VARIABLE SPEED LIMITS SIGNS: EFFECTS ON SPEED AND SPEED VARIATION IN WORK ZONES

by

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ABSTRACT

Variable Speed Limit (VSL) signs are used across the country in conjunction with Intelligent Transportation Systems to lower posted speed limits in areas affected by conditions such as congestion, construction, accidents, fog, snow, and ice. VSL signs let operators adjust the posted speed limit without changing the physical sign. As technology advances, the ease of using VSL signs is also increasing since speeds can now be changed at preset times via email or telephone, or manually at the site. The Utah Department of Transportation desired to evaluate the effectiveness of this technology on driver behavior before using it widely in work zones on state highways. The focus of this research is driver response to VSL signs. A six-mile test site with a long-distance work zone on I-80 north of Wanship, Utah, was used to test the response of drivers to VSL signs. Five speed detectors and two VSL signs were placed and vehicle speeds were monitored for about 3 months. The speed data analyses showed that driver response was positive. Though the average speeds between static speed limit signs and VLS signs were not statistically different at a 95% confidence level, variation in speeds was reduced in general, especially at the first speed detector location downstream of the first VSL sign. Providing drivers with speed restrictions that reflect actual conditions builds “trust” in the posted speed. Long-term use of VSL signs is recommended for evaluating their long-term effect on driver compliance to reduced work zone speed limits.

Key words: Variable speed limit sign, Work zone speed compliance, Work zone safety, Driver response

INTRODUCTION

Variable Speed Limit (VSL) signs are used across the country in conjunction with Intelligent Transportation Systems to lower posted speed limits in areas affected by conditions such as congestion, construction, accidents, fog, snow, and ice. VSL let operators adjust the posted speed limit without changing the sign.

The Utah Department of Transportation (UDOT) desired to test the use of VSL signs in a construction project. Long construction zones often have actual construction occurring in only short segments of the zone, but they use static speed limit signs as if construction occurs throughout the entire construction zone all the time. In reality, the intensity, duration, and location of construction vary throughout the zone. Providing variable speed restrictions based on the level of construction improves safety and provides more accurate information to drivers, helping them comply with the posted regulatory speed.

Reducing vehicle speeds in construction zones improves safety for drivers and construction workers and can reduce the severity of crashes that occur in the zone. It is often said that crashes involving vehicles traveling at high speed are more severe than those at low speed (*1*). Reducing the speed of individual drivers is important; however, reducing the variation of speed among all drivers increases safety even more (*1*). It is reported that regardless of the average speed on a highway, the more a vehicle deviates from the average speed, the greater its chances of crashing (*1*).

The purpose of the study is to investigate the applicability and effectiveness of VSL signs at work zones in Utah. The study attempts to answer the question, would the use of VSL signs better control the variability of vehicle speeds by providing drivers with more accurate information, particularly during construction periods? Figure 1 shows the VLS sign used in the study.

This paper presents a brief literature review, study methodology, study findings, and conclusions and recommendations.

LITERATURE REVIEW

VSL signs have been used for both non-work zones and work zones. Figure 1 shows one of the variable speed limit signs used in this study. The Washington DOT has a VSL system on a mountain pass on I-90 that responds to weather conditions to advise motorists of safe speed limits, and it has instituted a VSL system on a 23-mile section of US-2 that alters speed according to road conditions (*2*). Many other transportation agencies have used this technology to reduce speeds on roads. On the New Jersey Turnpike, 120 signs over 148 miles display variable speed limits based on the speed and volume data collected by inductive loop detectors (*2*). The posted speed limit can be reduced for six reasons: crashes, congestion, construction, ice, snow and fog (*2*). New Mexico had a VSL system on an urban section of I-40 from 1989 to 1998 that used traffic speed, time, and precipitation to determine safe speed limits (*2*). In Colorado on I-70 at the Eisenhower Tunnel, VSL technology weighs downhill traveling vehicles and advises trucks to alter their speed. It is reported that since system deployment, truck-related accidents have declined on steep downhill sections while volume of truck traffic has increased by an average of 5 percent per year (*2*). Oregon also uses a similar system for downhill trucks on I-84 (*2, 4*).

As for use of VSL signs in work zones, the Washington DOT has used them to inform the drivers about the reduction of speed limit in work zones; for instance, they used VSLs to change speed limit from 70 mph to 60 mph. Minnesota DOT used VSL signs in work zones on I-494 in the Twin Cities area to decrease upstream traffic speed from 65 mph to 45 mph when drivers approach the work zone bottleneck (*2, 5*). There are also numerous examples of countries outside the United States using this technology (*2*).

(Photo by Thomas McMurtry, July 2007)

FIGURE 1 Variable speed equipment used in the study.

STUDY METHODOLOGY

Hypothesis

Improved safety to motorists and construction personnel occurs when drivers follow predictable patterns and speeds. VSL signs, which adjust the speed limit based on conditions, will have greater compliance than static signs. This compliance will result in more drivers traveling within the posted speed limit and fewer drivers traveling either significantly faster or slower than the posted speed. In this study the average speed and speed variation around the average speed were used as performance evaluators instead of the 85th percentile speed and its variation because the average speed was more close to posted speed limit.

Study Site Location and Construction Project Description

The study site was located on I-80 in Summit County near the Utah-Wyoming border. The AADT of this section of I-80 was 13,280 in year 2007. Single unit trucks accounted for 5% and combination trucks accounted for 43% of the AADT. This study site was chosen because the section became an active construction area just prior to the data collection. This study site had a

pavement "crack and seal" work zone from milepost 185 to 191 with lane closures in both the eastbound and westbound directions. Travel in both directions was restricted to one lane through the work zone at all hours for the duration of the project—from summer to fall 2007. For this study, only westbound traffic was used due to steep continual upgrades on the eastbound lanes that slow traffic significantly. The vertical alignment of the westbound direction was milder than the vertical alignment of the eastbound direction.

