Motorists' Speed Response to Nonvariable and Variable Work Zone Speed Limits and Other Work Zone Conditions

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Transportation professionals view the setting of appropriate regulatory speed limits on public roads, including those under repair or reconstruction, as an important tool in promoting safe and efficient operations. The Ohio Department of Transportation sponsored a study to evaluate its work zone speed zoning processes. Researchers observed motorists' speed choices upstream of and adjacent to several combinations of work zone conditions and factors that were used to justify reduced speed limits in Ohio work zones. Researchers also observed motorists' speed choices upstream of and within pilot variable work zone speed zones. Researchers confirmed that motorists reduced their speed only if they clearly perceived a need to do so. Therefore, whenever possible, the first work zone speed limit sign should be installed within view of a work zone condition. In general, the speed reduction downstream of the first nonvariable and variable work zone speed limit signs ranged from 1 to 6 mph and 3 to 11 mph, respectively. In addition, researchers found that the speed reduction on entering a lane shift, within a lane closure, and on entering a median crossover ranged from 4 to 15 mph. On the basis of previous research and the results of the studies documented in this paper, the research team developed work zone speed zone guidelines for multilane highways with original posted speed limits greater than or equal to 55 mph. Researchers also made recommendations for where variable work zone speed zoning should be considered.

In April 2011, the Ohio Department of Transportation (DOT) published a new process for determining work zone speed zones (WZSZs) in an effort to enhance the safety of the traveling public and workers while providing efficient traffic flow. More than a year later, in September 2012, legislative changes enabled the Ohio DOT to establish speed limits in construction zones that varied according to agency criteria. On the basis of this legislation, the Ohio DOT developed a pilot variable WZSZ process to supplement the existing process. Research was needed to evaluate both of these speed-zoning processes. Therefore, the Ohio DOT sponsored research to determine motorists' reactions to the conditions currently used to warrant reduced speed limits and to recommend improvements to the current process (*1*).

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BACKGROUND

Current Speed Zoning in Ohio Work Zones

The current Ohio DOT WZSZ process states that all Ohio DOT construction projects, and all operations and maintenance work that is 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 (*2*). The process includes various figures, tables, and forms for determining if a WZSZ might be recommended, as well as a form to document when and where speed limit reductions are actually implemented. In general, a 10 mph or 15 mph speed limit reduction may be considered for the following conditions if at least one factor listed here exists: shoulder activity, lane encroachment, lane closure, temporary diversion, or center lane line encroachment.

The Ohio DOT WZSZ guidelines were developed on the basis of National Cooperative Highway Research Program (NCHRP) research recommendations from the mid-1990s (*3, 4*) and Ohio DOT internal procedures. However, this process resulted in many work zones with continuous speed limit reductions (i.e., for 24 hours), even though the condition that warranted the speed limit reduction (e.g., workers present and restricted geometries) was not always present. In addition, 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 2012, legislative changes to Ohio Revised Code 4511.98 enabled the Ohio DOT to establish speed limits in construction zones that varied according to conditions (*5*). With this, the Ohio DOT developed a pilot variable WZSZ process to supplement the existing WZSZ process. This pilot process allowed variable work zone speed limits on multilane highways with existing speed limits of 55 mph or greater when workers are present for three or more consecutive hours without positive protection (i.e., a barrier) and in the closed lane or lanes or within 10 ft of the edge of the traveled way. In the variable WZSZ, the speed limit could be reduced to 10 mph less than the original posted speed limit. The speed limit reduction was limited to the active portion of the project and to the work that justified the variable WZSZ. When conditions do not warrant a reduced speed limit, the original posted speed limit must be displayed. Beginning in September 2012, the Ohio DOT implemented pilot projects using variable WZSZs.

Do Slower Speeds Improve Safety?

