Use of Radar Equipped Portable Changeable Message Sign to Reduce Vehicle Speed in South Carolina Work Zones

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ABSTRACT

This research examines the use of radar equipped portable changeable message signs to reduce driver speeds in South Carolina DOT work zones. The 85th percentile speed, mean speed, and percentage of vehicles exceeding the speed limit were considered in evaluating four different message sequences tested within a two-phased data collection effort, and generally exhibited a range in speed reduction from 3 to 10 mph (4.8 to 16.1 km/h). All message sequences were found to reduce driver speeds, and two were selected for further study based on their effects and novelty. Research data support the findings that radar equipped changeable message signs are an effective means to reduce vehicle speeds in localized areas. Data collection and analysis are focused on singling out individual speeding vehicles and providing the driver specific messages. The messages evaluated in this research included special instructions, speed notifications and feedback, and the magnitude of legal penalties. However, long-term impact of messages on motorists was not evaluated; rather attempts were focused on finding the most effective speed reduction message sequence. Previous research on the use of changeable message signs with radar as a work zone speed reduction device is discussed.

INTRODUCTION

The South Carolina Department of Transportation (SCDOT) controls and maintains approximately 63-percent of the 66,208 miles (106,551 kilometers, km) of roads within the state *(1)*. Correspondingly, on a national basis, state controlled roads comprise only 21-percent of all roads, ranking South Carolina as the forth-highest state for state-maintained roadway mileage. The state also has one of the lowest state fuel tax rates, at $0.16 per gallon. These two factors contributed to development of a bonding program launched in 1999 promoted as “27 in 7.” The plan compressed 27 years of planned work into seven years to take advantage of low interest rates, avoid construction inflation costs, and accelerate completion of needed road improvements. As a result, work zone activity has dramatically increased, and SCDOT has made a concerted effort to systematically address work zone safety issues using quantitatively-based research-supported methods. The potential of radar equipped changeable message signs (CMS) to improve work zone safety by decreasing vehicles speeds was studied for possible wide scale use. This paper presents findings from a study conducted to evaluate the effect of this countermeasure on vehicles traveling though construction work zones by analyzing data collected from several case study locations within the state. Clemson University, The Citadel and SCDOT have undertaken this joint research project to improve work zone safety by improving driver compliance to posted construction speed limits.

The evaluation summarized in this research provides an examination of a portable changeable message sign with radar (CMR) in SCDOT work zones and its impact on 85th percentile speed, mean speed, and number of drivers speeding. The research described herein focuses on the following objectives:

1. formulation of a quantitative analysis evaluating possible benefits of CMR on vehicles within a work zone,
2. comparative analysis of the impact of four individual message sequences on vehicles within a work zone, and
3. evaluation of speed reduction message sequence for drivers approaching a work zone area.

The research procedure initially centered on data collection for four CMR messages to determine relative effectiveness, and then two messages were selected for further study. These two messages were used at multiple work zone locations to expand the number of data samples and collection sites examined. It should be noted that the long-term impact of such messages on motorists was not evaluated, but rather attempts were focused on finding the most effective speed reduction message sequence via consideration of observed driver modification based on the 85^{th} percentile speed, mean speed, and number of speeders.

BACKGROUND

Portable changeable message signs (CMS) have been used along roadsides for decades and are frequently placed in work zone areas to provide special instructions, warnings, or other information to motorists. Changeable message signs are frequently used to convey safety information, and/or to provide additional emphasis to timely driver information. Previous research has documented that radar equipped changeable message signs may potentially reduce 85^{th} percentile speeds of passenger vehicles, decrease speed variability, and lower the number of speeders within work zones *(1)*. However, other work has shown drivers do not maintain reduced speeds after passing a CMS. In addition, temporary, localized effects, in speed reduction within longer work zone limits are frequently ineffective, even when using multiple signs *(2)*. Other relevant research conducted on changeable message signs is summarized in the following sections.

Experience with Changeable Message Signs with Radar

Research in Virginia examined seven work zones with lengths in excess of 1,500 feet (457 meters), large number of repeat users, and locations outside of urban areas where congestion would dictate speed *(1)*. The four messages examined produced speed reductions of 5 to 10 mph (8.0 to 16.1 km/h). Use of a CMR resulted in a reduction of observed speeders by half. However, statistical differences in speed reduction could not be determined for the following messages conveyed to drivers:

1. YOU ARE SPEEDING SLOW DOWN
2. HIGH SPEED SLOW DOWN
3. REDUCE SPEED IN WORK ZONE
4. EXCESSIVE SPEED SLOW DOWN

A 1998 study conducted in Georgia examined the impact of different messages on driver speeds for three consecutive weeks. The longer study period evaluated the novelty effect of the sign on driver speed behavior over time. Data was collected at stations located before, at, and after the sign location. Speeds, volumes, and vehicle lengths were collected using Nu-Metrics Hi-Star portable traffic classifiers. At the sign location, speeds were reduced by six to seven mph (9.7 to 11.3 km/h), but the reduction was not maintained throughout the work zone *(3)*. A previous study in Georgia conducted in 1995 examined strategies, and as in the 1998 study, reduced speeds for CMR were not maintained for the work zone length. However, speed reduction remained relatively consistent for three weeks of the study, and the novelty the CMR did not appear to subside *(2)*.

A 1998 Virginia study examined 85^{th} percentile speed, speed variance and correlations with vehicle type. Vehicle types included passenger cars, pick-up trucks, buses, and tractortrailers. The study included three test sites, two of which were on interstate highways and the other on a primary highway. The researchers conducted a survey to find how frequently motorists used the roadways. The interstate highway survey indicated 65-percent of drivers used that road daily, whereas the primary highway survey indicated 80-percent daily usage. The seven-week study concluded a CMR effective in reducing speeds for the "long term." Drivers observed to be speeding before the sign reduced their speeds by approximately eight mph (12.9 km/h). Observed behavior across all vehicle types was similar exhibiting a similar speed reduction variance. However, due to the driver tendency to speed up after sign placement, the study suggested using a second CMR to extend the range of the message's effect *(4)*.

