Development and Evaluation of a Speed-Activated Sign to Reduce Speeds in Work Zones

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ABSTRACT

Excess speed is one of the most significant factors contributing to work zone crashes, which, along with work zone fatalities, have increased substantially in the last decade. From the beginning of 2000 to the end of 2003, the number of work zone crashes in South Carolina nearly tripled. In 2005, the South Carolina Department of Transportation (SCDOT) initiated a research project to evaluate speed reduction measures in work zones. Through an in-depth literature review of work zone speed control techniques, researchers found that new innovative technologies are often too expensive, making them impractical for large-scale implementation. Thus, there is a need for less expensive technologies that are effective in reducing speeds in work zones.

This paper discusses the development and evaluation of a speed-activated sign. Data were collected in work zones on two-lane primary and secondary highways in South Carolina and the effectiveness of the speed-activated sign was evaluated based on changes in mean speeds, 85^{th}-percentile speeds, and percentages of vehicles exceeding the speed limit. Mean speed reductions ranged from 2 to 6 mph (3.2 to 9.7 kph) with an average reduction of 3.3 mph (5.3 kph). This average reduction improved to 4.1 mph (6.6 kph) at sites where more then 50 percent of the vehicles were speeding prior to introduction of the sign. Further study was conducted using two speed-activated signs on a multi-lane divided highway and an interstate freeway where similar speed reductions were experienced. From this study, researchers recommend the speed-activated sign be used in short-term work zones.

INTRODUCTION

In 1999 South Carolina leveraged bonds so that 27 years of maintenance and construction activities could be completed in just 7 years. During this time, the number of South Carolina interstate work zone-related crashes and fatalities has risen. According to statistics provided by the South Carolina Department of Transportation (SCDOT), the number of crashes in work zones has nearly tripled in recent years, increasing from 677 in 1998 to 2,601 in 2003 (*1*). In all of these years, a leading cause of vehicle crashes was driving too fast for conditions. Due to this increasing amount of work zone crashes and fatalities in South Carolina, research into innovative ways to improve driver attention and reduce vehicle speeds in work zones has become a priority of the SCDOT.

For the past several decades, transportation agencies have taken different approaches to reduce speeds in work zones, including using traffic control devices, design alterations, and police enforcement. Although it is generally agreed that law enforcement has the most significant effect in lowering speeds, this measure is often unavailable due to workforce limitations and cost (*2*). One new technology that has proven effective in reducing vehicle speeds is the use of dynamic message signs with radar. These signs can indicate current speeds or display a dynamic message based on the vehicle speed. Many transportation agencies have purchased such signs at costs ranging from $16,000 to $20,000 (*3*,*4*). As a result, funding to obtain an adequate number of these signs to deploy in a majority of work zones is cost prohibitive. Further, dynamic message signs are trailer based requiring significant personnel and vehicle resources to setup. Because of the limited availability of law enforcement and inadequate funding for widespread deployment of expensive technologies, transportation agencies need more affordable technologies to reduce speeds in a wide variety of work zone applications including short-term maintenance applications. To address this need of the SCDOT, this research focuses on the development of a traffic control device that will effectively reduce speeds in work zones and allow widespread deployment by being portable and cost-effective. The research fulfills the following two objectives:

1. The development and evaluation of a fixed-message, speed-activated sign that triggers a flashing beacon when a pre-determined speed threshold is exceeded; and
2. The quantitative assessment of the traffic impact of this sign through the following measures of effectiveness:
    - change in mean speed,
    - change in 85th percentile speed, and
    - change in the percentage of vehicles exceeding the designated speed limit.

The methodology developed to accomplish these objectives is based on an in-depth literature review of speed reduction measures in work zones, as well as various meetings with the SCDOT. For the purpose of this study, several work zones on 2-lane primary and secondary highways were evaluated to produce results that are applicable to a wide range of road conditions. Additional work zones on an interstate freeway and divided multilane highways were evaluated using a dual sign configuration. Conclusions are based on quantitative data collection as well as a qualitative analysis conducted during each data collection effort. The research findings and experience gathered in this study lead to recommendations on how to best and most effectively use this technology.

PREVIOUS WORK ZONE SPEED REDUCTION TECHNOLOGIES

A substantial amount of research has been previously conducted on the effectiveness of various measures of controlling speeds in work zones (*5*). The measures currently available for implementation can be classified into two main categories: (1) standard strategies and practices, and (2) technological strategies. Standard strategies and practices refer to basic traffic control plans (TCP) outlined in the Manual of Uniform Traffic Control Devices (MUTCD)(*6*). Also included in this category are non-technological measures including lane width reductions, temporary rumble strips, optical speed bars, and the use of flaggers and police enforcement. Technological solutions cover a vast array of innovations resulting from advances in electronics over the last two decades including drone radar, speed monitoring displays, changeable message signs, and vehicle activated signs.

Technological measures are typically used to supplement standard Traffic Control Devices (TCD) in work zones. While these measures can include portable ITS systems, drone radar, and other technologies, the focus of this paper is on the effectiveness of innovative message signs. The following sections provide information on three categories of technological devices: speed monitoring devices, changeable message signs (with and without radar), and vehicle-activated signs.

Speed Monitoring Display

Speed monitoring displays (SMD) consist of a trailer unit equipped with a radar device to determine and display the speeds of approaching vehicles using large numbers on a message board in conjunction with standard regulatory speed limit signs. This type of reduction measure assumes that drivers will slow down to an acceptable speed level once they are made aware of the speed they are traveling. One particular drawback of this measure is that some drivers may intentionally exceed the speed limit to test the radar against their vehicles odometers.