It is generally perceived that slowing traffic in a work zone improves the overall safety of the work zone. Such claims are based predominantly on the common-sense recognition that slower vehicle speeds increase the time available for a motorist to react to any unexpected events, reduce stopping distances, and allow more significant evasive maneuvers to be executed without loss of vehicle control. Slower vehicle speeds would also presumably allow greater time for workers to move out of the way should an errant vehicle enter the work space, and reduce the likelihood of severe injury to workers and motorists should a crash occur. However, it is not clear whether the use of reduced speed limits in itself is sufficient to lower vehicle speeds enough to significantly reduce the probability of severe injury to a worker 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. 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) (*6–11*). In other words, traffic moving along at a steady, but fast, pace may be safer than attempting to slow traffic by reducing the speed limit because this can increase speed variability if only some drivers reduce their speed.

How Do Motorists Drive in Work Zones?

The NCHRP research previously mentioned (*3, 4*) found that motorists reduce speeds in work zones, even those without 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 study confirmed that work zone speed limit reductions should be avoided as much as possible. However, motorists might not always fully comprehend all of the hazards present in a work zone. Therefore, researchers recommended that speed limits in work zones could be reduced from their original levels if any of a number of potentially hazardous site conditions were present. Speed limit reductions of more than 10 mph were discouraged, because previous research (*12–14*) had shown that motorists will not typically slow down more than 10 mph through a work zone even if enforcement is present.

Previous research (*15–18*) 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. Often, most motorists are exceeding the reduced speed limit throughout the work zone. Low levels of compliance with reduced work zone speed limits have been reported in a number of studies (*18–20*).

In a recent Texas A&M Transportation Institute study, researchers conducted field studies in work zones in Texas to determine motorists' speed choices adjacent to the conditions and factors currently used by most state agencies to warrant reduced speed limits (*18*). The 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 posted speed limit. The other sites had either a 5 mph or a 15 mph speed reduction for the work zone. The study sites included three work zone conditions for which the speed limit may be reduced: 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.

Consistent with previous research, the 85th percentile speeds downstream of reduced work zone speed limit signs tended to decrease slightly (on average by 3 mph); however, the 85th 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 use the amount of the speed limit reduction to judge how much they should reduce their speed. This study found that motorists reduced their speeds in work zones when they perceived a need to reduce it; however, the amount of speed reduction appeared to depend on the normal operating speed of the roadway, the imposing nature of the situation, and enforcement activities.

Another recent study examined speed characteristics and compliance in four work zones in Missouri (*21*). At three of the sites, the speed limit was decreased by 10 mph (70 down to 60 mph). At the fourth site, the speed limit was decreased by 20 mph (70 down to 50 mph). Researchers found that the presence of construction activity significantly decreased vehicle speeds. 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.

FIELD STUDIES

Study Locations and Data Collection Methodology

In June 2013, researchers conducted field studies at eight Ohio work zones to determine motorists' speed choices upstream of and adjacent to the following conditions commonly used to justify reduced speed limits in work zones: lane shifts, lane closures, and temporary diversions (i.e., median crossovers). All of these work zones had work zone speed limits 10 mph below the original posted speed limit for passenger cars.

In August and September 2013, researchers collected data at eight additional work zones in Ohio to determine motorists' reactions to the pilot variable WZSZs and associated conditions. 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 without positive protection in the closed lane. 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. At all of the sites, the variable WZSZs were implemented using digital speed limit signs (Figure 1). When conditions warranted, the reduced work zone speed limit was displayed and the alternating flashing beacons were activated. Otherwise the original posted speed limit was displayed and the alternating flashing beacons were deactivated.

At each work zone, researchers used handheld lidar speed measurement equipment to collect the free-flow speeds at multiple locations (e.g., 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, and so on). At each data collection location (or node), researchers attempted to collect the speed of a minimum of

FIGURE 1 Example of digital speed limit signs.

125 passenger vehicles. Researchers did collect some commercial vehicle speed data; however, because similar sample sizes could not be obtained at all of the data collection locations across the work zones, the commercial vehicle speed data were not included in the analysis. Data were collected for traffic 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 and documented site characteristics.