Data Collection

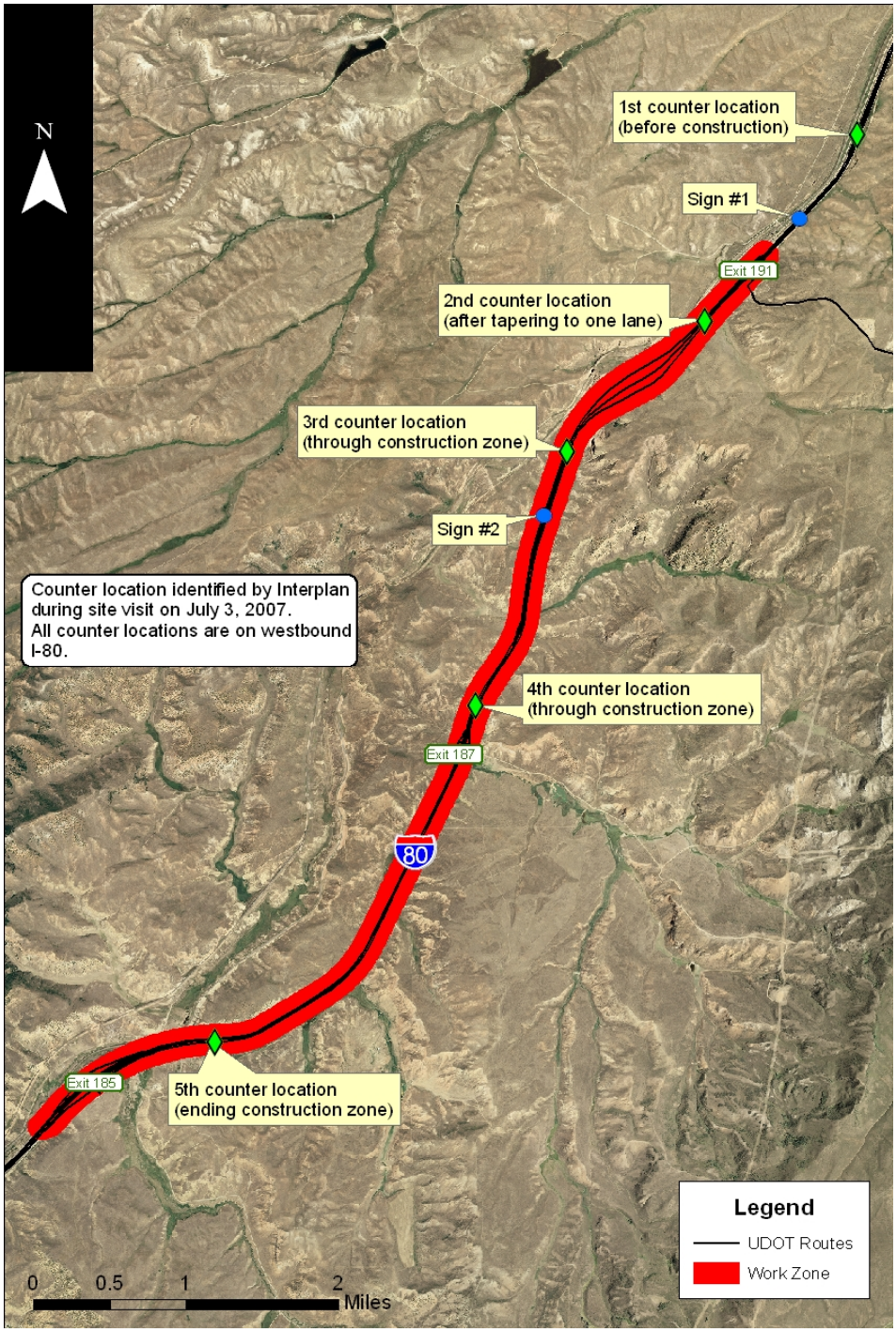
Vehicle speed data were collected at five locations on westbound I-80 for all hours of the day. The data were collected from July 10, 2007, through September 29, 2007. Data were collected using Jamar tube counters. Traffic counting tubes were used due to accuracy of defined speed bins, although maintenance requirements were high. There were several occasions when the tubes were removed for paving or were torn out by traffic. The data collection period was set at 12 weeks to account for losses and to accurately count all roadway scenarios.

The five locations were chosen to give a representative spectrum of speeds under multiple conditions of the construction zone. Figure 2 shows a map of the study section with the speed counter locations and VSL sign locations. The first counter was placed upstream of the construction to capture vehicles under normal conditions. The second counter was placed at the beginning of the construction zone just after the roadway was tapered down to one lane. The third and fourth counters were placed through the construction zone, in no particular specific location, but spaced about a mile and a half apart. The fifth counter was placed near the end of the construction zone where there was still only one lane open, but not in active construction. The construction work moved along the work activity area during the data collection period. The size of the speed limit sign was 30 inches by 36 inches, which was smaller than the size 48 inches by 60 inches defined by the Manual of Uniform Control Devices (MUTCD) (6) and the size of each digit was 18 inches by 12 inches (See Figure 1 for the VSL sign used in the study).

For the purpose of this study, two VSL signs were tested against the existing static sign. Speed data were collected under the three different conditions listed below. UDOT did not allow the speed limit for this segment of I-80 to be reduced from 75 mph to 55 mph using a standard static 55 mph speed limit sign. They allowed the use of VSL signs showing 55 mph speed limit because this reduction was made for a research purpose.

- Standard 65 mph speed limit sign
- VSL sign posted at 65 mph 24 hours per day, 7 days per week
- VSL sign varying between 55 mph during the day and 65 mph at night

Data were collected for the standard 65 mph sign for the first three weeks of the testing period. Following that, the two VSL conditions were alternated in two-week blocks. The schedule of the data collection is displayed in Figure 3.



Source: GIS data from Utah Automated Geographic Reference Center (AGRC) (7)

FIGURE 2 Location of the VSL signs and sensor locations.

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
JULY						
CONSTRUC-TION ON-GOING	2	3	4	5	6	7
8	STANDARD SIGN 65 MPH 24/7	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
AUGUST						
29	30	VSL 65 MPH 24/7	2	2	3	4
5	6	7	8	9	10	11
12	VSL 65 MPH NIGHT 55 MPH DAY	14	15	16	17	18
19	20	21	22	23	24	25
SEPTEMBER						
VSL 65 MPH 24/7	27	28	29	30	31	1
2	3	4	5	6	7	8
9	VSL 65 MPH NIGHT 55 MPH DAY	11	12	13	14	15
16	17	18	19	20	21	VSL 65 MPH 24/7
23	24	25	26	27	28	29

FIGURE 3 Data collection schedule.

