

Control of Vehicle Speeds in Temporary Traffic Control Zones (Work Zones) Using Changeable Message Signs with Radar

NICHOLAS J. GARBER AND SURBHI T. PATEL

Studies have shown that most drivers do not slow down in response to the standard regulatory or advisory speed signs that are customarily used to regulate speeds at temporary traffic control zones (work zones). This study evaluated the effectiveness of the Changeable Message Sign (CMS) with a radar unit in reducing speeds at work zones. Four CMS messages designed to warn drivers that their speed exceeded the maximum safe speed were tested at seven work zones on two interstate highways in Virginia. Speed and volume data for the whole population traveling through the sites were collected with automatic traffic counters. To assess the effect of the CMS with radar (on high-speed drivers in particular), vehicles that were traveling above a selected threshold speed triggered the radar-activated display and were videotaped as they passed through the work zones. The data obtained from the videotapes were used to obtain speed characteristics of these speeding drivers as they traversed these study sites. Statistical tests were then conducted using these speed characteristics to determine whether significant reduction in speed accompanied the use of CMS. The results indicate that the CMS with radar significantly reduced the speeds of speeding drivers. The messages used were rated according to their level of effectiveness in the following order: (1) YOU ARE SPEEDING SLOW DOWN, (2) HIGH SPEED SLOW DOWN, (3) REDUCE SPEED IN WORK ZONE, and (4) EXCESSIVE SPEED SLOW DOWN.

With over 90 percent of the national interstate highway network infrastructure completed, emphasis is now being placed on the rehabilitation and widening of existing highways rather than the construction of new ones. Thus, there are more and more temporary traffic control zones (work zones) on U.S. highways. The number of accidents and fatalities in work zones increased significantly as spending on highway construction grew during the 1980s, most of which was for rehabilitation work along heavily traveled roadways (1-3). In 1991, 680 persons died in construction/maintenance zones, and work zone fatal crashes represented approximately 3.75 percent of all fatal crashes on interstates, freeways, or expressways in the United States (3).

Many studies have identified excessive vehicle speeds in these zones as a major contributing factor in crashes (4-7). It has been shown that the static or passive methods endorsed in the *Manual on Uniform Control Devices* (MUTCD) do not in most cases influence drivers to respond to the posted speed limit or maximum advisory speed signs at these zones (8). Thus, many attempts have been made to develop additional techniques to control speeds at work zones, (9).

In this project, the Changeable Message Sign (CMS) integrated with radar was used to influence drivers speeding in the work zone to reduce their speed. The radar, attached directly to the CMS, was

used to determine the actual speeds of individual vehicles in the traffic stream. Upon detecting a speed higher than a present threshold limit, the CMS was programmed to display a preselected warning message to the driver.

To evaluate the effectiveness of the CMS with radar, an investigative study to test its operation was conducted. In the past, the CMS has been successfully used in an informational and advisory capacity. However, in this new role, the sign represents an excellent application of Intelligent Vehicle Highway System (IVHS) technology as it provides credible, real-time information based on the determination of actual vehicle speeds as the vehicles enter the work zone. In this study, four messages were used, and each influenced speeding drivers to significantly reduce their speed in the work zone.

PURPOSE AND SCOPE

The purpose of this project was to evaluate the effectiveness of the CMS with radar effective means of influencing drivers to reduce their speed work zones, especially those traveling at speeds much higher than the posted speed limit. The project was designed to study four different messages in several different environments and to determine their effects on speed profiles as described by characteristics such as average speeds, 85th percentile speeds, and speed variance.

The scope of the study was limited to temporary traffic control zones (work zones) on interstate highways in Virginia. Only those zones that called for speed reduction were selected for the project, and the zones were studied only by daylight and under dry weather conditions. In addition, the work zones chosen also had to meet certain criteria regarding length, the amount of traffic on the roadway, and the provisions for the safety of the data collection team.

The specific objectives of the study were to

1. Determine the speed characteristics of work zones on different types of highways using standard signing as specified in the MUTCD (10),
2. Determine the speed characteristics of the same work zones using both the standard MUTCD signing and the CMS,
3. Compare the results from Objectives 1 and 2 and assess the overall effect of CMS on the speed characteristics and speed profiles of the work zone areas,
4. Determine the effect of CMS on individual driver behavior, particularly high-speed drivers, as opposed to the whole population, and
5. Determine to what extent and under what traffic conditions this technique will be most effective.