Message Display and Content

The noteworthy operational difference between permanent and portable changeable message signs is that the Manual on Uniform Traffic Devices (MUTCD) allows a permanent CMS to have three line messages with up to twenty characters per line. Conversely, a portable CMS can provide three line messages with a maximum of eight characters per line. The intent is for portable CMS to display messages that are concise and easy for drivers to understand *(5)*. When equipped with radar, a CMS can relay customized messages based on individual driver speeds. The controller can be set to change message sequences and content based on a threshold speed, speed range, and/or time of day. Changeable message signs can also behave similarly to a speed monitoring display by incorporating the drivers' speeds into messages. Since the number of characters displayed on a CMS is limited, message brevity is important.

Research conducted in Texas identified a lack of knowledge (or disregard of knowledge) relating to the proper format and use of changeable messages. The Federal Highway Administration's "Portable Changeable Message Sign Handbook" discourages using changeable message signs under two conditions: 1) when the CMS would replace MUTCD-approved signage, or 2) when static signs adequately convey the same information. The handbook also suggests that no more than three phases should be used in a single sequence, but a maximum of two is recommended. This recommendation contradicts the MUTCD standard. The study found 40% of the signs observed used three or more phases. Two of 47 signs studied were found to use four phases. Additionally, 19-percent of messages were split improperly between phases *(6)*.

In addition to the number of characters per line, the number and duration of message phases are limited due to the time required for drivers to read and comprehend a message or sequence. The message complexity and number of phases depends on the message to relay, vehicle speed, and legibility distance. Further, information provided on a CMS can be divided into three categories: description, location, and action. First, the description informs the driver about the problem or activity ahead. Second, the location information describes the location of or distance to the event. Third, the action message provides instructions to the driver. This complies with MUTCD guidance, which states each display should convey a single, complete thought. For a single-phase message with three lines, each line should relay one of the three categories in order. In a three-phase sequence, each phase presents the three categories. Two-phase sequences present the first and third points in independent phases, while omitting the location category *(7)*.

DATA COLLECTION

The trailer-mounted Silent Messenger CMS (Model number MB-22-905) used in this study was manufactured by Solar Technology Incorporated and was equipped with their radar unit package.

The sign's message panel measures 126 inches wide by 76 inches high (320 centimeters wide by 193 centimeters high) and is capable of displaying one, two, and three lines of text as well as graphical messages.

Four message sequences were selected for the initial phase of the study based on input from SCDOT and review of previous research projects. The four message sequences included in phase 1 are depicted in Figure 1, and are shown as each appeared on the CMR. The default message played continuously unless it was preempted by a radar-activated message sequence. Sequences 1 and 4 were repeated twice, while the other two only ran once per triggering event. Occasionally one vehicle could trigger the message sequence more than once while within the radar's range. Based on initial evaluations, all of the message sequences were determined to exhibit a significant influence on motorist mean speed when entering a work zone area. However, message sequences 3 and 4 were chosen for continued study in phase 2 because of their performance and since they have not been previously tested.

Four work zone locations were selected in the upstate area of South Carolina. Two of these sites were used in the phase 1 data collection effort and all 4 sites were used in phase 2. Each site had no more than four lanes, speeds no higher than 55 mph (88.5 km/h), a suitable setup location for the changeable message sign, and adequate cover to conceal data collection observers. The work zone sites represented a variety of rural and urban site locations and posted speed limits of either 45 mph or 55 mph (72.4 km/h or 88.5 km/h). An overview of work zone data collection site conditions is presented in Table 1.

Data was obtained at each of the four data collection locations prior to introduction of the CMR message sequences to establish baseline vehicle speeds. Baseline data was used to compare approach speeds with and without the presence of a work to ensure values were homogenous across both conditions. Most of the data collection was accumulated during morning peak hour periods for all sites under conditions so that traffic congestion would not influence speeds. Data was collected to ensure results at a 95-percent confidence level. A minimum sample size of 97 was determined by using the following equation *(8)*:

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

where:

N = minimum number of measured speeds
S = estimated sample standard deviation, mph (5.0 mph or 8.0 km/h)
K = constant corresponding to the desired confidence level (1.96)
E = permitted error in the average speed estimate, mph (1.0 mph or 1.6 km/h)

Samples chosen for the study consisted only of individual vehicles with headways greater than a few seconds or the lead vehicle in a platoon where traffic queuing existed. This methodology allowed samples to be collected where drivers were traveling at their desired speed, eliminating confounding variables that may affect the study. For each of the site locations, data was collected at three data collection stations. The first station, no less than 1,000 ft (304.8 m) and no more than one half mile (0.8 km) in advance of the CMS, provided information about the initial condition of the vehicle speeds, via use of a laser speed gun. The second location, located immediately after the CMS but within 300 feet (91.4 m), was used to determine the initial impact on driver speeds, with data collected using an Autoscope unit for video detection of vehicle

Table 1 – Summary of Work Zones Evaluated

Work Zone Location	Collection Dates	Length	Speed Limit	Non-work zone Speed Limit	Construction Description	Study Phases
I-585	2/22/06 3/07/06 3/15/06	6.0 miles (9.7 km)	45 mph	55 mph	New interchange, controlled access	Phases 1 & 2
SC 72	2/21/06 3/09/06 3/16/06	4.0 miles (6.4 km)	55 mph	55 mph	Widening from 2 to 5 lanes	Phases 1 & 2
SC 290	3/22/06	6.0 miles (9.7 km)	45 mph	55 mph	Widening from 2 to 5 lanes	Phase 2
SC 101	3/23/06	8.1 miles (13.0 km)		45 mph	Widening from 2 to 5 lanes	Phase 2