In 1995, McCoy conducted research through the South Dakota Department of Transportation on speed display units in work zones (*7*). The study team tested two units; both positioned 310 feet (94.5 meters) in advance of the first taper and collected speed data prior to and after the placement of the units. Results indicated a mean speed reduction of 4 mph (6.4 kph) and 5 mph (8.0 kph) for vehicles with two axles and vehicles with more than two axels, respectively. The study also found a significant decrease in the number or vehicles traveling at excessive speeds at least 10 mph (16.1 kph) over the posted speed limit.

In 2004, Nebraska researchers evaluated the long-term effectiveness of SMDs in rural work zones by placing three SMDs in a work zone on a four-lane section of Interstate 80 and studying the site for approximately 5 weeks (*8,9*). The SMDs had a light emitting diode (LED) numeric display reporting travel speed with an advisory speed sign and a message sign stating "YOUR SPEED." Data were collected once before the SMDs were positioned and once per week for five weeks afterwards to evaluate the following measures of effectiveness (MOE): Mean Speed, Standard Deviation, 85th Percentile Speed, Percent complying with speed limit, Percent complying with speed limit plus 5mph (8.0 kph), and Percent complying with speed limit plus 10 mph (16.1 kph). The analysis yielded improvements in all measures of effectiveness (MOE) at sites downstream of SMDs including 3 to 4 mph (4.8 to 6.4 kph) reductions in mean speed, 2 to 7 mph (3.2 to 11.3 kph) reduction in 85th percentile speed, and a 20 to 40 percent increase in speed compliance. The study team observed that 78 percent of traffic was non-commuter traffic and drivers may have been seeing the SMDs for the first time.

Changeable Message Signs

Changeable message signs (CMS) are control devices that give drivers information about the current driving conditions. Many DOTs use these signs in the form of a portable trailer or permanent roadside installation to warn drivers of an approaching work zone by displaying short messages such as "SPEED LIMIT 45 MPH." One of the first research efforts into the effects of CMS in work zones was conducted by Richards et al. in 1984 on Texas interstates. The study found that CMS reduced speeds from 0 to 5 mph (0 to 8.0 kph) depending on the CMS location. The results indicated a greater speed reduction when the CMS was located close to the actual work area as opposed to in advance of the work zone warning sign sequence (*10*).

Changeable Message Signs with Radar

Another form of CMS combines the standard changeable message sign with a built in radar detector referred to as a changeable message sign with radar (CMR). The radar signal is processed onboard, and depending on the settings and present speed, the device can display a variety of programmed messages.

In 1990, Benekhal and Linkenheld, evaluated the speed reduction of a CMR with an attached audible system at a work zone in Illinois (*11*). The unit consisted of a radar unit that activated a horn if motorists exceeded the threshold speed. Researchers collected data for 188 vehicles and indicated that there was a 9.7 mph (15.6 kph) reduction in the speed of vehicles traveling at speeds greater than 60 mph (96.6 kph). Researchers noted that the horn and radar system did produce a decrease in the mean speeds, but the noise and other human factor considerations could limit the application.

A study in 1995 by Garber and Patel tested the effectiveness of CMR with speed monitoring display on interstates in Virginia by testing the following four messages to determine the most effective in reducing mean speeds (*11*):

- "YOU ARE SPEEDING, SLOW DOWN",
- "HIGH SPEED, SLOW DOWN",
- "REDUCE SPEED IN WORK ZONES", and
- "EXCESSIVE SPEED SLOW DOWN."

The vehicles that activated the message reduced their speeds an average of 15.3 mph (24.6 kph), which caused the mean speed of the overall traffic stream to decrease by 4 mph (6.4 kph). The team used a 5 mph (8.0 kph) speed threshold but recommended that the threshold for activation of the message be 3 mph (4.8 kph) above the posted speed limit for optimal results. The radar triggered CMS message of "YOU ARE SPEEDING, SLOW DOWN," produced mean speed reductions of 8 to 9 mph (12.9 to 14.5 kph) and notable responses from all vehicles. The 95-percent confidence intervals for speed reduction at the sites ranged for 4.8 to 11.6 mph (7.7 to 18.7 kph) and mean speeds and 85th percentile speeds decreased at all sites.

The Georgia Department of Transportation (GDOT) funded a study to test CMR in Georgia work zones (12). The CMR were set to display the message, "YOU ARE SPEEDING, SLOW DOWN NOW" for vehicles traveling 5 mph (8.0 kph) or more over the posted work zone speed limit of 45 mph (72.4 kph), while for vehicles traveling below 50 mph (80.5 kph), the sign displayed the message "ACTIVE WORK ZONE, REDUCE SPEED." Once the CMRs were introduced, speeds immediately reduced 6 to 8 mph (9.7 to 12.9 kph) and lanes in the opposite direction decreased speeds up to 2 mph (3.2 kph). However, researchers determined that the CMR did not appear to influence speeds in the activity area several miles downstream. The influence of the CMR remained constant throughout the implementation period of three weeks; however the study team reported that placing the CMR in closer proximity of the work zone activities could cause the residual effect to continue into the active work zone area.

Vehicle Activated-Signs

Vehicle Activated Signs, similar to CMRs, dynamically display a message corresponding to road conditions. Historically, these signs have been used to display speed limits, provide curve and intersection warning, and display safety camera information. As with CMRs and SMDs, the primary assumption is that drivers are considerably influenced to decrease speeds when they are specifically targeted.