Data Reduction and Analysis

At each site and across sites, researchers computed the following descriptive statistics for each data collection location: sample size, mean speed, variance, standard deviation, 85th percentile speed, and the percent of vehicles exceeding the speed limit. Changes in these descriptive statistics were computed as the difference between the statistic at the work zone condition and factor combinations of interest and the statistic measured upstream of the work zone (i.e., the base condition). Thus, positive values represent increases and negative values represent decreases.

In an attempt to align work zone speed limits more closely with actual motorists' speed choices, researchers deemed it is desirable to have the 85th percentile speed within approximately 5 mph of the work zone speed limit. In addition, researchers wanted to minimize the change in the speed variance in order to reduce crash risk. (Of course, researchers also considered worker safety.) Researchers used standard statistical analysis methods to determine if changes in the mean speed and variance were significant. A 5% significance level ($\alpha = .05$) was used for all statistical analyses.

Results

Speed Characteristics Upstream of Work Zones

First, researchers reviewed the speed characteristics upstream of the work zones to identify trends in the normal speeds on the facilities. As expected, the 85th percentile speed was greater than the original posted speed limit at almost all of the sites (94%). However, at approximately three-quarters of these sites (74%), the 85th percentile speed was within 5 mph of the original posted speed limit. In contrast, at 26 percent of these sites, the 85th percentile speed was 6 to 9 mph over the original posted speed limit. The mean speed was more closely aligned with the original posted speed limit (typically within a few miles per hour). Speed variance upstream of the work zones ranged between 10.5 and 33.8 mph^2. Overall, these findings are supported by previous research (*22*).

As mentioned earlier, lower speeds do not always mean lower speed variance. For example, one site had the lowest mean and 85th 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).

Speed Characteristics Downstream of First Nonvariable Work Zone Speed Limit Sign

Next, researchers compared the speed characteristics of the roadway upstream of the work zone with the speed characteristics downstream of the first nonvariable 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 shift or lane closure) to isolate the effects of the work zone speed limit sign itself.

Table 1 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. Although it does appear that motorists slightly decreased their speed downstream of the first nonvariable work zone speed limit sign, the 85th percentile speeds at the first work zone speed limit sign were still 13 to 15 mph over the reduced work zone speed limit. In addition, the speed variance and total percent exceeding the speed limit significantly increased (by 11.6 mph^2 and 30.7%, respectively). These findings are consistent with previous research (*15, 16, 18*) and reiterate that motorists need to see the reason for the reduced speed limit before they will typically lower their speed.

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 1. 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. Although the speed variance for the third condition (55 mph lane closure) was found to be significantly different from that of the upstream locations, it was still less of an increase than was 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%). Overall, although 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.

TABLE 1 Daytime Speed Characteristics Downstream of First Nonvariable Work Zone Speed Limit Sign

Number of Nodes	Original Speed Limit (mph)	Work Zone Speed Limit (mph)	Sample Size	Work Zone Condition in View	Metrics	85th Percentile Speed (mph)	Mean Speed (mph)	Speed Variance (mph²)	Percentage Exceeding Speed Limit by ≤5 mph	Percentage Exceeding Speed Limit by >5 mph	Total Percentage Exceeding Speed Limit
4	65	55	573	None	Overall[a]	69	63.4	30.5	23.9	67.7	91.6
					Range[b]	68–70	62.0–64.8	25.8–33.2	15.4–30.3	53.9–80.0	84.2–95.4
					Change[c]	–1	–3.1[d]	11.6[d]	–20.1	50.8	30.7
2	65	55	280	Lane shift	Overall[a]	63	58.2	22.9	41.2	26.8	68.6
					Range[b]	62–64	58.2	19.2–26.3	37.3–46.9	25.4–28.0	65.3–72.3
					Change[c]	–6	–7.6[d]	4.0	–0.7	14.9	14.9
2	60	50	261	Lane closure	Overall[a]	58	53.4	23.3	41.0	29.1	70.1
					Range[b]	58–59	53.5–53.9	19.5–26.8	40.8–41.2	26.9–31.3	67.7–72.5
					Change[c]	–6	–6.9[d]	2.2	–1.0	19.8	18.8
8	65	55	1,108	Lane closure	Overall[a]	62	57.0	28.2	34.1	23.0	57.0
					Range[b]	57–66	53.0–59.9	18.5–33.2	18.7–43.4	9.1–40.1	41.5–81.7
					Change[c]	–5	–6.4[d]	4.6[d]	4.1	18.4	22.4