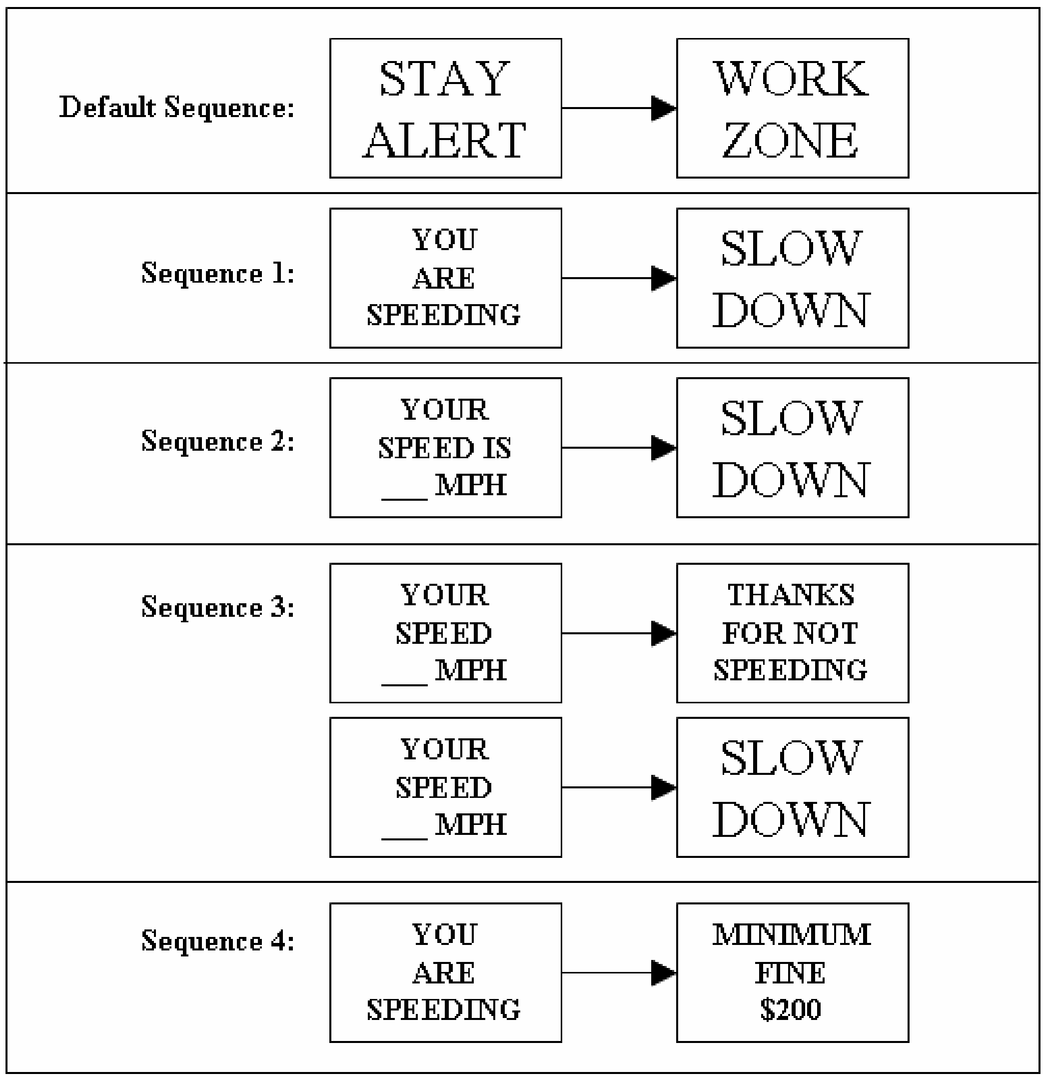

Figure 1 – Default and Radar Activated Message Sequences

speeds and type. Lastly, the third location, located approximately 1,200 feet (365.8 m) downstream from the CMS, provided data about the continued impact of the CMS on observed speeds was collected with a radar gun. The use of the laser gun at the first station was important because researchers did not want vehicles reacting to the radar prior to the detection of the CMS. Vehicles were tracked going away from the laser gun to minimize the chance that a vehicle equipped with a laser/radar detector would detect the laser as well.

DATA ANALYSIS

Data collected for the two phases of the CMR evaluation was examined to determine the changes in 85th percentile speed, mean speed, frequency of speeds, and number of observed vehicles speeding. 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 by 5 mph and 10 mph (8.0 and 16.1 km/h); 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 follows a normal distribution *(9)*. In this study, the data obtained was assumed to be normally distributed therefore parametric hypothesis testing was conducted to test for equal means and change in the percentage 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 5 mph and 10 mph (8.0 and 16.1 km/h). Each test was conducted to ensure a 95 percent level of confidence.

The two-sample t-test showed a significant reduction in mean speeds at station 2, ocation of the CMR, for all of message sequences at all four sites, with the exception of one. The results from the two-sample z test conducted on the percentage of vehicles exceeding the speed limit indicates that all of the message sequences displayed on the CMR produced a significant reduction in vehicles exceeding the speed limit by more than 5 mph (8.0 km/h) at all sites and by more than 10 mph (16.1 km/h) at almost all sites. The message 2 sequence used in phase 1 on SC 72 westbound was the only exception because there were very few vehicles speeding by more than 10 mph (16.1 km/h) at all 3 data collection stations. A general discussion of the results is given in the following sections for both data collection phases.

Phase One: Evaluation of CMR Message Sequences

All four of the message sequences exhibited a decrease in the 85th percentile speed between the three data collection stations. Table 2 lists observed 85th percentile speeds, and includes speed reductions between the stations for each message. The typical 85th percentile speed at Data Collection Station 1 ranged from 48 to 53 mph (77.3 to 85.3 km/h) for Interstate 585, and 57 to 59 mph (91.7 to 95.0 km/h) for South Carolina Route 72. The largest decreases occurred at the I-585 site and ranged from 6 to 9 mph (9.7 to 14.5 km/h). SC-72 showed a reduction in the 85th percentile speed ranging from 2 to 4 mph (3.2 to 6.4 km/h).