In 2001, vehicle activated signs were evaluated on rural two-lane roads in the four England cities: Norfolk, Wiltshire, West Sussex, and Kent (*13*). The research team selected sites based on accident statistics where excessive speeds were the contributing factor. The team collected a minimum of seven days' worth of data at each of the test sites before and after the implementation of junction and bend warning signs, results indicating a mean speed reduction up to 7 mph (11.3 kph). Overall the results indicated that these signs significantly reduced the number of vehicles exceeding the speed limit, with a one-third reduction in accidents across all of the Norfolk sites.

A variation of these vehicle activated signs were implemented by the Texas Department of Transportation (TXDOT) beginning in the late 1990's where it began upgrading at-grade highway-railroad intersections from passive to active warning systems. One aspect of these projects, developed at the Texas Transportation Institute (TTI), used a vehicle-activated strobe light to alert drivers to the signs on the signpost (*14*). These signs, mounted beneath the strobe light, were the traditional round advanced warning sign as well as a new sign saying, "LOOK FOR TRAIN AT CROSSING". TTI observed driver reactions before and after the implementation of the signs, concluding that the enhanced sign system was an effective traffic control measure increasing safety at these intersections, but did not cause a significant decrease in speeds approaching the intersection.

<u>Summary</u>

Previous research has shown that police presence and ghost police cars generally lead to the greatest reduction of speeds in work zones; however, availability of law enforcement is limited. As a result of the demand for new technologies, changeable message signs, speed monitoring displays, and changeable message signs with radar have been developed and proven to provide significant results in speed reduction. Table 1 displays a summary of effectiveness and cost of the three speed control technologies just discussed.

TABLE 1: Speed Reduction Technologies (*7,15,16*)

Speed Control Technique	Change in Mean Speed*	Approximate Cost
Changeable Message Signs	3.0 - 7.0 mph	$15,000
Speed Monitoring Displays	4.0 - 5.0 mph	$10,000
Changeable Message Signs with Radar	4.0 - 8.0 mph	$20,000

*1 mph = 1.61 kph

Many transportation agencies have purchased these signs, but due to their cost, funding to obtain an adequate number to deploy in all work zone activities is not available. Because of the limited availability of law enforcement and inadequate funding for expensive technologies, there currently is interest in new affordable technologies to reduce speeds in work zones.

SPEED-ACTIVATED SIGN DEVELOPMENT AND DATA COLLECTION

The research discussed here developed and evaluated a fixed-message speed-activated sign (referred to from this point forward as speed-activated sign) that triggers a flashing beacon when a predetermined speed threshold is exceeded. The objective of this research was to evaluate the effectiveness of this affordable technology while maintaining the goal of providing the SCDOT with a proven strategy to heighten safety and lower speeds in work zones.

The resulting speed-activated sign, shown in the left pane of Figure 1, was a 4-foot (1.23-meter) by 4-foot (1.23-meter) corrugated plastic reflective sign with 6-inch (15.24 centimeters) lettering reading "YOU ARE SPEEDING IF FLASHING." The research team considered alternative messages including "SPEEDING IF FLASHING" but decided the "YOU ARE" would make it was obvious to drivers that they were being specifically targeted. Although the alterative message was not tested in this project, some jurisdictions may consider using the simpler message in work zones with complex signing and traffic control schemes.

To increase the speed-activated sign's visibility, the study team added two 1-foot (0.31-meters) by 1-foot (0.31-meters) orange plastic flags. The beacon atop the speed-activated sign was a solar-powered high-intensity type B flashing beacon light.

FIGURE 1: The speed radar (right) activates a flashing beacon atop the work zone sign (left).

The speed-activated sign's radar system, shown in the right pane of the figure, contained a dual switchboard that allowed setting of the speed threshold, on-delay, and off-delay. When the programmed speed threshold was reached, the radar system paused for a time period equal to the on-delay and then activated a relay that turned on the beacon, which flashed at a fixed rate based on its built-in capacitor. The relay opened after the off-delay period passed and the beacon turned off. The radar system was enclosed in a hard-shell waterproof box that allowed for mounting the system directly to the sign post. Two 12-volt gel batteries wired in parallel powered the radar. The battery pack, which cannot be seen in Figure 1, sat at the base of the sign. The speed-activated sign met all of the established objectives for development, and the prototype sign assembly including the portable stand cost approximately $1,500. Nearly two-thirds of this cost was for the speed-activated radar, which would be significantly reduced if the radar assembly were produced in quantity. With the prototype system established, the Clemson research team took the sign to the field to test its effectiveness as a speed reduction measure in work zones.

Data Collection Procedure

Data were collected at three locations in each work zone studied. The stations were positioned before, at, and after the speed-activated sign. Station 1 was used to collect information about the initial condition of vehicle speeds. Data were collected from the first location using a laser speed gun because it was least likely to influence the speed of vehicles equipped with radar detectors. Station 2 was used to determine the initial impact of the sign on driver speeds. Finally, Station 3 provided data about the continued impact and credibility of the sign on observed speeds. Radar guns were used to collect speeds at Stations 2 and 3. The typical layout of the observers in relation to the sign is shown in Figure 2.