[a]Overall value for the entire data set.
[b]Range across nodes.
[c]Change from upstream (base) nodes is shown on bottom.
[d]Significantly different at a 5% significance level.

Speed Characteristics at Sites with Lane Shifts

Researchers analyzed speed data from three sites where both travel lanes were shifted by a full lane width from their existing alignment. In addition, at all three sites, a barrier was used to separate the work activity from the active travel lanes. For these work zone conditions and factors, the speed limit was reduced from 65 to 55 mph.

Table 2 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 (9.5 mph^2).

TABLE 2 Daytime Speed Characteristics, by Work Zone Conditions

Number of Nodes	Original Speed Limit (mph)	Work Zone Speed Limit (mph)	Sample Size	Work Zone Condition	Metrics	85th Percentile Speed (mph)	Mean Speed (mph)	Speed Variance (mph²)	Percentage Exceeding Speed Limit by ≤5 mph	Percentage Exceeding Speed Limit by >5 mph	Total Percentage Exceeding Speed Limit
3	65	55	424	Entering	Overall[a]	64	59.5	28.9	40.3	37.0	77.3
				lane shift	Range[b]	64–67	58.7–61.1	24.9–34.4	38.3–42.2	31.0–45.3	71.6–87.5
					Change[c]	–6	–7.1[d]	9.5[d]	–3.9	20.0	16.1
2	60	50	264	Within lane	Overall[a]	56	52.2	20.2	50.0	17.4	67.4
				closure	Range[b]	55–58	50.9–53.5	17.9–19.2	42.4–55.3	11.4–22.7	53.8–78.0
					Change[c]	–8	–8.1[d]	–0.9	8.0	8.1	16.1
3	65	55	412	Within lane	Overall[a]	57	54.1	13.8	31.1	2.7	33.7
				closure	Range[b]	58	53.3–54.4	12.6–15.3	28.6–33.8	0.8–5.6	31.0–35.6
					Change[c]	–12	–11.7[d]	–1.8	–12.6	–7.2	–19.8
2	65	NA	258	Within lane	Overall[a]	62	56. 6	35.1	4.7	1.9	6.6
				closure	Range[b]	59–64	54.3–58.7	28.6–32.1	0.8–8.3	0.8–3.0	1.6–11.3
					Change[c]	–4	–5.7[d]	13.1[d]	–16.2	–1.2	–17.4
1	60	50	125	Entering	Overall[a]	49	44. 8	20.3	10.4	0.8	11.2
				median	Range[b]	NA	NA	NA	NA	NA	NA
				crossover	Change[c]	–15	–15.7[d]	–0.8	–42.9	–9.4	–52.2
4	65	55	548	Entering	Overall[a]	56	49.3	44.9	13.5	4.2	17.7
				median	Range[b]	51–59	44.9–54.2	24.4–40.7	0.7–32.2	0.7–9.1	1.4–41.3
				crossover	Change[c]	–13	–14.5[d]	11.7[d]	–16.3	–6.7	–22.9

NOTE: NA = not an appropriate metric because data from only one node were analyzed.
[a]Overall value for the entire data set.
[b]Range across nodes is shown.
[c]Change from upstream (base) nodes.
[d]Significantly different at a 5% significance level.

As noted earlier, 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 the speed variance. 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 that is 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 (*18*).