Table 3 provides a listing of observed decreases in mean speed through the entire observation area, as well as providing values for mean speed decreases between data collection stations. For both sites, mean speeds at the first data collection station were relatively close to the respective posted speed limits of 55 mph and 45 mph (88.5 to 72.4 km/h). For SC-72, mean speeds were 54 or 55 mph (86.9 to 88.5 km/h), and for I-585 mean speeds of 43 to 47 mph (69.2 to 75.6 km/h) were observed. For each successive station, a decrease in mean speed was observed through the study area. For the I-585 site, speed was reduced 7 to 9 mph (11.3 to 14.5 km/h) between the first two stations. The mean speeds remained the same or nearly the same between the second and third stations. However, this trend was not replicated at the SC-72 site, where the drop in mean speeds ranged from 5 to 7 mph (8.1 to 11.3 km/h) between the first two stations, and dropped again at the third station. The mean speed reduced ranging from 9 to 14 mph between the first and last stations. The continued deceleration may be due to the 55 mph (88.5 km/h) speed limit along SC-72. Because traffic was traveling faster at the SC-72 site, vehicles may not have had enough distance to decelerate to a lower sustained speed before reaching station 2, provide a representation of motorist behavior across data collection stations

Table 2 – I-585 and SC 72 Observed 85th Percentile Speeds and Speed Reduction

I-585, speed limit 45 mph (72.4 km/h)								
	Observed 85th Percentile Speeds at Station 1		Reduction in 85th Percentile Speeds					
			Station 1 to 2		Station 1 to 3		Station 2 to 3	
Message	mph	km/h	mph	km/h	mph	km/h	mph	km/h
1	53	85.3	9	14.5	10	16.1	1	1.6
2	51	82.1	8	12.9	8	12.9	0	0
3	48	77.2	6	9.7	8	12.9	2	3.2
4	50	80.5	7	11.3	7	11.3	1	1.6
SC-72, speed limit 55 mph (88.5 km/h)								
Message	Speeds at Station 1		Station 1 to 2		Station 1 to 3		Station 2 to 3	
1	58	93.3	3	4.8	11	17.7	8	12.9
2	59	95.0	4	6.4	4	6.4	0	0
3	58	93.3	4	6.4	7	11.3	3	4.8
4	57	91.7	2	3.2	5	8.0	3	4.8

Table 3 – I-585 and SC 72 Observed Mean Speeds and Speed Reduction

I-585, speed limit 45 mph (72.4 km/h)								
	Observed Mean Speeds at Station 1		Reduction in Mean Speeds					
			Station 1 to 2		Station 1 to 3		Station 2 to 3	
Message	mph	km/h	mph	km/h	mph	km/h	mph	km/h
1	47	75.6	9	14.5	10	16.1	1	1.6
2	46	74.0	9	14.5	9	14.5	0	0
3	43	69.2	7	11.3	7	11.3	0	0
4	44	70.8	7	11.3	7	11.3	0	0
SC-72, speed limit 55 mph (88.5 km/h)								
Message	Speeds at Station 1		Station 1 to 2		Station 1 to 3		Station 2 to 3	
1	54	86.9	5	8.0	14	22.5	9	14.5
2	55	88.5	5	8.0	9	14.5	4	6.4
3	54	86.9	7	11.3	10	16.1	3	4.8
4	54	86.9	6	9.7	10	16.1	4	6.4

Frequency and cumulative frequency of observed speeds were determined by stratifying vehicle speed data into 2 mph (3.2 km/h) increments. The resulting frequency tables and graphs within the study area limits. Figure 2 depicts the frequency distribution of speeds for Message Sequence 4 observed at each of the three data collection stations. The figure clearly indicates that there was a beneficial shift in the speed characteristics of vehicles due to the CMR. The rightmost curve, representing Data Collection Station 1, exhibits a higher speed distribution than the other two stations. The speed distribution for stations 2 and 3 are pretty similar indicating that drivers are maintaining their speed reduction.