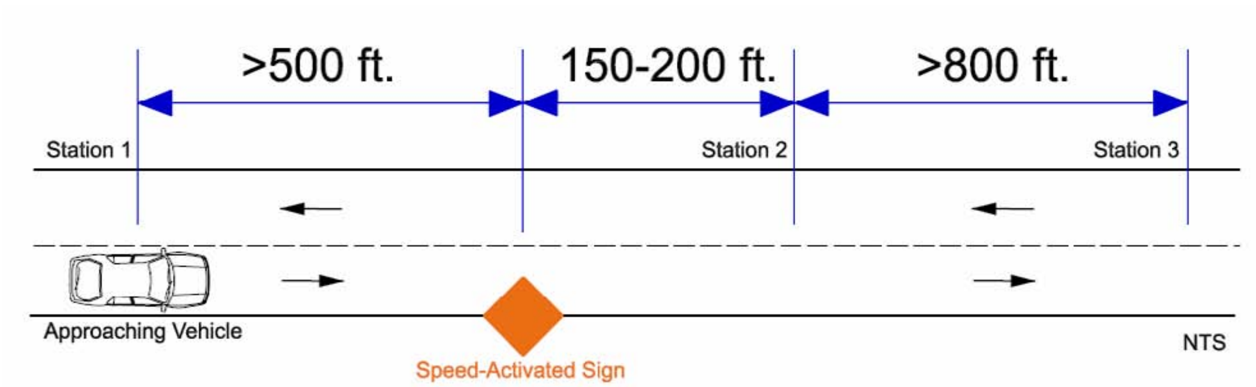


FIGURE 2: The typical placement of the speed-activated sign for data collection shown in the schematic (top) was implemented at multiple sites, including State Route 290 in Spartanburge (bottom).

Nu-Metrics Histar Traffic Counters were considered for the data collection; however, were ruled out to allow for more user discretion when collecting the data. In many cases, construction vehicles frequented the work zone area and were aware of the data collection activities. By using handheld lidar and radar, the data collectors easily eliminated the vehicles from the study. Speed variations could also be monitored by tracking vehicles over short distances with the handheld devices.

Concealment of the laser and radar guns was important for preventing skewed or biased data as well as motorist distraction; therefore, data collectors attempted to hide behind vegetation and roadside structures. All speeds were measured as vehicles moved away from the guns, rather than approaching, making it more difficult for drivers to see the gun as speeds were monitored.

Speed data were collected for two conditions—one without the speed-activated sign and one with the speed activated sign in place—to allow the researchers to determine the effect of the speed-activated sign on vehicle speed. Conditions such as work zone locations, types of work activities, times of day, weather, speed limits, and existing traffic controls were recorded at each site to identify trends if irregularity in the data existed.

The method of sampling chosen for this study was all-vehicle type platoon-leader sampling including single-vehicle platoons when traffic volumes did not support queuing. This sampling technique gathered data by measuring speeds of all platoon leaders passing a point for a given time period.

Data were collected to ensure results at a 95-percent confidence level. A minimum sample size of 97 was determined by using the following equation (17):

$$N = (S * \frac{K}{E})^2 \qquad (1)$$

where

N = minimum number of measured speeds
S = estimated sample standard deviation, mph (5.0 mph)
K = constant corresponding to the desired confidence level (1.96)
E = permitted error in the average speed estimate, mph (1.0 mph)

Data Collection Sites

The process of locating future and ongoing work zone projects to evaluate the effectiveness of the speed-activated sign began in August 2005 by contacting the SCDOT construction and maintenance engineers across the state. To prevent conditions independent of the speed-activated sign from predominantly dictating vehicle speeds, one criterion established for selecting potential sites was a requirement that the work zone be operating at a high level of service to allow vehicles to travel at free-flow conditions with minimal speed influence from traffic congestion. In addition, it was important that work zones be active and that activity during data collection periods be continuous and similar in nature. Based on these criteria, three data collection sites on secondary highways in South Carolina were chosen for analysis. These sites are summarized in Table 2.

TABLE 2: Data Collection Site Summary

Location (County)	Route	Type of Work Zone	Length* (miles)	Volume (veh/hr)	Dates of Data Collection
Newberry	SC 219	Widening	2.1	183 - 250	15, 16, 19 Aug., 2005
Spartanburg	SC 290	Widening	4.5	122 - 201	1, 8,9,28 Sept., 2005
Laurens	SC 72	Widening	8	124 - 201	19,20 Oct., 2005

*1 miles= 1.61 kilometers

<u>*Radar Calibration*</u>

As mentioned, the speed-activated sign had an interface that allowed the speed threshold and on/off-delay to be set. At all of the sites evaluated, the posted speed limits were 45 mph (72.4 kph) and the speed thresholds were set at 48 mph (77.2 kph) to provide a 3-mph (4.8 kph) buffer. The radar settings depended on terrain and curvature of the roadway; therefore, a trial-and-error procedure was used for calibration. In general, for 45 mph (72.42 kph) speed limit sites, the goal was for the flashing light to activate when a speeding vehicle was approximately 200 feet (60.96 meters) in front of the sign and to continue to flash until that vehicle had passed the sign. Typically, the on-delay was set to one second and off-delay to two seconds.

DATA ANALYSIS AND RESULTS

Upon completion of the data collection for this project, statistical procedures were performed to analyze the results of the study. The collected data were examined for the following:

- To test for significant differences in the change in mean speed and change in percent of vehicles exceeding the speed limit [(for 3+ and 10+ mph or (4.8+ and 16.1+ kph)] for each of the three data collection stations under the control (speed-activated sign off) and treatment (speed-activated sign on) conditions; and
- To determine the change in 85th percentile speeds between the control and treatment conditions.