N. J. Garber and S.T. Patel, Civil Engineering Department, University of Virginia, Charlottesville, Va. 22903, and Virginia Transportation Research Council, 530 Edgemont Road, Charlottesville, Va. 22903.

DATA COLLECTION

Identifying Suitable Work Zone Sites

Initially, information on anticipated maintenance and reconstruction activities throughout the state of Virginia was requested from resident engineers by distributing a survey letter. The survey requested information on the project location and a description of specific characteristics of the work zone, for example, day or night operation, the number of lanes to be closed, and the length of the work zone. If the work zone appeared to be feasible during this preliminary evaluation, then a site visit was warranted, and it was submitted for the final selection process.

For the site to be suitable for data collection, the work zone had to meet the following qualifications:

- The length of the work zone had to be at least 457.2 m (1,500 ft) or more to allow drivers who wished to vary their speed along the study area to do so.
- As congested flow usually predominates on highways with high annual average daily traffic (AADT), the estimated free flow traffic on the highway in question had to be at least 30 percent of the total traffic. This condition allowed for the monitoring of the individual speeds of a sufficient number of vehicles being driven at the drivers' desired speed.
- The work zone had to be able to safely accommodate the CMS equipment and researchers without interfering with construction vehicles and workers or obstructing the traffic flow.

Seven sites were selected for data collection throughout the course of the project (Table 1). The normal speed limits shown in Table 1 are the posted speed limits on these roads under normal conditions (i.e., when no work is being performed on the roads). Only regulatory signs were used for the posted speed limits at all study sites. Figure 1 shows an example of a typical work zone study area.

TABLE 1 Work Zone Study Sites

| ROUTE NUMBER | NEAREST CITY OR TOWN | COUNTY | 1991 AADT | NUMBER OF LANES | NUMBER OF LANES OPEN TO TRAFFIC | NORMAL SPEED LIMIT | POSTED SPEED LIMIT | TYPE OF WORK ZONE | DATES OF STUDY |
|--------------|----------------------|------------|-----------|-----------------|---------------------------------|--------------------|--------------------|--|------------------------------|
| 81 South | Lexington | Rockbridge | 24,000 | 2 | 1 | 105 km/hr | 88.5 km/hr | Rockslide Damage Control | 8/18-8/21/92 8/25-8/26/92 |
| 64 East | Covington | Alleghany | 8,400 | 2 | 1 | 105 km/hr | 88.5 km/hr | Bridge Deck Repair | 9/14-9/16/92 |
| 64 East | Short Pump | Henrico | 25,000 | 2 | 2 | 105 km/hr | 88.5 km/hr | Construction of Additional Lane | 10/26-10/29/92 |
| 81 North | Bristol | Washington | 33,000 | 2 | 2 | 105 km/hr | 88.5 km/hr | Bridge Reconstruction | 5/24-5/27/93 |
| 81 North | Abingdon | Washington | 24,000 | 2 | 1 | 105 km/hr | 72.4 km/hr | Bridge Reconstruction | 7/12-7/14/93 |
| 81 South | Abingdon | Washington | 24,000 | 2 | 1 | 105 km/hr | 88.5 km/hr | Reconstruction & Complete New Interchange Construction | 8/23-8/26/93 |
| 64 East | Shadwell | Albemarle | 21,000 | 2 | 1 | 105 km/hr | 88.5 km/hr | Concrete Joint Repair | 11/1-11/3/93 |

1 km = 0.6 mi.

Speed and Volume Data: Automatic Traffic Counts

The first step entailed laying down the pneumatic tubes and automatic traffic counters (StreeterAmet 141A traffic counters) to collect the speed and volume data for all vehicles traveling through the work zone. These data were collected continuously, day and night, during the course of the data collection period to provide the data for all the vehicles without the CMS and also with the CMS during actual videotaping and sign display.

The tubes were set down at the following three locations within the temporary traffic control zone (work zone):

- At the advance warning area, just before the beginning of the transition area (station 1),
- At approximately the midpoint of the activity area (station 2), and
- Just before the end of the work zone (station 3).

These three locations were chosen because (a) at the entrance to the transition area, vehicle speeds are usually those preferred by the drivers; (b) in the middle of the activity area, vehicle speeds may be influenced by the speed control effort; and (c) at the end of the work zone drivers may choose to regain their speed, believing that they have passed the monitored area.