STUDY FINDINGS

Data Points

The data were collected in 5 mph intervals for each hour of day throughout the study. Analysis could be performed, therefore, to answer specific questions. For instance, a question like "How many vehicles traveled between 55 and 59 mph on Tuesday from 9 AM to 10 AM at counter number 3?" can be answered by the data collected in the study. Data indicating the type of vehicle (truck, trailer, recreational vehicle, motorcycle, etc.) were not collected. Periods where

data were not collected, generally due to equipment malfunction when tubes were stripped off the pavement, occurred randomly by date, time, and counter.

Speed Distribution

The distribution of speeds observed at various counters followed an expected bell-shaped curve; however, speed distribution was more coherent with VSL signs than with regular static speed limit signs. Figure 4 shows the difference between the two methods. It should be noted that these show speed distributions of typical one-day data. Figure 4(a) shows speed distributions at the five counters on Thursday, July 12, 2007, when speed limit 65 mph signs were presented by regular static speed limit signs; Figure 4(b) shows speed distributions at the five counters on Thursday, August 30, 2007, when speed limit was presented by VSL signs. As seen in these two plots, there are two distinct speed groups with VSL signs: one bell-shaped distribution for the upstream of the work zone at counter 1 where speed limit was 75 mph and the other bell-shaped distributions for the counters within the work zone where speed limit was 65 mph. As far as these two days are concerned, the speed distribution with VSL signs appear more consistent than that with static speed limit signs.

Standard Deviation of the Data

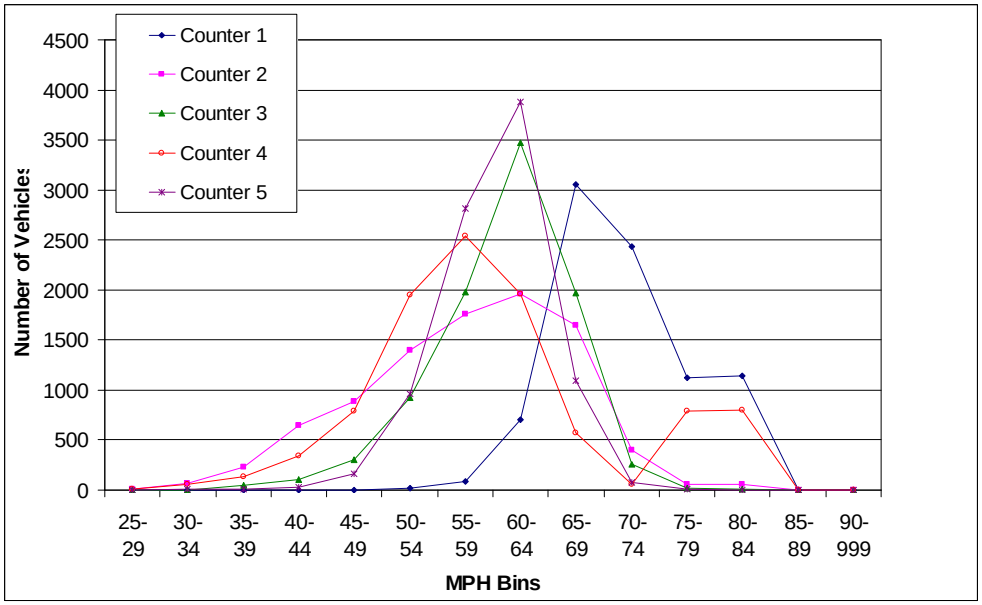
Examination of the daily standard deviation of speed showed that, for the most part, Counter 1 had larger standard deviation than the other counters after the VSL signs were installed, as shown in Figure 5(a). This was expected because vehicle speeds in the merge area into the work zone tend to vary more than in the work zone. After the VSL signs were installed on July 31, Counter 1 had the highest standard deviation 31 days of the 50 days with complete data, or 62 percent of the time. Between August 13 and 20 and between September 10 and 20, Counter 1's standard deviation is lower than the other counters. This may be because construction on those days frequently interrupted traffic in the work zones, leading to greater deviation in speed at the remaining counter locations, making the variation in speeds at Counter 1 smaller than the other counters. In July, however, counters 2, 3, and 4 had unusually high standard deviations. Wide speed fluctuations during heavy construction were expected. The leve of construction activities during the day (note that there was no construction at night), however, could not be separated from the data in any methodical way.

This study sought to compare the variability of speeds under different speed limit sign presentation methods. Therefore, to examine speed variation without construction interruptions, nighttime (from 7 PM to 6 AM) standard deviation was analyzed.

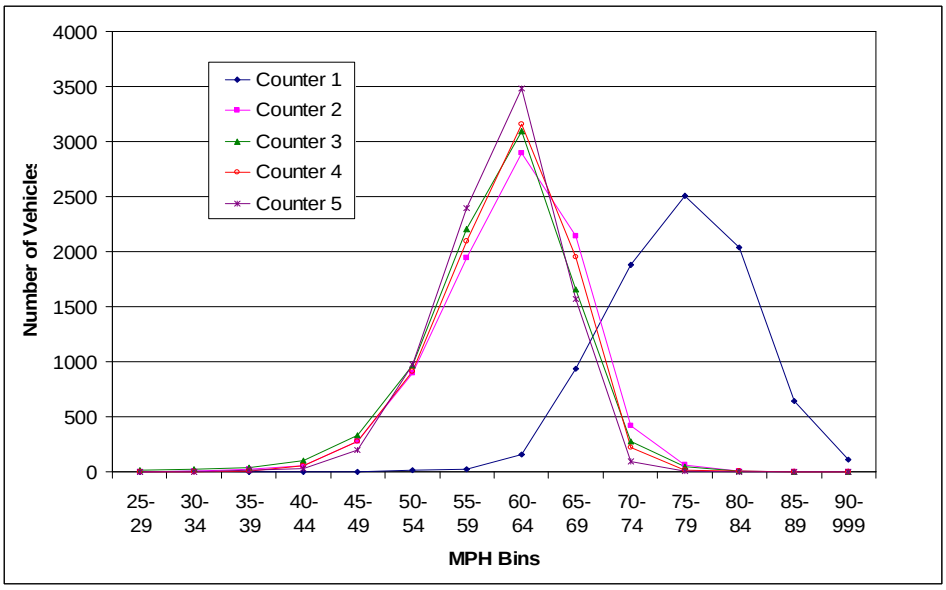
Nighttime standard deviation was highest at Counter 1 when VSL signs were present, as shown in Figure 5(b). Starting July 20 and July 27 when standard static 65 mph sign was used, standard deviations at counters 2 and 3 were unusually high. There was no night work around this time according to the engineer's diary. In fact, this work zone was practically a day-time only construction. In Utah, July 24 is a holiday (Pioneer Day) and higher traffic was anticipated around this time of the month. Of the 22 days with complete data from August 13 through September 9, Counter 1 has the highest standard deviation for 16 days, or 70 percent of the time .This is a slightly higher percentage than found measuring full 24-hour periods.