Unfortunately, researchers were unable to collect lane shift data at sites on multilane highways with an original posted speed limit of 60 or 55 mph. Even so, on the basis of previous research findings (*3, 4, 18*) researchers believe a 5 mph reduction in the posted speed limit is applicable on these types of facilities when workers are present without positive protection. However, when workers are not present, or when workers are present but protected by a barrier, it is not necessary to reduce the speed limit.

Speed Characteristics at Sites with Lane Closures

Researchers previously discussed a portion of the lane closure data in relation to the first work zone speed limit sign (Table 1). Additionally, researchers analyzed speed data within lane closures at two sites where the speed limit was reduced from 60 to 50 mph and at three sites where the speed limit was reduced from 65 to 55 mph. Researchers also analyzed speed data within lane closures at two sites where there was no speed limit reduction (posted speed limit equal to 65 mph). At all of the locations analyzed, the lane closure was delineated with drums, but there was no active work in the immediate vicinity. Although barriers were used near the work area at most of these sites, researchers could not safely collect data in those areas because of constricted roadway geometries. This lane closure analysis included both right and left single-lane closures on four-lane highways (i.e., with two lanes in each direction).

Table 2 shows the speed characteristics within these lane closures (i.e., with one travel lane open and one travel lane closed). For both speed limit conditions, there was a reduction in the 85th percentile and mean speeds (8 to 12 mph), which yielded 85th 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 85th percentile and mean speeds (4 and 5.7 mph, respectively) were less than for the sites with a 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 (*3*) 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 area when workers were present and not protected by a barrier. However, previous research (*18*) recommended a 10 mph speed limit reduction whenever workers are in a closed lane unprotected by a barrier.

Overall, 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 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 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. At two other sites, a hybrid median crossover design was used (i.e., only a portion of traffic was routed across the median). Four sites were on roadways where the speed limit was reduced from 65 to 55 mph, and one site was on a roadway where the speed limit was reduced from 60 to 50 mph. Because 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 2 shows the speed characteristics entering the crossover (i.e., in the reverse curve). For both speed limit conditions, there was a reduction in the 85th percentile (13 to 15 mph) and mean speeds (15 to 16 mph), which yielded 85th percentile speeds within 5 mph of the work zone speed limit. In addition, the percent exceeding the speed limit was less than 20% (the lowest for all the work zone conditions studied with a reduced speed limit). However, although 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 location). Although 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.

On the basis of 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, on the basis of previous NCHRP research (*3, 4*), the speed limit reduction should not be more than 10 mph.

Speed Characteristics Downstream of the DSL Signs

Table 3 shows the speed characteristics downstream of the first digital speed limit sign with a reduced speed limit displayed, as well as the change in the speed characteristics from the upstream location. The first row in this table shows the speed characteristics when a lane closure is not within view. As expected, motorists decreased their speed only slightly (by 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 85th percentile and mean speeds occurred (3 to 11 mph and 5 to

TABLE 3 Speed Characteristics Downstream of 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	85th Percentile Speed (mph)	Mean Speed (mph)	Speed Variance (mph^2)	Percentage Exceeding Speed Limit by ≤5 mph	Percentage Exceeding Speed Limit by >5 mph	Total Percentage Exceeding Speed Limit
Day	4WB	55	45	137	None	Overall[a]	61	55.1	35.1	12.4	82.5	94.9
						Change[b]	–3	–4.5[c]	10.2[c]	–29.5	43.7	14.2
Day	5WB	60	50	135	Lane closure	Overall[a]	68	61.1	33.9	9.6	86.7	96.3
						Change[b]	3	0.4	15.8[c]	–26.5	74.6	48.1
Night	5WB	60	50	135	Lane closure	Overall[a]	60	55.5	29.0	25.2	54.8	80.0
						Change[b]	–5	–4.7[c]	10.7[c]	–6.6	42.7	36.1
Day	1EB	65	55	131	Lane closure	Overall[a]	62	56.0	22.3	29.0	18.3	47.3
						Change[b]	–8	–10.8[c]	5.0	–23.3	3.2	–20.1
Night	8WB	70	55	134	Lane closure	Overall[a]	63	57.7	26.5	32.8	28.4	61.2
						Change[b]	–11	–11.3[c]	2.7	2.4	19.6	22.0
Night	6SB	70	60	135	Lane closure	Overall[a]	70	63.8	26.8	40.7	33.3	74.1
						Change[b]	–3	–4.8[c]	6.6	7.4	31.2	38.6
Night	7EB	70	60	140	Lane closure	Overall[a]	61	56.3	26.5	15.7	2.9	18.6
						Change[b]	–11	–10.9[c]	0.3	–6.8	–1.7	–8.5