Data Collection with CMS

Placement of CMS

The CMS was placed a short distance behind the first set of tubes (at the beginning of the taper if vehicles were channelized into a single lane) to detect vehicle speeds as they entered the work zone. The

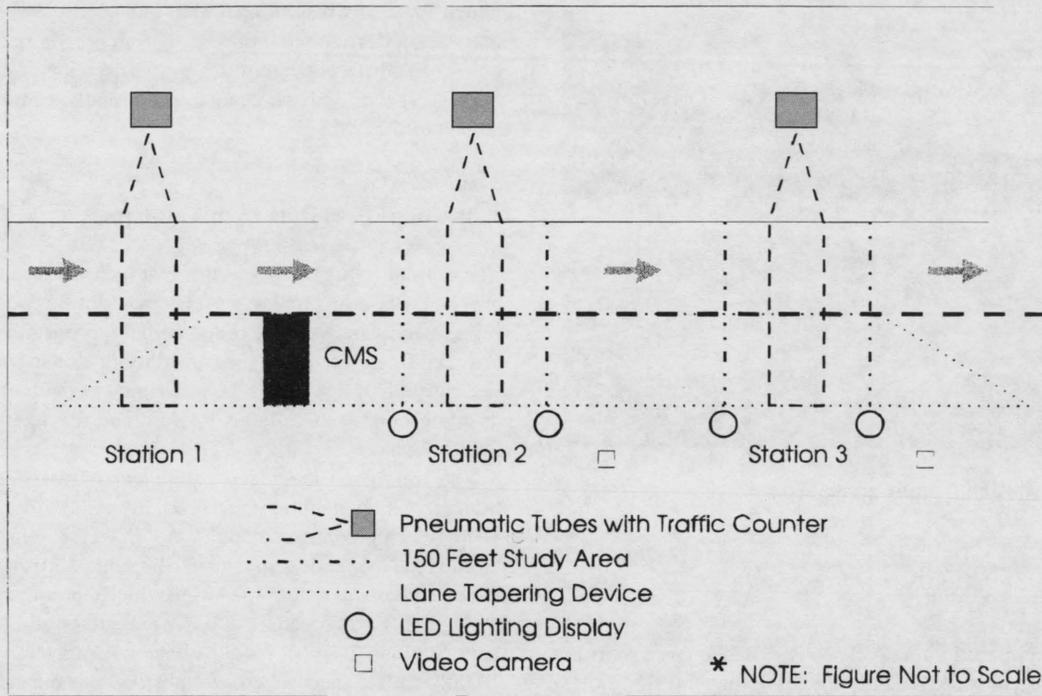


FIGURE 1 Example of typical work zone study area—two-lane highway tapered to one lane.

CMS that was used in this project was specially designed for the study. It used the standard message display board (CMS-T300, American Signal Company). The radar unit attached to the side was a special feature (Figure 2). This radar (TRACKER TDW-10 Wide Beam Vehicle Detector) was connected to the central processing unit that controls the functions of the message display. If the radar was activated and it detected a speed higher than a preset threshold speed, the message display could be programmed to flash a particular message instantaneously.

The radar, attached directly to the side of the message display (Figure 2), was positioned to align with vehicles as they entered the work zone at a range of 91.4 m to 182.9 m (300 to 600 ft). Generally, the main objective was to direct the radar to a point where only *one* vehicle's speed would be detected by the radar. The purpose of this particular arrangement was twofold. First, when the radar detected a speeding vehicle, an observer was able to identify that particular vehicle, take note of its key characteristics (color of vehicle, vehicle type) and relay this descriptive information over the walkie talkie to the crew activating the video cameras. At the same time, the driver of the vehicle would be in the range to see the message as it came up on the display and then be able to act accordingly, if he or she so desired.

Marking the Study Areas

At the second and third locations (near Stations 2 and 3, where the counters were placed), additional tubes were set down marking a distance of 45.7 m (150 ft). These tubes designated a section of known distance to calculate the speeds of those vehicles for which the message was activated. The cameras provided the means to determine the vehicles' travel times across the sections as their movements were recorded on film. The speeds of the vehicles at

these two locations in the work zone were calculated by time and distance.

