size	Mean (mph)	Variance (mph^2)	Standard Deviation (mph)	85th Percentile Speed (mph)	Percent Exceeding Speed Limit
Baseline free flow	70	125	69.0	23.8	4.9	74	39.2
1st digital VSL sign	55	134	57.7	26.5	5.1	63	61.2
2nd digital VSL sign	55	130	49.9	35.3	5.9	56	16.9
3rd digital VSL sign	55	127	53.1	17.9	4.2	58	30.7
End left lane closure	70	129	65.2	27.9	5.3	70	13.2

VSL = Variable Speed Limit.