NOTE: WB = westbound; EB = eastbound; SB = southbound.
[a]Overall value for the entire data set.
[b]Change from upstream (base) nodes.
[c]Significantly different at a 5% significance level.

11 mph, respectively). At most sites, the change in the speed variance was not significantly different. Interestingly, the decreases in the 85th percentile and mean speeds were less at the lower WZSZ sites. In addition, the increases in the speed variance were higher (and found to be significant) at the lower WZSZ sites.

Figure 2 shows the 85th percentile speed at the digital speed limit signs encountered by motorists traveling through the lane closure 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 digital speed limit signs. It is important to note that this was where workers were present in the closed lane without a barrier.

As seen previously, the 85th percentile speed within the lane closure was generally between 55 and 60 mph independent of the work zone speed limit. Although 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 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 (*3, 4, 18*). However, lane closure conditions that result in WZSZs where the speed limit is less than 55 mph should not be implemented unless significant enforcement is used, because motorists are less likely to reduce their speeds voluntarily.

Other Considerations

Although this study did not include observations adjacent to shoulder activity, previous research (*18*) found the following for shoulder activity with lane encroachment (worst-case scenario):

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

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

CONCLUSIONS AND RECOMMENDATIONS

The main objective of this research was to determine the effectiveness of the Ohio DOT's processes for establishing WZSZs and variable WZSZs. Researchers observed motorists' speed choices upstream of and adjacent to several combinations of work zone conditions and factors used to justify reduced speed limits in work zones. Researchers also observed motorists' speed choices upstream of and within pilot variable WZSZs.

In general, the speed reduction downstream of the first nonvariable and variable work zone speed limit signs ranged from 1 to 6 mph and 3 to 11 mph, respectively. In addition, researchers found that the speed reduction entering a lane shift, within a lane closure, and entering a median crossover ranged from 4 to 15 mph. On the basis of on these data, researchers confirmed that 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 because of site conditions. If speed decreases are desired in this area to prepare motorists for the downstream work zone condition, law enforcement should be used, because motorists are less likely to reduce their speeds voluntarily.

On the basis of previous research and the results of the studies documented here, the research team made the recommendations shown in Table 4 for multilane highways with original posted speed limits greater than or equal to 55 mph. In most cases, the work zone