Before the installation of VSL signs, Counters 2 through 5 had speeds whose daily standard deviation ranged from 4.3 to 14. After VSL signs were installed, the highest daily speed standard deviation was 7.9, about one half of the maximum standard deviation experienced before VSL signs were used. The graph also demonstrates that when the VSL sign was set to 65

mph, standard deviation for Counters 2 through 5 was higher than 6 mph on only three occurrences. This low standard deviation of average speeds indicates that few vehicles were moving either much faster or much slower than other vehicles.

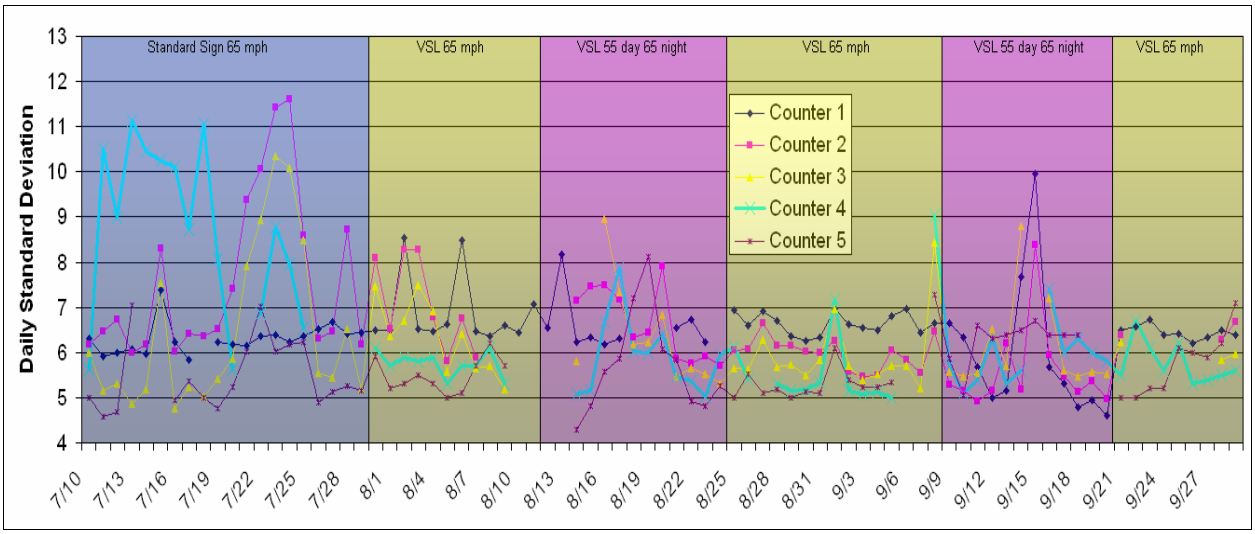


(a) Thursday, July 12, 2007: Static 65 mph sign all day.

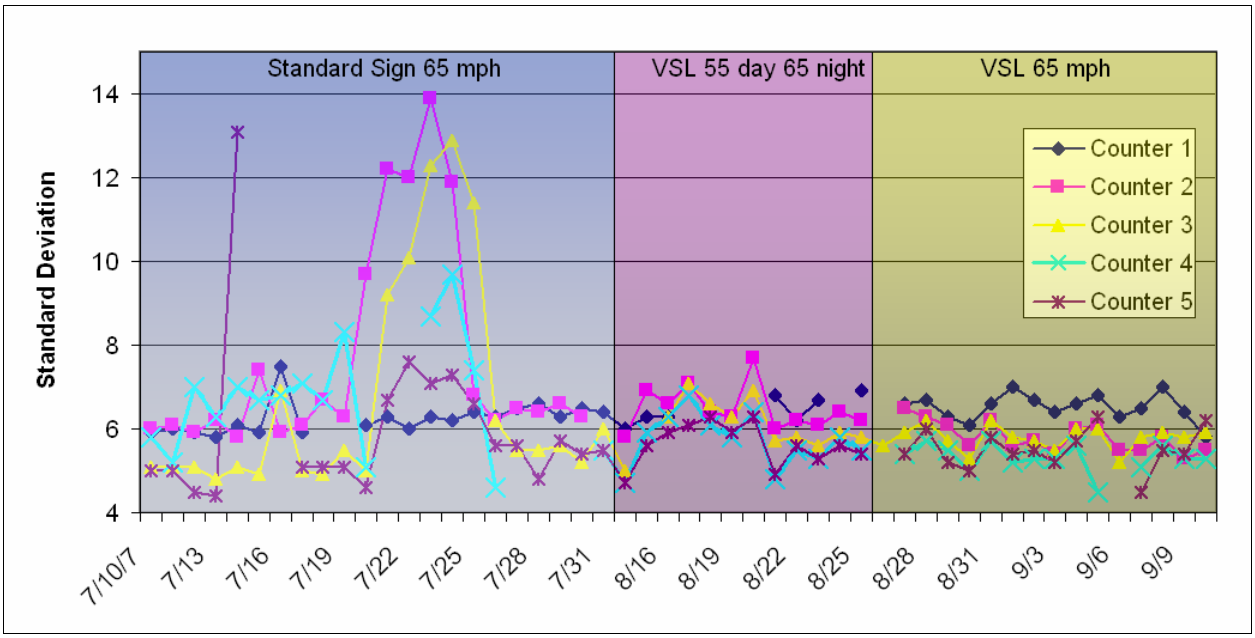


(b) Thursday, August 30, 2007: VSL sign 65 mph all day.

FIGURE 4 Comparison of speed data distribution under different speed limit presentation.



(a) Standard deviation of speed during the entire data collection period.



(b) Nighttime standard deviation of speed.

FIGURE 5 Standard deviation of speed.

Average Speed

In order to find trends where construction was underway, daytime average speeds were analyzed and presented in Figure 6. Daytime average speeds at Counters 2 through 5 are less than at Counter 1, except for a short period in September. Counter 1 was located at the 75 mph speed limit segment and all the other counters were at 65 mph or 55 mph speed limit segment as shown in Figure 6. Slow speeds in September at Counter 1 might have been due to congestion just upstream of the work zone. One possible reason is an increase in upstream demand. Counter 5 on the other hand experienced very high average speeds during that period, and other counters exhibited average speeds lower than during other periods. Increased speeds at Counter 5 may reflect vehicles speeding up significantly to make up for time lost in congestion upstream.