To enhance the visibility of the tubes, during the extraction of the data from the video tapes, an air-pressure-activated lighting device, which consisted of a light-emitting diode (LED) display, was constructed. The lighting device was attached to each of the two tubes marking the entrance and exit of the 45.7-m (150-ft) sections (Figure 2). The light was activated when the tire exerted pressure on the tubes, giving a clear indication of when each vehicle's front wheels entered and exited the study area. The light did not in any way distract or endanger drivers as it was placed off the traveled way and faced the opposite direction of travel. A typical study area is shown in Figure 3.



FIGURE 2 Changeable message sign with radar unit.



FIGURE 3 Typical 150-ft study area.

Placement of the Video Cameras

Two cameras were placed a relatively long distance apart so as to capture any changes in speeds of the vehicles as they traveled along the roadway. With the strategic placement of the cameras, driver behavior, as well as the effectiveness of the speed control device, was studied. As the speeding vehicle entered the work zone, its progress was monitored by two camera operators.

In addition to videotaping, the second camera operator was also required to manually record data on each speeding vehicle's description using a predesignated form. Information regarding the type, color, and size, as well as the make of the vehicle, was marked on the data collection sheet to help identify each speeding vehicle on the videotapes during the data reduction process.

Data Recording with CMS

Each time a speeding vehicle triggered the automated speed display, the observer at the CMS identified the vehicle and relayed the descriptive information to Stations 2 and 3 so the progress of that specific vehicle could be monitored through the work zone by videotaping its movement.

The following four messages were tested at each site:

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

Compiling Speed and Volume Data from Traffic Counters

Using the StreeterAmet T240, the speed and volume data were extracted from the traffic counters on a daily basis. Using the data from the automatic counters as well as the speed data obtained from the videotapes, a detailed analysis was carried out for (a) the period during work activities but before the installation of the CMS, (b) the period during which the CMS was in operation with the video cameras and data collection team present, and (c) the period during

which the CMS was in operation but without the video cameras and data collection team present. Differences in speed characteristics for the different conditions were determined by comparing the average speed, 85th percentile speed, and speed variance downstream of the CMS.

Extracting Speed Data from Videotapes

The normal 1/2-in. videocassettes that were used in the video cameras had to be converted to professional 3/4-in. tapes as the 3/4-in. editing system was used to extract the data from the videotapes. The 3/4-in. editing system has the capability of slowing frames down to one-thirtieth of a second. The movement of the frames is managed by a jog control that allows forward and reverse frame-by-frame adjustments.

The timing on the video equipment is recorded on a control tracker, which maintains accuracy to $\pm 2/30$ sec (two frames). Using the jog control to obtain the times the vehicle's front tires crossed the first and second tubes, the vehicle's travel time between the two tubes was determined from which the vehicle's velocity was computed. This procedure was carried out for all of the vehicles at both Stations 2 and 3 for all of the messages at each site. Over 10,000 vehicle speeds were computed in this manner.

ANALYSIS

Calculation of Average and Percentile Speeds

Camera Data

Having computed all of the speeds at Stations 2 and 3, the average and 85th percentile speeds of those vehicles exceeding the threshold speed were computed at each station for each message using all of the data.

The camera data were then divided to assess the effect of the messages on high-speed drivers in particular. The speed data at Station 1 were sorted into two categories: 95 to 103 km/hr and ≥ 104 km/hr (59 to 64 mi/hr and ≥ 65 mi/hr). The corresponding speeds at Stations 2 and 3 for each vehicle were also sorted along with Station 1. Average speeds for the two speed categories were then calculated at each station for each message. The main purpose for this division was to observe the behavior of the two different groups of speeding vehicles as they traveled through the work zone.

Traffic Counters Data

Three separate sets of data were extracted from the traffic counters. The first set represented the speeds of vehicles when only the standard MUTCD traffic control signs were in place, including the regulatory speed signs, without the use of the CMS. This condition represented the base condition for analysis, and under this condition, only the regulated speed signs informed drivers of the speed limit at the work zone. The second and third sets were obtained for the times when the CMS was in place, in addition to the standard MUTCD traffic control signs including the regulatory speed signs, with and without the data collection team present.

The average and 85th percentile speeds, the speed variance, and the pace were calculated at each station and for each message.