Speed data collected from a moving traffic stream in stable flow generally follow the normal distribution (*18*). In this study, the data obtained were assumed to be normally distributed; therefore, parametric hypothesis testing was conducted to test for equal means and changes in the percentages of vehicles exceeding the speed limit. The two-sample *t*-test was use to evaluate the difference in mean speeds, while the *z*-test for comparing proportions taken from two independent samples was used to test for significant differences in the proportion of vehicles exceeding the speed limit by 3 mph (4.8 kph) and 10 mph (16.1 kph) at each station. Each test was conducted to ensure a 95-percent level of confidence.

The two-sample *t*-test showed a significant reduction in the mean speeds at Station 2 (150 to 200 feet [45.7 to 60.9 meters] past the sign) for all of the data sets when the speed-activated sign was on. Results from Station 1 (more than 500 feet [152.4 meters] before the sign) indicated that there was not a significant reduction in speed for the two conditions before drivers encountered the sign location. The lack of speed reduction was expected, as this station was located at such a distance away that the speed-activated sign could not be seen. Results from Station 3 (more than 800 feet [243.8 meters] past the sign) showed a significant reduction in the means for all of the treatment data sets.

Table 3 displays a summary of the hypothesis testing for the means. The test was not conducted for Stations 1 and 3 for the initial projects because researchers identified the need for Station 1 and 3 after these locations were already collected.

TABLE 3: Summary of Statistical Analysis of Mean Speeds

			Station 1				Station 2				Station 3			
Work Zone Location	**Date**	**Time**	**Speed Change**	**t value**	**Pr > |t|**	**Sig**	**Speed Change**	**t value**	**Pr > |t|**	**Sig**	**Speed Change**	**t value**	**Pr > |t|**	**Sig**
Newberry SC-219	15-Aug	9:00-11:00	-	-	-	-	-6.12	-10.32	<.0001	Y	-	-	-	-
		13:00-15:00	-	-	-	-	-4.78	-8.38	<.0001	Y	-	-	-	-
Newberry SC-219	16-Aug	7:15-9:15	-	-	-	-	-6.11	-10.32	<.0001	Y	-	-	-	-
		9:15-11:15	-	-	-	-	-2.76	-3.90	0.0001	Y	-	-	-	-
		12:15-14:15	-	-	-	-	-3.38	-5.99	<.0001	Y	-	-	-	-
Newberry SC-219	19-Aug	8:00-10:00	-	-	-	-	-1.75	-3.16	0.0017	Y	-	-	-	-
		10:00-12:00	-	-	-	-	-3.97	-7.73	<.0001	Y	-	-	-	-
Spartanburg SC-290	1-Sep	8:00-10:00	-	-	-	-	-3.12	-4.06	<.0001	Y	-	-	-	-
		10:15-12:15	-	-	-	-	3.69	-4.86	<.0001	Y	-	-	-	-
Spartanburg SC-290	8-Sep	8:00-10:00	-	-	-	-	-1.91	-2.89	0.0041	Y	-	-	-	-
Spartanburg SC-290	19-Sep	6:45-8:45	-1.072	-1.70	0.895	N	-2.64	-4.39	<.0001	Y	-1.67	-2.34	0.0197	Y
		8:45-10:45	-0.050	-0.66	0.510	N	-3.49	-4.66	<.0001	Y	-2.37	-3.13	0.0018	Y
Spartanburg SC-290	28-Sep	6:15-8:15	0.918	1.43	0.153	N	-1.74	-2.94	0.0034	Y	-2.31	-3.44	0.001	Y
Laurens SC-72	20-Oct	7:00-9:00	-1.308	-1.95	0.055	N	-4.12	-6.43	<.0001	Y	-3.73	-5.44	<.0001	Y
		9:00-11:00	0.817	1.27	0.206	N	-2.60	-3.93	<.0001	Y	-2.98	-4.33	<.0001	Y
Laurens SC-72	28-Oct	7:00-9:00	-1.400	-2.01	0.970	N	-3.20	-4.30	<.0001	Y	-4.40	-8.2	<.0001	Y
		9:00-11:00	-0.300	-0.65	0.740	N	-4.40	-8.20	<.0001	Y	-3.70	-7.68	<.0001	Y

The results from the two-sample *z* test conducted on the percentages of vehicles exceeding the speed limit indicated that the speed-activated sign produced significant reductions in vehicles exceeding the speed limit by more than 3 mph (4.8 kph) and more than 10 mph (16.1 kph). For Station 2, all data sets indicated a significant reduction in the percentage of vehicles exceeding the speed limit by more than 3 mph (4.8 kph). A significant reduction in vehicles speeding by 10 mph (16.1 kph) or more was present in all but two treatment sets of data; however, these two sets indicated that less than 8 percent of all vehicles were speeding by more than 10 mph (16.1 kph) under the control condition (speed activated sign off).

Combining all treatment and control data for Stations 2 and 3, the histogram in Figure 3 shows that when the speed-activated sign was on, far more people obeyed the speed limit and approximately 50 percent fewer vehicles traveled at speeds over 55 mph (88.5 kph), which was 10 mph (16.1 kph) over the posted speed limit. Also, a greater number of vehicles traveled at or less than the posted speed limit with the speed-activated sign on.