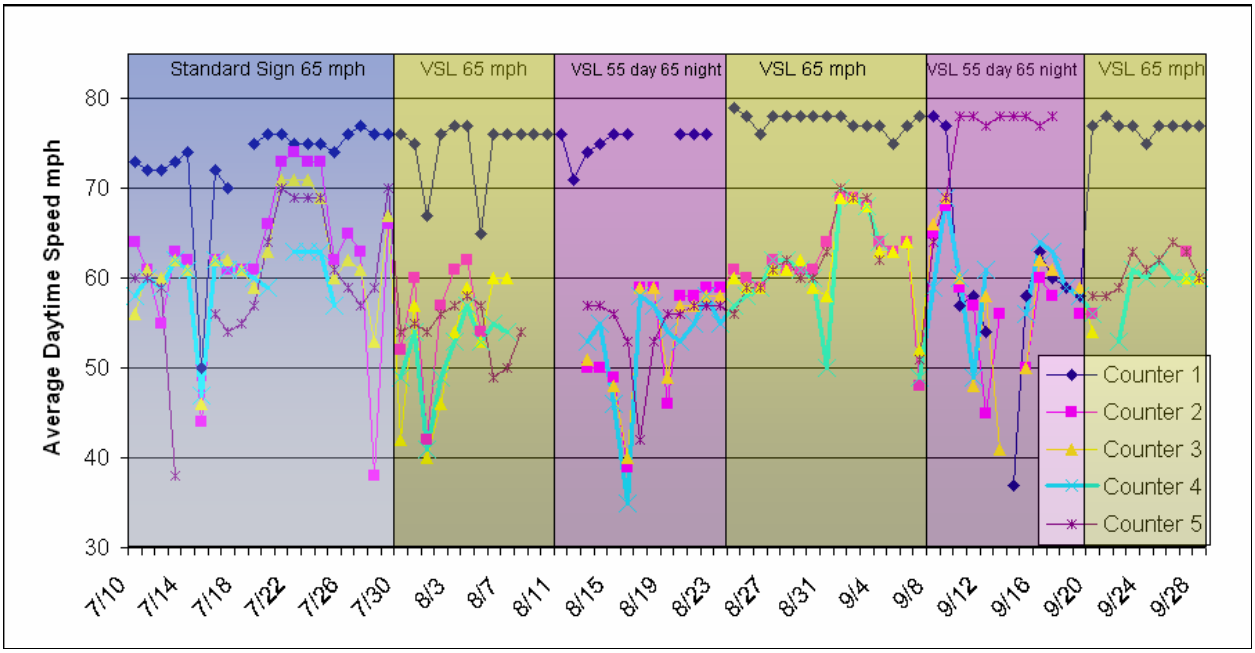


FIGURE 6 Daytime average speed, July 10 to September 28.

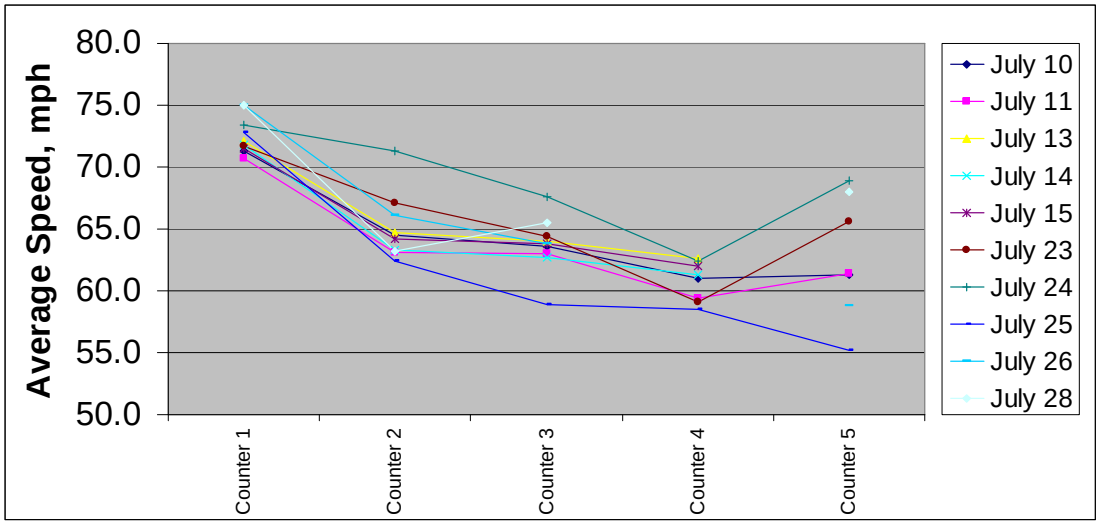
Nighttime Average Speed

To evaluate the effect of VSL signs without construction work, average speeds from 7 PM to 8 AM at the five counter locations were plotted. With the static 65 mph work zone speed limit signs average speeds varied as shown in Figure 7(a). The standard deviation of the average speeds at each counter location varied from about 1.5 mph to 5.0 mph. Ten samples were obtained to evaluate the effectiveness of regular static speed limit signs. The static limit at Counter 1 was 75 mph while it was 65 mph at Counters 2 through 5. Not all days had complete data; those days listed in the figures were selected from the ones that had complete data for the daytime period.