Significance Testing

The statistical techniques used to test the significance of the speed reductions achieved with the CMS included the *odds ratio*, the *analysis of variance* (ANOVA), and the *t*-test. The odds ratios were used to determine the odds of exceeding the speed limit in the work zone under the various conditions prescribed in the study, for example, the use of the four different messages on the CMS. The effectiveness of the CMS was measured by the decrease in the odds for speeding when using the CMS as compared with the odds for speeding when not using the CMS. ANOVA was used with the whole population data to determine whether there were significant reductions in average and 85th percentile speeds, as well as speed variances, as a result of using the CMS. In addition, ANOVA was also used with the camera data to determine if there was a significant difference in speeds when using any of the four messages on the CMS. And finally, the *t*-test was used with the camera data to test whether the drivers of the high-speeding vehicles were significantly reducing their speed as they traversed the three stations through the work zone. (Due to space constraints, only the results of the ANOVA tests are presented.)

Analysis of Variance

Camera Data

ANOVA was conducted with the speed data obtained from the videotapes (data on speeding drivers only) to determine whether there were significant differences between the four messages with regard to average and 85th percentile speeds of the speeding drivers within the work zone. Using the data from all test sites, the following null hypotheses (1–10) were tested:

- 1. The average speeds at Station 2 are the same for all four messages on the CMS.
- 2. The 85th percentile speeds at Station 2 are the same for all four messages on the CMS.

These null hypotheses were also tested using the data obtained at Station 3.

Whole Population Data

Initially, ANOVA tests were conducted to determine whether there were significant differences in the speed data obtained when the data collection team was present at the study sites and the speed data obtained when the team was not present. If there were no significant differences in the two sets of data, then it would be reasonable to assume that the presence of the data collection team when recording the camera data did not bias the results.

The tests compared the two conditions for average speeds, 85th percentile speeds, and speed variances at Stations 2 and 3 using the whole population data. The following set of null hypotheses was developed [these were repeated for Station 3 speeds and for each of the other two speed characteristics (i.e., 85th percentile speeds and speed variance)]:

- 3. The average speeds at Station 2 with the data collection team present are the same as the average speeds without the data collec-

tion team present for the message EXCESSIVE SPEED SLOW DOWN.

4. The average speeds at Station 2 with the data collection team present are the same as the average speeds without the data collection team present for the message HIGH SPEED SLOW DOWN.

5. The average speeds at Station 2 with the data collection team present are the same as the average speeds without the data collection team present for the message REDUCE SPEED IN WORK ZONE.

6. The average speeds at Station 2 with the data collection team present are the same as the average speeds without the data collection team present for the message YOU ARE SPEEDING SLOW DOWN.

The whole population data obtained from the automatic counters were also used to evaluate the effect of the CMS on three particular characteristics of the speed profiles through the work zone: the average speeds, 85th percentile speeds, and the speed variances.

The next four null hypotheses pertain to the average speeds that were calculated at Station 2. It should be noted that the 85th percentile speeds, the speed variances, and the percentages of vehicles speeding in each category were all tested in a similar manner. In addition, all of the speed characteristics were evaluated at Station 3 as well.

7. The average speeds at Station 2 using the CMS displaying the message EXCESSIVE SPEED SLOW DOWN are the same as when using standard MUTCD signing only.

8. The average speeds at Station 2 using the CMS displaying the message HIGH SPEED SLOW DOWN are the same as when using standard MUTCD signing only.

9. The average speeds at Station 2 using the CMS displaying the message REDUCE SPEED IN WORK ZONE are the same as when using standard MUTCD signing only.

10. The average speeds at Station 2 using the CMS displaying the message YOU ARE SPEEDING SLOW DOWN are the same as when using standard MUTCD signing only.

RESULTS

Tables 2 through 4 contain the statistics for the camera data, which include the average speeds and 85th percentile speeds in Tables 2 and 3, respectively. Table 4 provides the average speeds that were determined at each station when Station 1 speeds were divided into two categories: 94.9 to 103 km/hr and ≥ 103 km/hr (59 to 64 mi/hr and ≥ 65 mi/hr). Table 4 shows the benefits of using the CMS to reduce speed variance. The notable trend in this table can best be described with an example: For the speeds at I-81 South at Buffalo Gap for the message EXCESSIVE SPEED SLOW DOWN, the difference in average speeds at Station 1 for the two speed categories was approximately 9 km/hr (5.6 mi/hr, i.e., 66.6 to 61.0 mi/hr). By Station 2, this difference reduced to approximately 5.4 km/hr (3.4 mi/hr, i.e., 54.3 to 50.9 mi/hr). And finally, by Station 3, the difference in average speeds for the two high-speeding groups dropped to 1.1 km/hr (0.7 mi/hr, i.e., 50.8 to 50.1 mi/hr). The average speeds for all of the messages at all of the sites showed a similar trend in driver behavior, although to slightly different degrees. The fact that all of the high-speeding vehicles tend to converge to a similar speed by the time they