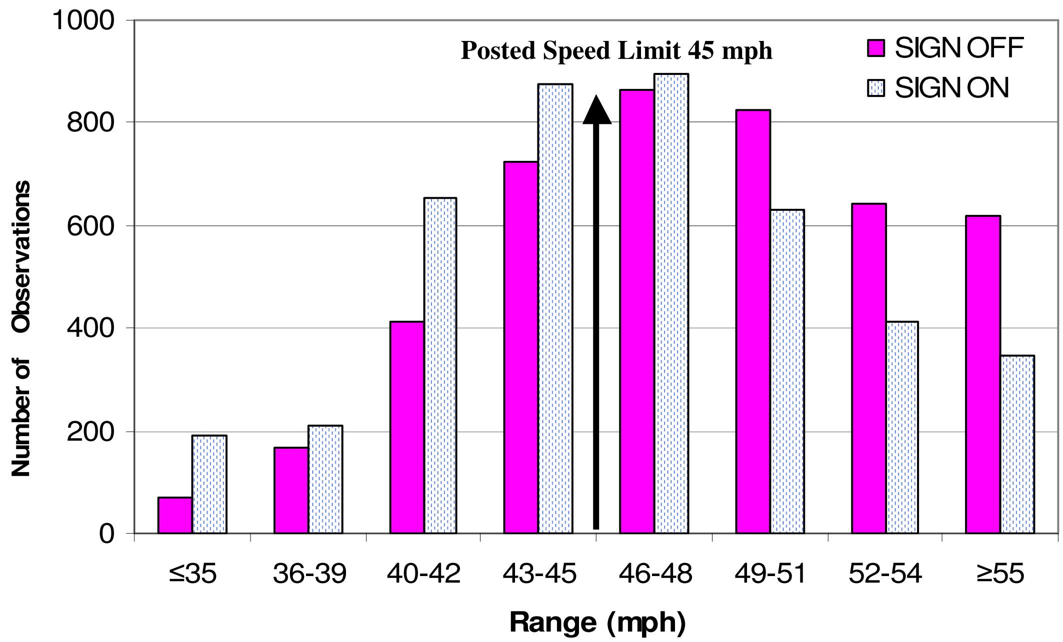


FIGURE 3: Histogram of Speed Data

Table 4 summarizes the results for all data collection sites and indicates that the speed-activated sign caused reductions in mean speed, 85th percentile speed, and percentage of vehicles exceeding the speed limit.

TABLE 4: Summary of Overall Speed Reductions

Measure of Effectiveness	Overall Speed Reductions*		Overall Speed Reductions during Periods of Excessive Speeding*	
	Average Speed Reduction	Speed Reduction Range	Average Speed Reduction	Speed Reduction Range
Mean Speed	3.29 mph	2.0 - 6.0 mph	4.12 mph	2.5 - 6.0 mph
85th Percentile Speed	3.22 mph	1.0 - 6.5 mph	3.67 mph	1.0 - 6.5 mph
% of Vehicles Exceeding Speed Limit by 3mph+	23.42 %	15.0 - 41.5 %	31.71 %	18.5 - 41.5 %
% of Vehicles Exceeding Speed Limit by 10 mph+	5.75 %	0.5 – 20.0 %	9.98 %	2.5 – 18.0 %

*1 mph = 1.61 kph

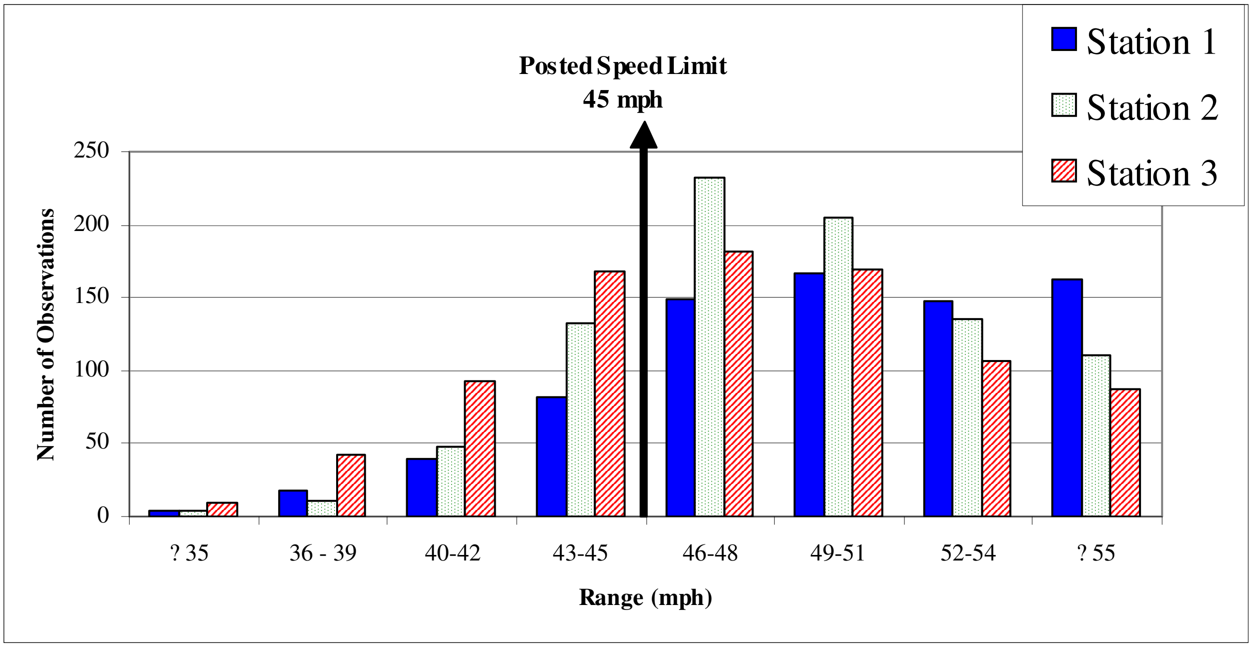
Table 4 depicts the large variation in the ranges of reductions in the measures of effectiveness, which can be attributed to the variation of the number of vehicles traveling over the posted speed limit for each period. The rightmost columns of the table show a summary of speed reduction averages and ranges for the periods when at least 50 percent or more of the volume has been exceeding the speed limit by three mph (4.8 kph) or more. This comparison demonstrated that the speed-activated sign was most effective during periods of excessive speeding.