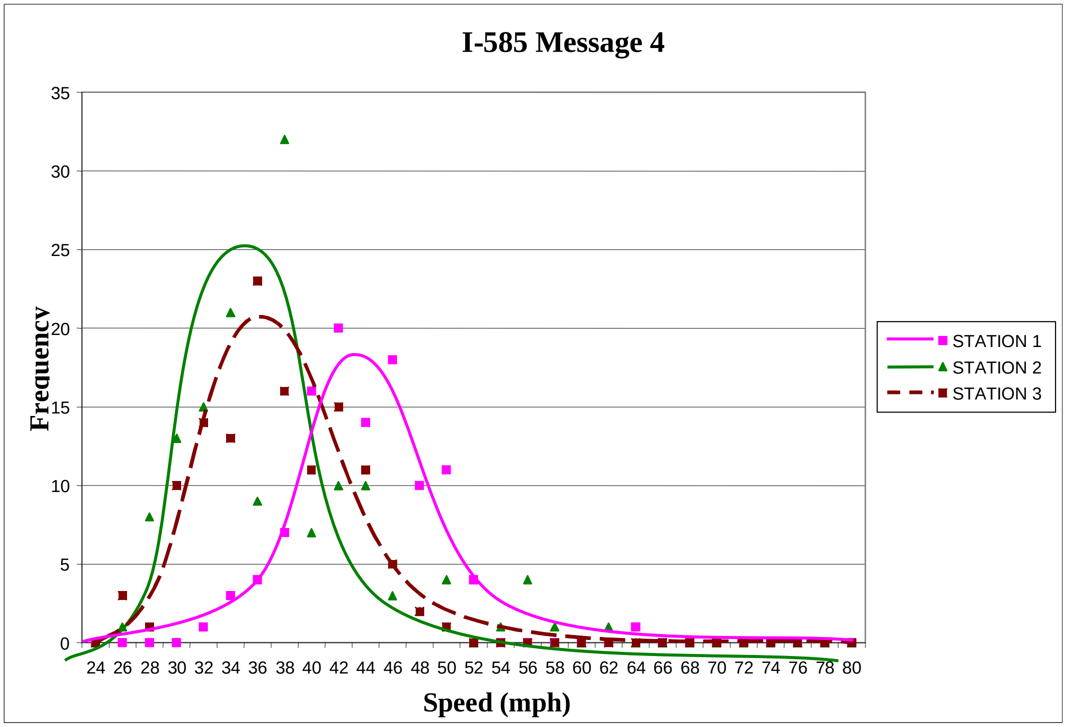

Figure 2 – Speed Frequency Graph for I-585 Message 4

The I-585 data collection site experienced a decrease in the number of vehicles speeding in excess of 5 mph (8 km/h) between stations 1 and 2, and 1 and 3 all CMR message sequences. The site experienced a decrease in the number of vehicles speeding in excess of 10 mph (16.1 km/h) between stations 1 and 3 for all CMR message sequences and for all but 1 message sequence between stations 1 and 2. Figure 3 and 4 summarize percent drivers in both speeding categories for all four CMR message sequences throughout data collection stations on I -585. It should be noted that CMR Message Sequence 1 caused the highest observed reductions in the percent of drivers speeding, and is thought to be indicative of commonly excessive speeds associated with interstate highway systems driving habits. This was due to the unusually high number of vehicles traveling at speeds greater than 5 mph over the speed limit when message sequence 1 was deployed. Even though message sequence 1 performed well, it was not studied in the second phase of this study, since it has been used extensively by other researchers and yielded similar findings. Message Sequence 1 was primarily used to verify the validity of data collection methods and analysis procedures used in Phase 1, and essentially served as a baseline for further study.

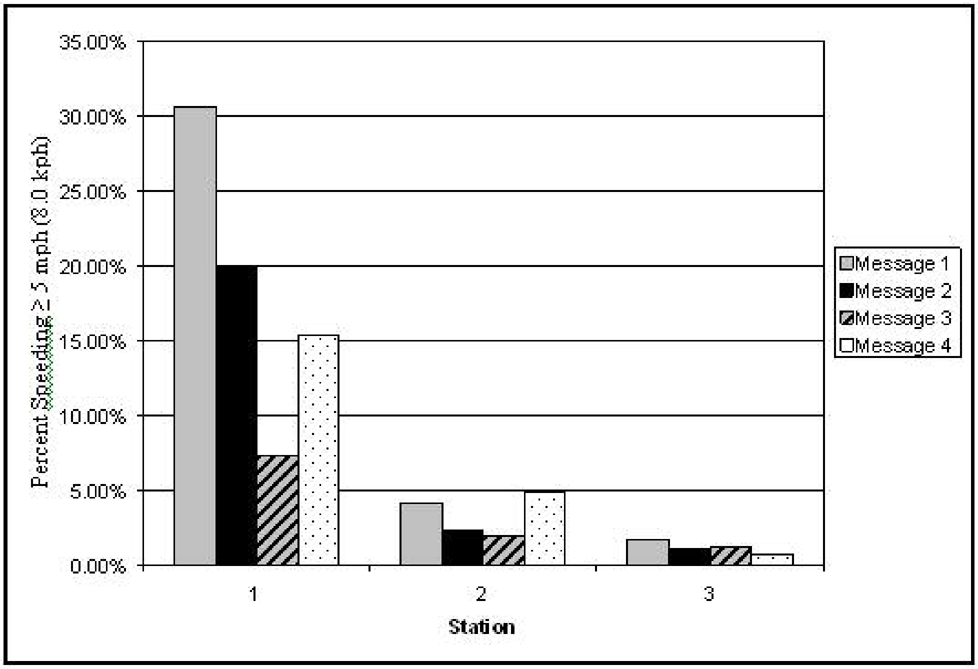

Figure 3 – I-585 Drivers Speeding 5 mph (8.0 km/h) or more above the Speed Limit

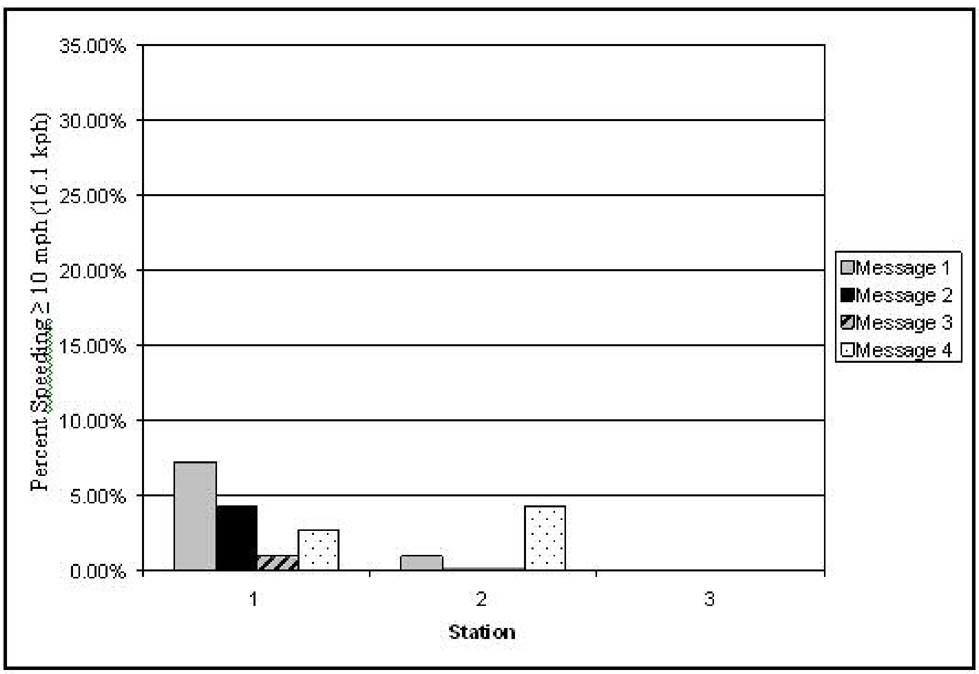

Figure 4 – I-585 Drivers Speeding 10 mph (16.1 km/h) or more above the Speed Limit