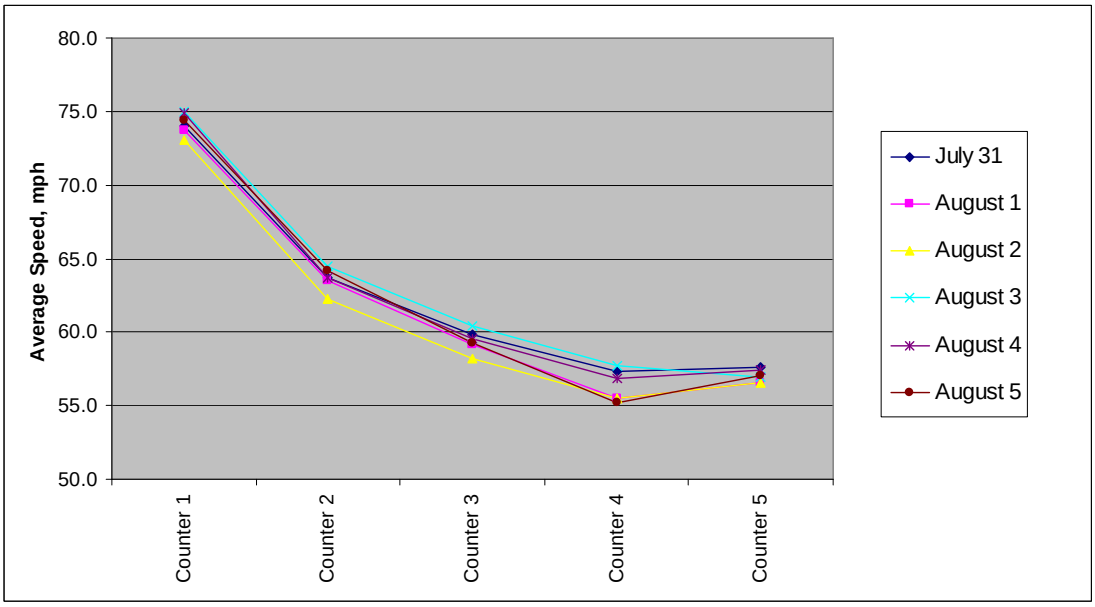
As Figure 7(a) illustrates, Counter 1 recorded average speeds between 70 and 75 mph, which was expected. Between Counters 2 and 4, there was a general trend of decreasing average speeds in the work zone; however, at Counter 5, speeds actually increased. Figure 7(a) shows that there

were wide variations of average speeds during the nighttime with regular static signs as compared to VSL signs.

With VSL signs displaying 65 mph, reductions in average speeds were consistent at each location, as shown in Figure 7(b). The standard deviation of the means at each counter location varied from about 0.5 mph to 1.0 mph. This means that at night drivers are more compliant to the reduced speed limit with VSL signs than with static speed limit signs. One potential reason would be that the lighted VSL speed limit signs were visible much farther than the static speed limit signs, increasing the compliance level.



(a) Nighttime average speed, July 10 to July 28.



(b) Nighttime average speed, July 31 to August 5.

FIGURE 7 Nighttime average speed comparison.

Daytime Average Speed

During the day from 9AM to 7 PM, it seems average speeds were affected by the magnitude of work underway in the work zone, as shown in Figures 8(a) and 8(b). Some of the days show that average speeds were significantly lower than at other locations. Figure 8(a) shows the trend in average speeds at each counter with the static speed limit sign, and Figure 8(b) shows the trend in average speeds at each counter with VSL signs. In general, speed changes are more consistent with VSL signs than with static speed limit signs. These two daytime average speeds and their variances were compared using a F-test and a t-test. The analysis results are shown in Table 1.

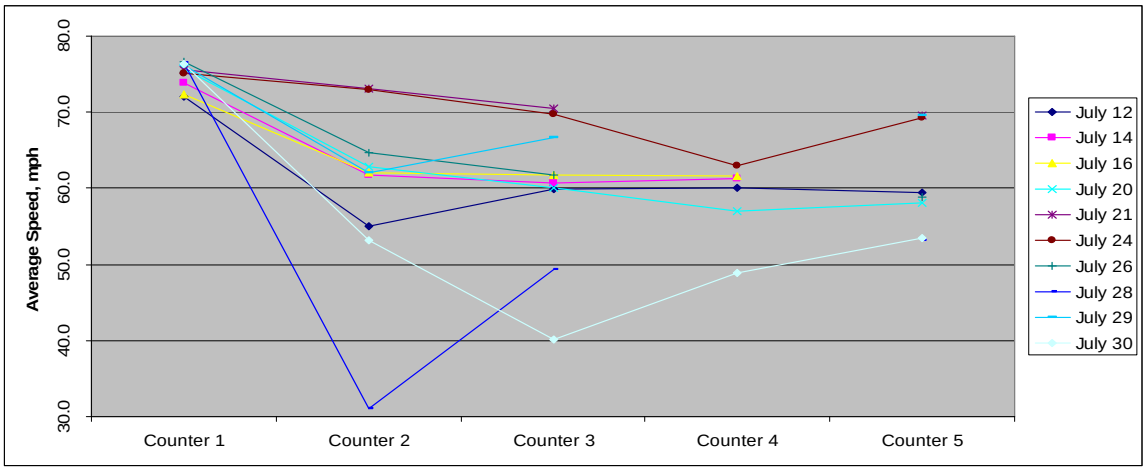
F-tests for the five counters showed that the differences in speed variance at counters 1 and 2 for the static 65 mph speed limit sign and the VSL 65 mph speed limit sign were statistically significant and at the other three counters the differences in speed variance were not statistically significant at a 95% confidence level. This means VLS helped reduce the speed variation at counters 1 and 2 locations. T-tests for the five counters showed that the differences in average speed was significant at counter 1, and not significant at a 95% confidence level at the other counters.

Figure 8(c) shows the trend in speed reduction with VSL signs displaying a 55 mph speed limit. Because static speed limit signs showing 55 mph were never shown to drivers, it was infeasible to compare the benefit of VSL signs over static speed limit signs at the 55 mph speed limit level. What is obvious is that with a 55 mph speed limit, drivers slowed down but not down to 55 mph. They tend to speed up at the downstream end of the work zone, as demonstrated by the average speeds at Counter 5. Four samples started with 75 mph at the upstream of the work zone, and their speeds decreased to 50 to 60 mph. As shown in Figure 8(c), drivers maintained that speed until they passed the active work zone. One day (September 12) started with a lower average speed (53 mph) upstream of the work zone. It is likely a slow-moving queue formed upstream: drivers seemed to become impatient, and they sped up at Counter 3. Near Counter 5, they sped up to 77 mph (see Figure 8(c)).