ADDITIONAL RESEARCH AND RECOMMENDATIONS

Based on the results obtained from the initial study, an additional phase of research was developed. First, the speed-activated sign was redesigned to use a single modular power supply that could power both the radar unit and the flasher. The benefit of having a solar flasher in the first phase was negated because the radar unit could not be powered by the flasher's small three-volt solar cell; therefore, a battery system was still required. Further, the solar flasher used initially was not designed to be charged by an alternative electrical source, thus, it was inconvenient and impractical to use, as it had to be left in the sunlight to charge. The battery packs chosen for the second phase were standard 12-volt flashing beacon battery packs that contain two six-volt lantern batteries. Rechargeable lantern batteries were purchased and fitted in the battery packs. The benefit of these battery packs was that they are quite common in work zone use and are easily interchangeable, making them more practical in widespread field application.

Second, another data collection phase was added to the study to identify the effectiveness of using the speed-activated sign on multi-lane highways and freeways. A second sign was constructed so that two signs placed on either side of the same direction of highway could be studied. Initial field testing was done in one direction of a divided highway near the Clemson University campus and researchers found that regardless of the orientation of the signs, the radar units could not be focused on a single lane. Some spill-over was inevitable, but most could be minimized through trial and error adjustment.

Next, the researchers tested the two-sign configuration on Interstate 585 in Spartanburg and different directions of a multi-lane highway (SC 278) in Hilton Head. Figure 4 shows histograms of the performance of the signs at these two sites. Station 1 was used as the control condition for each of the sites. The histograms indicated a beneficial shift in the speed characteristics of vehicles due to the signs. It is noteworthy that Station 3 on both of the histograms showed the lowest speeds, suggesting that vehicles were still decelerating and kept their speeds down well after the signs.



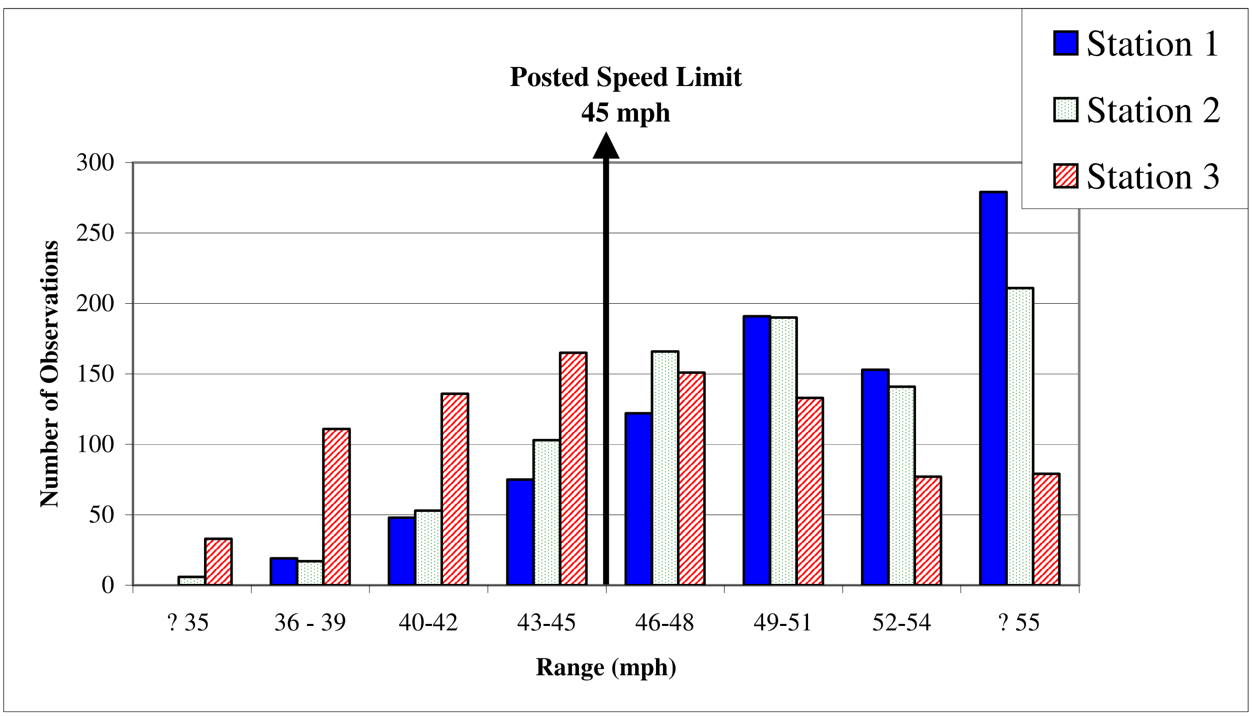


FIGURE 4: Data for the two-sign configuration were considered in histograms, as shown for State Route 278 on Hilton Head Island (top) and Interstate 585 in Spartanburg (bottom).