Message sequences 2 and 3 performed similarly in the study, and were not significantly different from one another. The comparable performance of these two messages was likely due to the fact that the same message was displayed to speeders, with the only difference being the message displayed to non-speeders. Message 3 was chosen for further study because it involved a more novel approach to driver feedback and exhibited a slightly better performance, albeit not supported through statistically proven data results. Message sequence 4 performed very well between stations 1 and 3. With elimination of messages 1 and 2, the fourth message sequence was chosen because literature indicated, like message 3, it has not been studied on other projects.

Phase Two: Evaluation of CMR Message Sequences 3 and 4

CMR message sequences 3 and 4 were evaluated further at all four of the work zone site locations in a similar manner as described for phase 1. Table 4 summarizes observed 85th percentile speed reductions for each of the phase 2 work zone site locations. The average 85th percentile speed observed at the first station for all three 45 mph (72.5 km/h) work zone locations was determined to be 53 mph (85.3 km/h) for both message sequences. In the 55 mph (88.5 km/h) work zone site locations, the 85th percentile speed at the first station was 60 mph 96.6 km/h). Reductions in the 85th percentile speeds differed significantly between the three work zones (I-585, SC-101 and SC-290) with posted 45 mph (72.5 km/h) speed limits and the one location (SC-72) with a 55 mph (88.5 km/h) speed limit. SC-101 and SC-290 exhibited reductions in average 85th percentile speed of approximately 10 mph (16.1 km/h) for both message sequences between the first two stations, and reductions of 4 to 5 mph (6.4 to 8.0 km/h) between stations 1 and 3. The work zone with the 55 mph (88.5 km/h) speed limit, for SC-72 exhibited a continued decrease in the 85th percentile speed, which may be due to a slightly higher 85th percentile speed at station 1. All work zone site locations experienced speeds at station 3 of approximately 49 mph (78.9 km/h) regardless of varying speeds observed at station 1. For the I-585 work zone site, it is unclear why an increase in 85th percentile speed was recorded from Station 1 to 2 for Message 4. This could possibly be due to the affects of traffic congestion.

Table 4 – Phase 2 Observed Reductions in 85th Percentile Speeds for Message Sequences 3 and 4

Site	**Characteristics**	**Station 1 to 2**				**Station 1 to 3**			
	(45 mph = 72.4 km/h)	**Message 3**		**Message 4**		**Message 3**		**Message 4**	
	(55 mph = 88.5 km/h)	mph	Km/h	mph	Km/h	Mph	Km/h	mph	Km/h
SC-101	45 mph 2-lane	10	16.1	8	12.9	3	4.8	3	4.8
SC-290	45 mph 2-lane	10	16.1	13	20.9	4	6.4	7	11.3
	Mean	10	16.1	10.5	16.9	3.5	5.6	5	8.0
I-585	45 mph 4-lane	5	8.0	*-6*	*-9.7*	2	3.2	2	3.2
SC-72	55 mph 2-lane	8	12.9	4	6.4	10	16.1	10	16.1

A summary of the phase 2 mean speed data for message sequences 3 and 4 is shown in Table 5. Similar trends were observed in comparing 85th percentile speeds with mean speeds. The greatest reduction in speeds occurred between the first two stations, and nearly half of the reduced speed was regained by station 3. Generally, mean speeds dropped from approximately 3 mph (4.8 km/h) above the posted speed limit at the first station to between 5 and 8 mph (8.0 to 12.9 km/h) below the mean speed at the second station. At the last station, most mean speeds were measured to be at, or slightly, below the posted speed limit. This fluctuation in speed may be due to an over-reaction by drivers to the CMR. The accelerating back to the speed limit by the last station may suggest drivers realized they had overcompensated. Additional data collection at a forth data station located further downstream would be useful in helping to confirm this hypothesis.

Table 5 – Phase 2 Observed Reductions in Mean Speeds for Messages Sequences 3 and 4

Site	Characteristics	Station 1 to 2				Station 1 to 3			
	(45 mph = 72.4 km/h)	Message 3		Message 4		Message 3		Message 4	
	(55 mph = 88.5 km/h)	mph	Km/h	mph	Km/h	Mph	Km/h	mph	Km/h
SC-101	45 mph 2-lane	10	16.1	10	16.1	3	4.8	6	9.7
SC-290	45 mph 2-lane	12	19.3	12	19.3	6	9.7	7	11.3
	Mean	11	17.7	11	17.7	4.5	7.2	6.5	10.5
I-585	45 mph 4-lane	7	11.3	0	0	2	3.2	1	1.6
SC-72	55 mph 2-lane	8	12.9	6	9.7	14	22.5	11	17.7

In general, the frequency of measured speeds was determined to be similar to that observed in the Phase 1 data collection. Aggregated data for the station 1 location frequency curve produced a higher distribution of speeds then stations 2 and 3. Station 2 realized a wider disbursement of driver speeds, demonstrated by a wider bell curve and higher standard deviation of 7.4 mph (11.9 km/h). The second station also typically exhibited the lowest mean speed of the three data collections stations. Station 3 generally peaked between the first two curves and its distribution was varied.