TABLE 2 Average Speeds (km/hr) Calculated Using Camera Data

| | <u>EXCESSIVE SPEED SLOW DOWN</u> | | | <u>HIGH SPEED SLOW DOWN</u> | | | <u>REDUCE SPEED IN WORK ZONE</u> | | | <u>YOU ARE SPEEDING SLOW DOWN</u> | | | <u>SLOW DOWN NOW</u> | | |
|---------------------------------|----------------------------------|-------|-------|-----------------------------|-------|-------|----------------------------------|-------|-------|-----------------------------------|-------|-------|----------------------|-------|-------|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| 81 South Buff. Gap | 99.77 | 83.12 | 80.90 | 99.73 | 82.01 | 75.71 | 98.97 | 85.92 | 78.24 | 100.5 | 82.30 | 73.43 | Not | | |
| 64 East Covington | 100.1 | 75.34 | 69.31 | 101.3 | 77.97 | 70.65 | 100.4 | 80.17 | 73.70 | 101.4 | 77.21 | 66.16 | Tested | | |
| 64 East Short Pump ¹ | 99.04 | -- | 78.07 | 99.92 | -- | 80.46 | 100.1 | -- | 80.08 | 99.52 | -- | 79.13 | At | | |
| 81 North Bristol ² | 98.58 | 83.11 | 80.34 | 98.46 | 82.16 | 81.24 | 99.18 | 84.91 | 83.80 | 98.41 | 80.69 | 79.76 | These | | |
| 81 North Abingdon ² | 89.82 | 61.64 | -- | 89.21 | 63.13 | 55.62 | 90.83 | 68.75 | 67.03 | 88.39 | 62.25 | 59.11 | Sites | | |
| 81 South Abingdon | 99.44 | 71.81 | 73.45 | 99.07 | 75.69 | 75.95 | 99.23 | 72.86 | 73.93 | 99.20 | 71.87 | 74.87 | 99.23 | 72.03 | 73.93 |
| 64 East Shadwell | 101.2 | 94.29 | 94.24 | 100.9 | 89.86 | 85.94 | 101.6 | 93.24 | 94.21 | 102.4 | 88.66 | 85.52 | 101.7 | 90.73 | 89.49 |

1 km=0.6 mi.

¹ Two lanes open.

² Reduced to 72.4 km/hr.

-- Indicates that speeds were incalculable because a problem was encountered with the videotapes and travel times were unavailable.

TABLE 3 85th Percentile Speeds (km/hr) Calculated Using Camera Data

| | <u>EXCESSIVE SPEED SLOW DOWN</u> | | | <u>HIGH SPEED SLOW DOWN</u> | | | <u>REDUCE SPEED IN WORK ZONE</u> | | | <u>YOU ARE SPEEDING SLOW DOWN</u> | | | <u>SLOW DOWN NOW</u> | | |
|---------------------------------|----------------------------------|-------|-------|-----------------------------|-------|-------|----------------------------------|-------|-------|-----------------------------------|-------|-------|----------------------|-------|-------|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| 81 South Buff. Gap | 104.6 | 93.16 | 89.78 | 106.2 | 91.44 | 86.63 | 103.0 | 94.95 | 88.18 | 106.2 | 95.95 | 85.13 | Not | | |
| 64 East Covington | 104.6 | 86.63 | 80.95 | 107.8 | 86.63 | 83.68 | 106.2 | 91.44 | 83.68 | 107.8 | 88.18 | 79.65 | Tested | | |
| 64 East Short Pump ¹ | 103.0 | -- | 88.18 | 104.6 | -- | 88.18 | 104.6 | -- | 88.18 | 103.0 | -- | 88.18 | At | | |
| 81 North Bristol ² | 103.0 | 93.17 | 89.79 | 101.4 | 93.17 | 89.79 | 103.0 | 94.95 | 93.17 | 103.0 | 91.44 | 88.18 | These | | |
| 81 North Abingdon ² | 96.56 | 71.57 | -- | 96.56 | 72.61 | 63.31 | 98.17 | 78.37 | 74.82 | 94.95 | 70.54 | 67.64 | Sites | | |
| 81 South Abingdon | 104.6 | 82.86 | 83.94 | 103.0 | 85.85 | 85.36 | 104.6 | 82.86 | 82.56 | 103.0 | 82.86 | 85.36 | 103.0 | 82.86 | 83.94 |
| 64 East Shadwell | 104.6 | 98.75 | 100.8 | 104.6 | 93.16 | 91.44 | 104.6 | 98.75 | 100.8 | 106.2 | 96.82 | 91.44 | 106.2 | 94.95 | 94.95 |