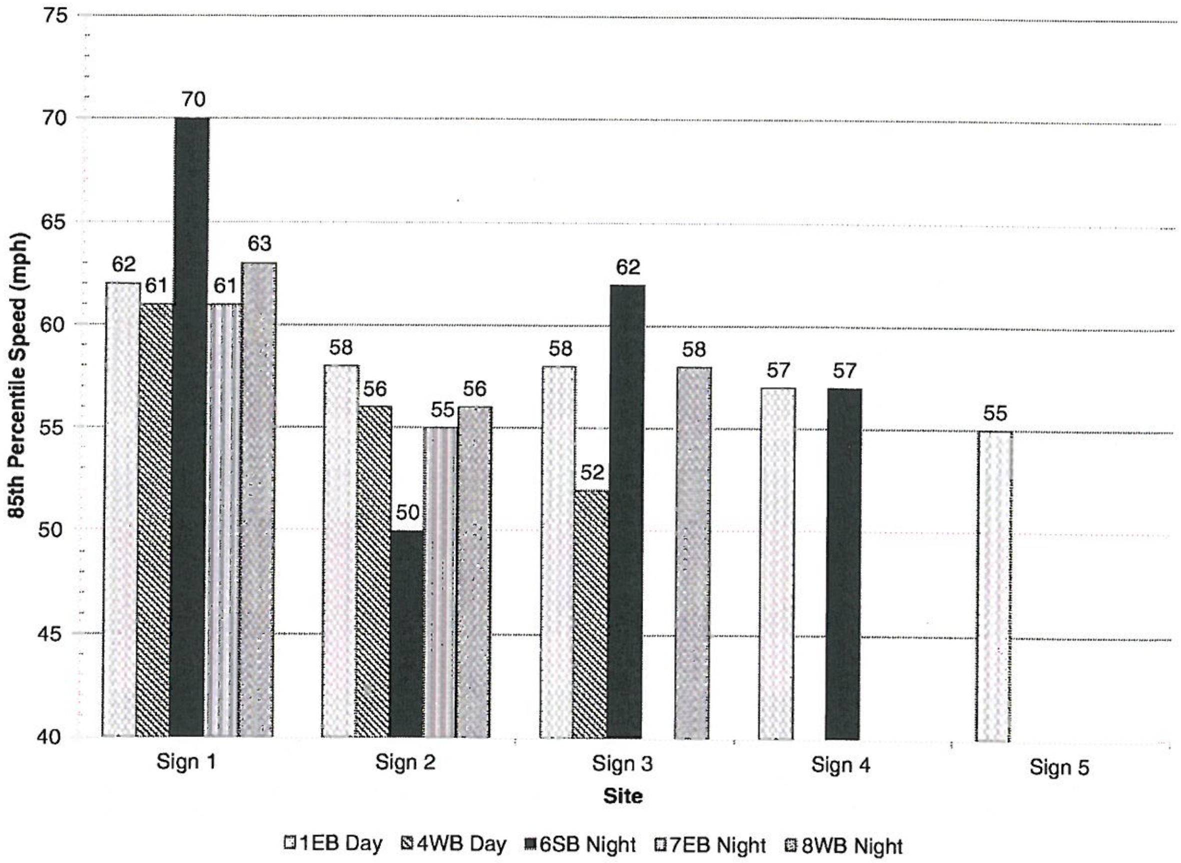

FIGURE 2 85th percentile speeds at digital speed limit signs.

TABLE 4 Work Zone Speed Zoning Recommendations for Multilane Highways

Work Zone Condition	Original Posted Speed Limit (mph)	Recommended Speed Limit Reduction (mph)	Provisions[a]
Shoulder activity (activities within 10 ft of the edge of the traveled way)	≥55	5	With workers present Without positive protection
	≥55	0	With workers present With positive protection
	≥55	0	Without workers present With and without positive protection
Lane shift (activities that require the active travel lanes to be shifted laterally by a full lane width)	≥65	5	With and without workers present With and without positive protection
	60 or 55	5	With workers present Without positive protection
	60 or 55	0	With workers present With positive protection
	60 or 55	0	Without workers present With and without positive protection
Lane closure (activities that require at least one travel lane to be closed)	≥65	10	With and without workers present With and without positive protection
	60 or 55	10[b]	With workers present Without positive protection
	60 or 55	5[b]	With workers present With positive protection
	60 or 55	5[b]	Without workers present With and without positive protection
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)	≥55	10	With and without workers present

[a]Positive protection refers to portable barrier that separates workers from the active travel lanes.
[b]Lane closures that result in work zone speed zones <55 mph should not be implemented unless significant enforcement is used, because motorists are less likely to reduce their speeds voluntarily.

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. When a work zone contains more than one condition, the highest individual speed limit reduction applies. Speed limit reductions for multiple work zone conditions should never be added together.

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 (e.g., shoulder activity, lane shift, or lane closure) remains in place 24 hours a day but the speed limit reduction varies depending on whether or not workers are present.
- The work zone condition (e.g., lane closure) is removed when workers are not present.

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