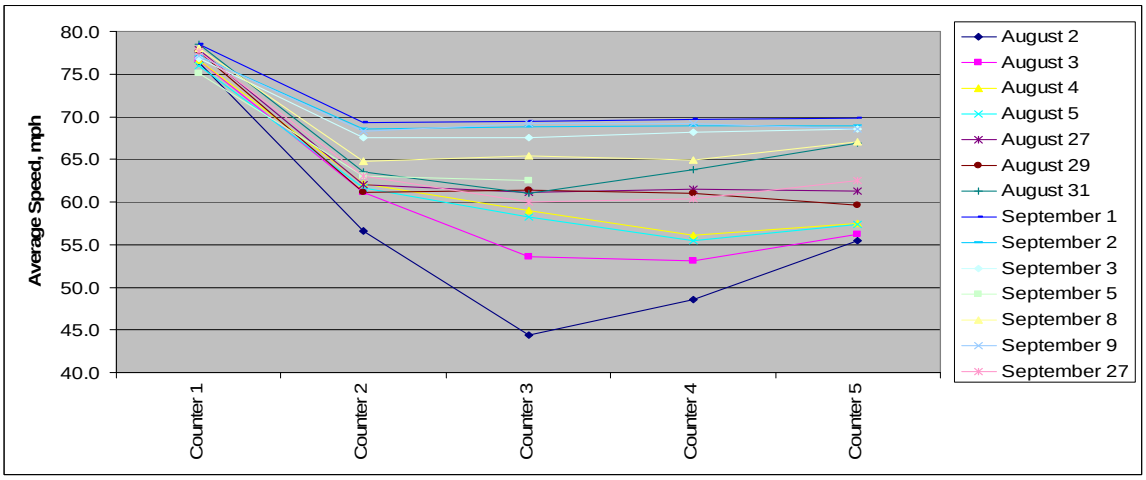
TABLE 1 Results of F-test on Variances and T-test on Sample Means

	Static 65 mph Daytime			VSL 65 mph Daytime			F-test on variance	t-test on two sample means
	No. of Samples	Mean	SD	No. of Samples	Mean	SD	p-value	p-value
Counter 1	10	75.00	1.71	14	77.11	0.98	0.032	0.004*
Counter 2	10	59.86	11.97	14	63.76	3.57	<0.001	0.341*
Counter 3	10	60.05	9.21	14	61.53	6.80	0.156	0.654
Counter 4	10	58.64	5.21	14	61.61	6.75	0.426	0.357
Counter 5	10	61.44	7.06	14	63.06	5.42	0.202	0.561

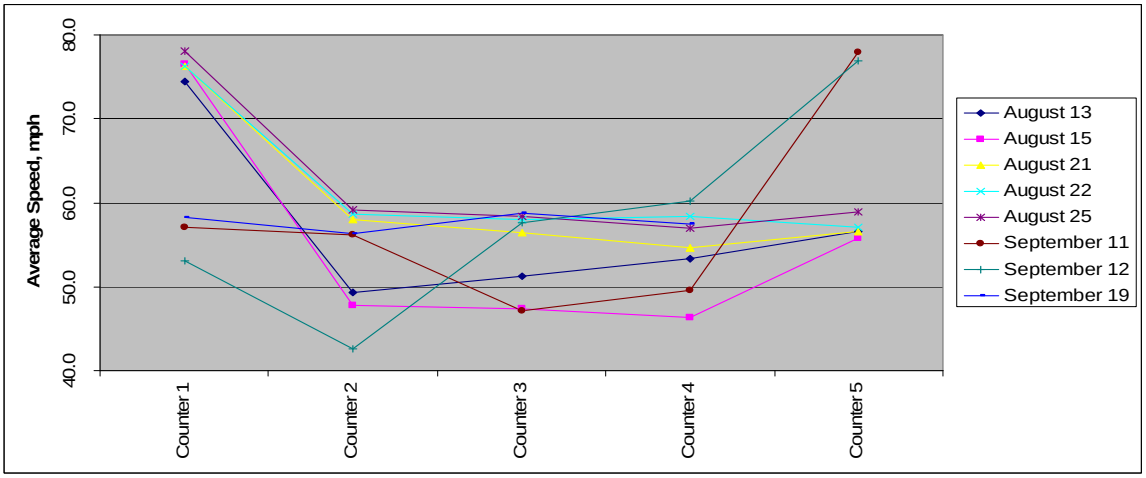
Note: * Two-sample assuming unequal variance



(a) Daytime average speed, July 12 to 30, 65 mph static, speed limit sign.



(b) Daytime average speed, 65 mph VSL sign.



(c) Daytime average speed, 55 mph speed limit sign.

FIGURE 8 Daytime average speed comparison.

Speed Limit Compliance

If the average speed of travel is taken for each hour at each data collection point for the entire length of the study, the observed speed can be compared to the posted speed limit. Figure 9 shows, by counter and by posted speed limit, the percentage of vehicles obeying the speed limit. At Counters 2, 3, and 5, the VSL at 65 mph has greater compliance than the static 65 mph signs. At Counter 4, the static sign has 100% compliance for hourly average speed of travel. At all the other counters, however, the VSL signs posted at 55 mph have the worst compliance rate.