Table 5 summarizes the results for the multi-lane data collection sites and indicates that the speed-activated sign caused reductions in mean speed, 85th-percentile speed, and percentages of vehicles exceeding the speed limit for freeways and multi-lane highways. Statistical tests on the multi-lane and interstate freeway data indicated that the reductions for each project were significant at the 95-percent confidence level.

TABLE 5: Summary of Speed Reductions for Multi-lane Sites

Measure of Effectiveness	**Average Speed Reduction***		**Speed Reduction Range***	
Roadway Type	US Highway	Interstate	US Highway	Interstate
Mean Speed	2.6 mph	6 mph	0.9-3.3 mph	2.9-10.3 mph
85th Percentile	2.5 mph	4.7 mph	1.6-4.7 mph	3.0-11.2 mph
% of Vehicles Exceeding Speed Limit by 3 mph	19%	37%	10.5-28.8 %	7.6-67.2 %
% of Vehicles Exceeding Speed Limit by 10 mph	7.8%	20.6%	3.7-20 %	9.5-32.7 %

*1 mph = 1.61 kph

As a result of this study and past research, the following recommendations can be made regarding the use of a speed-activated sign as a speed reduction measure in work zones.

- Highest consideration for the use of the speed-activated sign should be given to short-term work zones on two-lane primary and secondary highways. The novelty of the sign might not be as effective in long-term use.
- Similar speed reduction benefits can be experienced on multi-lane divided roads where a two sign configuration is recommended.
- Use of a two-sign configuration is not recommended when traffic is congested because excessive spill-over between lanes can cause false indications. These unwarranted indications can reduce the sign's credibility, which in turn will decrease its effectiveness.
- The MUTCD (may define) requires that a sign be mounted at least one foot (0.305 m) above the ground (Section 6F.04) (*6*); however, the speed-activated sign should be mounted at least 5-feet (1.52 m) above the ground (measured from the bottom of the sign) to avoid interference with other traffic control devices.
- The speed-activated sign should be placed in the advance-warning area of the work zones to slow vehicles prior to entering activity areas.
- The speed-activated sign should be removed from the stand and the radar turned off during non-operation hours of the work zone.
- The radar on the speed-activated sign should be calibrated based on each unique location and its respective terrain.
- The speed-activated sign should be properly maintained for cleanliness and visibility.

An important safety concern of the speed-activated sign is whether the device is crash worthy per NCHRP 350 Report (19). The research team contacted representatives from the Federal Highway Administration (FHWA) and they indicated that the flashing beacon mounted atop the temporary sign support would potentially need to be crash tested, but that the radar box would not be of worry as long as it was mounted at or below 24 inches (60.96 cm) which is 6 inches (15.24 cm) greater than bumper height for the smallest required test vehicle. The manufacturer of the temporary sign stand indicated that the stand was designed with a frangible coupling system that would cause the sign stand to fly over a vehicle if impacted. The small flashing beacon that was used during the additional research phase weighs 1.7 kg (1.5 lbs) and is roughly half the weight of the original solar beacon. The sign stand manufacturer indicated that a 1.5 lb beacon mounted on top of the sign would not adversely affect the trajectory of the stand if struck by a vehicle. However, they stated that the 4.0 lb (1.8 kg) radar box could cancel or slow down the break-away effect and cause the stand to impale the vehicle's windshield upon impact. Due to these findings, the research team recommends the speed-activated sign be re-designed removing the radar box from the sign support and mounting it on the battery box with a ballast and placing it in front of the sign support at a height no greater than 24 inches.

Further testing of this sign is recommended to obtain a more comprehensive evaluation of its long-term effectiveness. The research team acknowledges a novelty effect because most drivers during the experimental sessions were seeing this particular sign for the first time. Future evaluation should focus on long-term effects and include data collection over periods of weeks or months. Other potential applications of the speed-activated sign include its use in school zones or in residential areas where speeding is a problem. Researchers observed reduction in speeds during preliminary testing of the speed-activated sign around Clemson University's campus, which suggested its potential benefits in settings other than work zones. Minor alterations of the sign would be required by the MUTCD such as changing the sign's color to yellow or fluorescent yellow-green (*6*).

CONCLUSION

Research results demonstrated that the speed-activated sign reduced mean speed, 85^{th}-percentile speeds, and percentages of vehicles exceeding the speed limit. Even though the impact of the novelty of this technique and its long-term effects could not be determined from this study, the data revealed that significant reductions in vehicle speed can be achieved at least in the short-term.

In addition, the speed-activated sign developed through this research fulfilled the objectives set forth by the SCDOT of developing an affordable and easy-to-implement technology to reduce speeds in work zones. The total cost of the fabrication of this type sign (approximately $1,500) was substantially lower than the other technologies identified by the research team, including changeable message signs and speed monitoring displays. The cost of the speed-activated sign would be significantly reduced if the radar assembly were produced in quantity. Typically, one person could set up the speed-activated sign in less than 15 minutes, including calibration of the radar. Unlike most other technologies, the speed-activated sign did not require the use of a trailer for transport. Instead, it could be transported in the bed of a truck or back of a van or sports utility vehicle.

In conclusion, this research has shown that the speed-activated sign had a considerable positive impact on lowering vehicle speeds in short-term work zones. To society's benefit, safety increases with lower vehicle speeds, and the speed-activated sign provides a new technology for widespread cost-effective implementation to increase safety and potentially save the lives of highway workers, drivers, and pedestrians.

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