In some cases, more drivers were near the mean speed at station 3 than any other station, but other cases showed a wider distribution of speeds and a considerably flatter curve, as demonstrated for SC-290, CMR Message Sequence 4 in Figure 5. Furthermore, the percentage of drivers speeding 5 mph or more over the speed limit behaved differently in phase 2 than in phase 1. In the first phase, a continued reduction was observed throughout the work zone for all CMR message sequences. In the second phase, only message sequence 4 exhibited this trend. Message sequence 3 had a percentage at station 3 that was more than twice that of Station 2, but still less than half of station 1. Figure 6 summarizes the magnitude of speeders for this speed category.

The same relationship was observed for drivers speeding by 10 mph (16.1 km/h) or more over the speed limit, with the exception of the decrease in response to message sequence 4. For the first category, the majority of the decrease occurred between the first and second stations. For those speeding 10 mph and above, the largest drop occurred between stations 2 and 3. This difference may be due to increased deceleration time required for higher speeds and could account for the small decrease between the first two stations. These results are summarized in Figure 7.

In general, CMR Message Sequences were observed to reduce mean speed, 85^{th} percentile speed, and percentage of drivers exceeding the speed limit. The mean speed decreased between stations 1 and 3 from speeds as high as 6 mph (9.7 km/h) above the speed limit to speeds typically within a 2 mph (3.2 km/h) range of the speed limit. The 85^{th} percentile speeds were observed as high as 10 mph (16.1 km/h) above the speed limit before the sign, but dropped to about 5 mph (8.0 km/h) above the speed limit at the last station. The percent of drivers speeding also improved for all messages, varying among the messages.

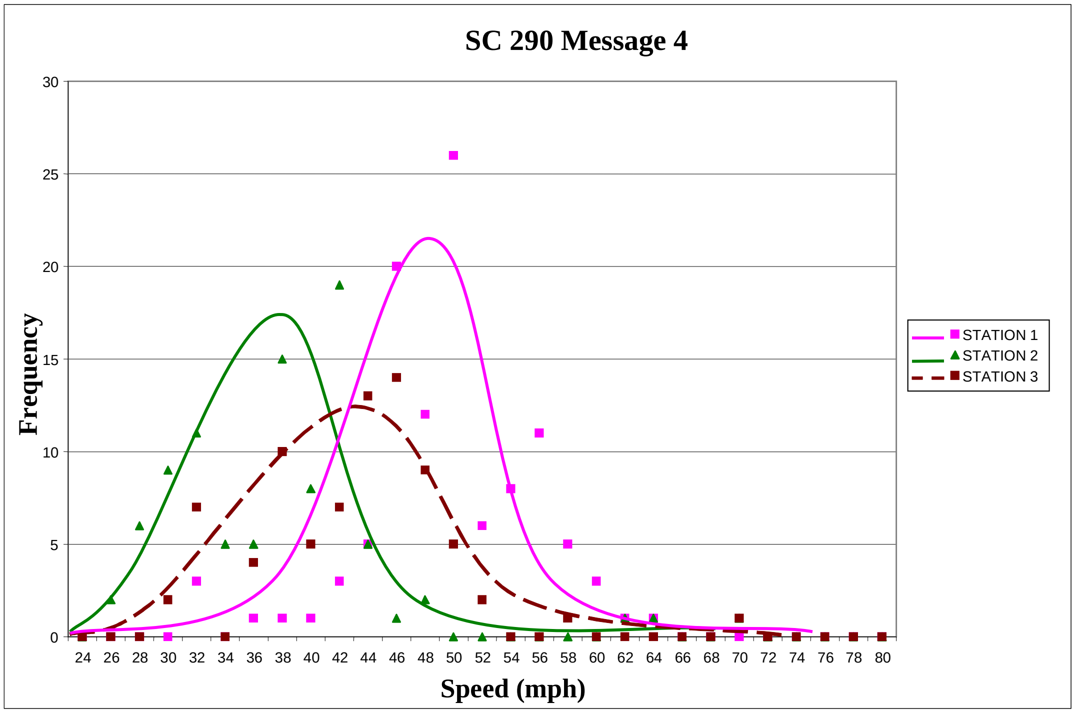

Figure 5 – Frequency Curve for SC-290, CMR Message Sequence 4

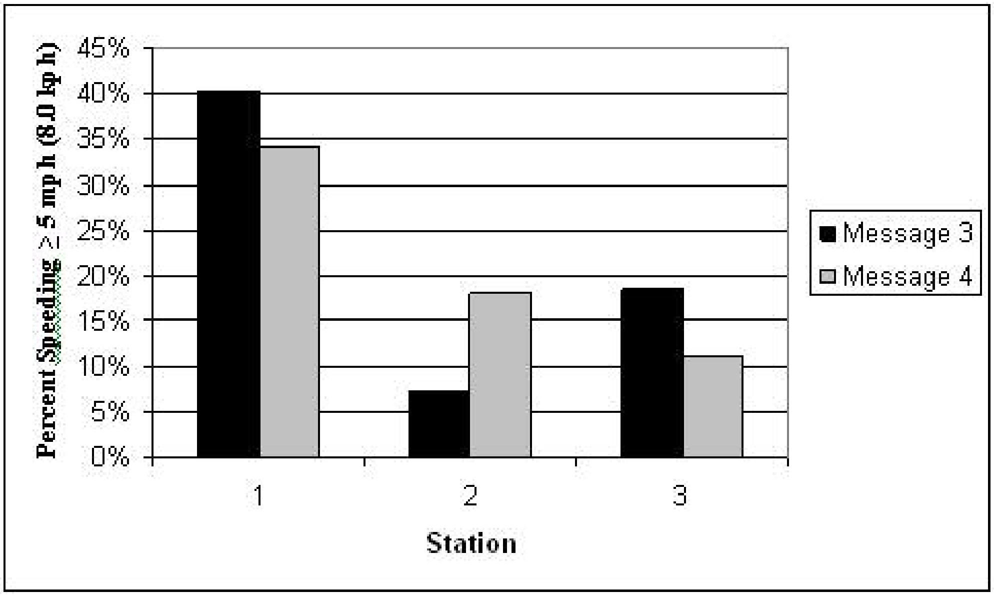

Figure 6 – Percent Speeding 5 mph (8.0 km/h) or more above Speed Limit for Messages 3 and 4