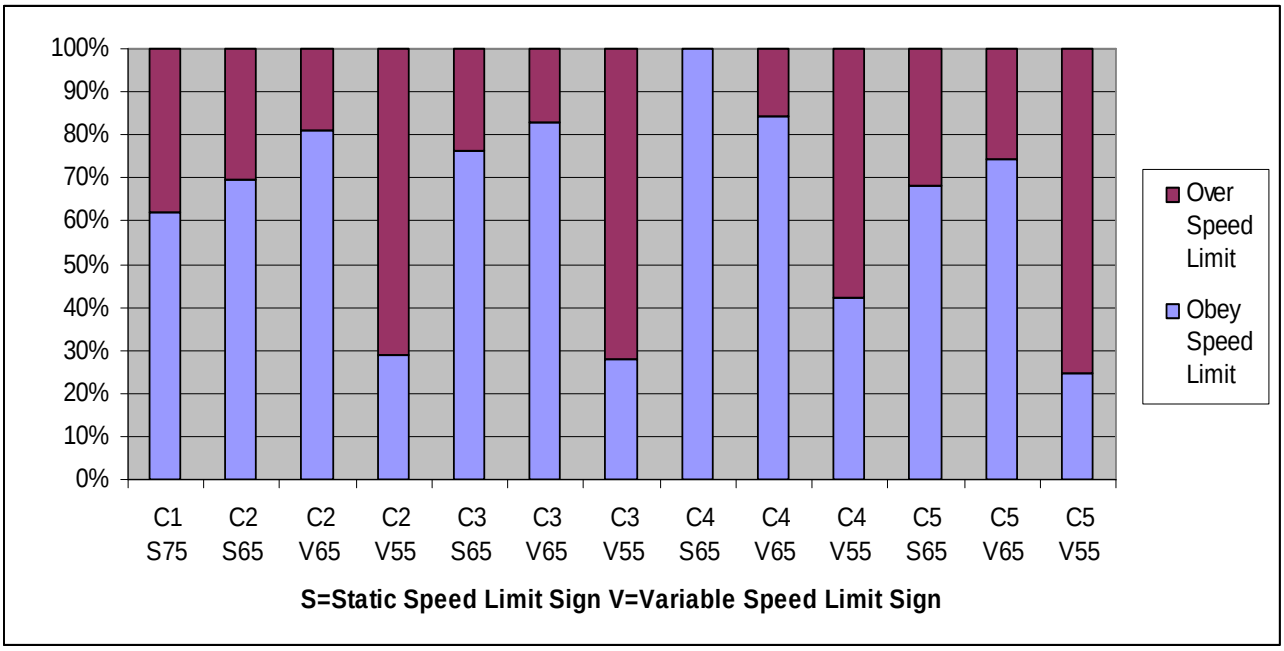


FIGURE 9 Speed compliance by hourly average speed.

Statistical Analysis on Speed Change from Nighttime 65 MPH to Daytime 55 MPH

The previous discussions on speed reduction from 75 mph to 65 mph on approaching the work zone indicated that both speed reduction signs (static 65 mph vs. VSL 65 mph) could achieve necessary speed reductions although VSL signs also reduce speed variances. Though not presented in this paper due to space limitation, these speed reductions were statistically significant at the 95% confidence level. In this section, some of the statistical analyses on speed changes are presented.

It is hypothesized that drivers comply with large speed reductions; hence, z-tests were performed to see if drivers complied with the daytime 55 mph speed limit. Several days had complete data sets to analyze the transition from the nighttime 65 mph speed limit to the daytime 55 mph speed limit shown by VSL signs. Table 2(a) presents the results of z-tests on speed differences between the two speed limits. As shown in the table, mean speed differences between

the nighttime 65 mph and the daytime 55 mph speed limit were significant during these seven sample dates, indicating drivers do respond to large speed reductions.

To find out if drivers complied with the daytime 55 mph speed limit throughout the work zone, a data set for the 55 mph speed limit with VSL signs was extracted and analyzed. Table 2(b) shows the results of the z-tests. As shown in the table, in the upstream of the work zone at Counter 1, the average speed was 76.2 mph, statistically higher than the 75 mph speed limit. Right after the first VSL sign, the average speed lowered to 58 mph. Although the difference between this value and the 55 mph speed limit is significant, the sign reduced average speed. At the remaining counters, the mean speed was close to 55 mph although the difference between those speeds and the 55 mph speed limit was statistically significant. Nevertheless, drivers seemed to comply with the 55 mph speed limit throughout the work zone.

CONCLUSIONS AND RECOMENDATIONS

This paper presented the results of a field test of VSL signs. The effect of VSL signs on drivers as manifested by their speeds in the test work zone was analyzed. The analysis showed that both speed reduction signs (static 65 mph vs. VSL 65 mph) could achieve necessary speed reductions. VSL signs were, however, helpful in reducing speed variances near the entry to the activity area of the work zone (counter 2 location). Speed variations at counters 3, 4, 5 were similar for both types of speed limit signs.

At night, when VSL signs were set to 65 mph and no construction activity was taking place, VSL signs resulted in average speeds that were in general lower than static speed limit signs. Daytime speeds showed greater variation because of congestion and construction. However, even dismissing the data impacts of low speeds during the daytime, VSL signs resulted in smaller speed variation than static speed limit signs near counter 2, the entry point to the work zone activity area.

The potential concern of lower speed limits resulting in greater variation in driver speeds did not occur. At night, when VSL signs were set to 65 mph, the standard deviation of speeds was reduced to 0.5 mph to 1.0 mph, down from 1.5 mph to 5.0 mph with the static signs.

Although crash data were not directly collected, it can be inferred from the results of this field test that VSL signs could contribute to reducing speed variation especially near the entry to the work zone activity area, thus preparing the drivers ready for the lower speed limit as they drive through the activity area. Reducing speed limit to 55 mph during the day seemed difficult but the data showed the average speed near 60 mph could be achieved. Providing drivers with speed restrictions that reflect actual conditions (construction underway during the day or no construction at night) builds “trust” in the posted work zone speed limit.

TABLE 2 Statistics on Speed Reduction by VSL Signs, from Nighttime 65 MPH to Daytime 55 MPH Speed Limit

(a) Z-Tests on Mean Speed Differences at Counter 2 (Critical Z-score = 1.65)

	Mean Speed Difference	Calculated Z-Value	Significance Test
8/13/2007 Nighttime 65 mph to 8/14/2007 Z Daytime 55 mph	7.2	36.3	Significant
8/14/2007 Nighttime 65 mph to 8/15/2007 Daytime 55 mph	11.8	61.00	Significant
8/15/2007 Nighttime 65 mph to 8/16/2007 Daytime 55 mph	6.1	34.29	Significant
8/16/2007 Nighttime 65 mph to 8/17/2007 Daytime 55 mph	3.1	19.33	Significant
9/10/2007 Nighttime 65 mph to 9/11/2007 Daytime 55 mph	7.2	46.01	Significant
9/11/2007 Nighttime 65 mph to 9/12/2007 Daytime 55 mph	10.8	54.63	Significant
9/12/2007 Nighttime 65 mph to 9/13/2007 Daytime 55 mph	7.1	47.80	Significant

(b) Z-Tests on Mean Speeds with Daytime 55 MPH Speed Limit for Work Zone by VSL Sign, Tuesday, 8/12/2007, between 9:00 AM and 7:00 PM (Critical Z-Score = 1.96)

Counter Number	Number of Samples	Mean Speed (mph)	Standard Deviation (mph)	95% Confidence Interval	Remarks
1	4,689	76.2	6.6	76.0 – 76.4	Statistically higher than 75 mph
2	4,921	58.0	5.6	57.9 – 58.2	Statistically higher than 55 mph
3	4,916	56.4	5.8	56.2 – 56.5	Statistically higher than 55 mph
4	4,919	54.6	8.0	54.3 – 54.8	Statistically lower than 55 mph
5	4,974	56.6	4.9	56.5 – 56.7	Statistically higher than 55 mph

Note: Counter 1 is in the 75 mph speed limit zone and the other counters are in the 55 mph speed limit zone. When the confidence interval does not contain 55 mph, the actual mean speed is either statistically higher or lower than 55 mph.

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