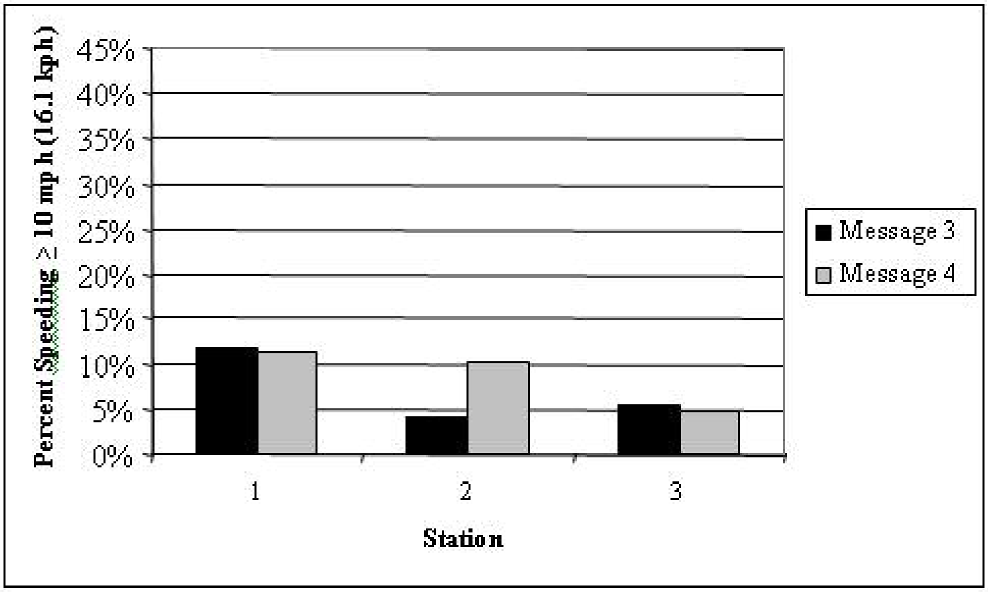

Figure 7 – Speeding 10 mph (16.1 km/h) or more above the Speed Limit for Messages 3 and 4

FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

Results from this study support the finding that radar equipped changeable message signs are effective in reducing mean speed, 85th percentile speed, and percentage of vehicles exceeding the speed limit. Specific findings from this research project include:

- Previous research from other sources has proven radar equipped changeable message signs are an effective means of reducing speeds in work zones.
- Message 1, "YOU ARE SPEEDING" followed by "SLOW DOWN", was used as a baseline for comparison in this study to other more novel message variations. However, based on data collected in phase 1, and as reflected extensively in previous studies, this message has been proven effective in reducing speeds in work zone areas.
- Message 2, "YOUR SPEED IS ____" followed by "SLOW DOWN", was determined to be effective in reducing work zone speeds through Phase 1 data collection, however, was primarily included to serve as a basis for comparison to Message 3 which included positive feedback for compliant drivers.
- Message 3, "YOUR SPEED IS ____" followed by either "THANKS FOR NOT SPEEDING" or "SLOW DOWN", performed similarly in the study and did not significantly differ from Message 2, despite the belief that positive feedback for compliant drivers would be useful in addressing the tendency of drivers to increase their speeds at station 3, downstream from the CMS.
- Message 4, "YOU ARE SPEEDING" followed by "MINIMUM FINE $200", showed comparable speed reductions to the other messages and incorporated a novel approach for displaying possible consequences for speeding.

In the past, standard changeable message signs have been used by the SCDOT and numerous contractors in South Carolina work zones to convey road conditions, construction activities, and other general information. As shown in this and previous studies, equipping these signs with radar and allowing them to aid in speed control measures will decrease speeds. While some messages exhibit greater speed reductions, any of the studied messages would improve driver compliance to the posted speed limits near the CMR, and future research may indicate a more lasting impact. Message Sequence 3 is especially recommended based on its performance and its credibility in that it indicates actual speed to the driver rather than a general statement that they are speeding. Improving speed limit compliance will help increase the safety of work zones for not only the motorists who travel through them, but also the dedicated and hardworking people who work in them

Future Research

Future research into changeable messages displayed to drivers within highway work zone areas should consider the extended impact of messages on drivers, driver opinion and comprehension, broader and more detailed data collection, and optimal location of radar unit when used in conjunction with CMS. Specific topics that would likely benefit from further research investigation and quantitative study include:

- Examination of long-term impact to evaluate viability of using messages as a speed calming measures for long-term temporary traffic control work zones– Certain messages or formats may have a more measurable affect on driver speeds for longer periods and/or distances than others. Placement and intermittent use within the work zone may have definable correlations with respect to lower vehicle speeds.
- Conducting detailed motorist surveys – Surveys have been used on previous research regarding CMR to see if drivers were regular users of the road. A more detailed motorist survey may better define the potential impact that CMR has on drivers with in construction work zones. Surveys may make it possible to identify message formats and key words that slow drivers and be used to better understand driver comprehension issues.
- Expanded data collection effort across wider array of roadway conditions and regional factors – Through the aggregation of more diverse sources of data, trends would likely become more clearly definable and lead to better understanding of related operational conditions. This may also help in recommending treatments for work zones of varying lengths.
- Evaluation of other means and configurations in which to affix the radar unit to the CMS for providing improved and optimally timed feedback to drivers as they approach work zone areas and speed reduction transitions – The proper positioning of the radar unit ensures that the CMS only notifies drivers within the legibility distance of approximately 500 feet (152.4 meters).

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