1 km=0.6 mi.

¹ Two lanes open.

² Reduced to 72.4 km/hr.

-- Indicates that speeds were incalculable because a problem was encountered with the videotapes and travel times were unavailable.

TABLE 4 Average Speeds (km/hr) Calculated Using Camera Data (According to Two Categories of Speeds)

| | Speed Category | EXCESSIVE SPEED SLOW DOWN | | | HIGH SPEED SLOW DOWN | | | REDUCE SPEED IN WORK ZONE | | | YOU ARE SPEEDING SLOW DOWN | | | SLOW DOWN NOW | | |
|-------------------------|----------------|---------------------------|------|------|----------------------|------|------|---------------------------|------|------|----------------------------|------|------|---------------|------|------|
| | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| 81 South | 95-103 | 98.2 | 81.9 | 80.6 | 97.8 | 79.9 | 74.5 | 97.5 | 85.3 | 78.1 | 98.3 | 80.4 | 69.7 | Not | | |
| Buff. Gap | ≥ 104 | 107.2 | 87.4 | 81.8 | 107.3 | 88.8 | 80.3 | 107.3 | 89.8 | 79.2 | 107.6 | 88.7 | 77.7 | | | |
| 64 East | 95-103 | 98.2 | 74.4 | 68.2 | 98.3 | 77.9 | 70.3 | 98.0 | 78.1 | 71.9 | 98.8 | 76.6 | 65.5 | Tested | | |
| Covington | ≥ 104 | 107.1 | 79.0 | 73.5 | 108.6 | 78.2 | 71.5 | 107.1 | 86.3 | 78.2 | 108.6 | 79.7 | 68.1 | | | |
| 64 East | 95-103 | 97.8 | -- | 77.7 | 98.3 | -- | 80.1 | 98.5 | -- | 79.7 | 98.2 | -- | 78.4 | At | | |
| Short Pump ¹ | ≥ 104 | 106.9 | -- | 84.7 | 107.2 | -- | 80.1 | 107.1 | -- | 82.1 | 107.3 | -- | 83.2 | | | |
| 81 North | 95-103 | 97.5 | 82.6 | 79.7 | 97.5 | 82.1 | 81.1 | 98.3 | 84.3 | 83.2 | 97.4 | 82.1 | 78.9 | These | | |
| Bristol ² | ≥ 104 | 107.2 | 87.1 | 87.1 | 107.1 | 83.7 | 83.2 | 107.2 | 90.4 | 90.4 | 106.2 | 79.8 | 82.4 | | | |
| 81 North | 79-87 | 83.8 | 60.7 | -- | 84.0 | 61.6 | 54.9 | 84.2 | 66.3 | 65.3 | 83.0 | 62.0 | 58.4 | Sites | | |
| Abingdon ² | ≥ 88 | 94.8 | 62.4 | -- | 93.8 | 64.4 | 56.3 | 95.4 | 70.5 | 68.1 | 94.6 | 62.6 | 60.0 | | | |
| 81 South | 95-103 | 98.0 | 71.3 | 72.9 | 98.2 | 74.8 | 75.3 | 97.8 | 72.7 | 73.9 | 98.0 | 71.9 | 74.8 | 98.0 | 71.3 | 73.5 |
| Abingdon | ≥ 104 | 106.9 | 74.2 | 76.6 | 106.2 | 82.6 | 81.4 | 106.8 | 73.7 | 73.9 | 106.4 | 71.8 | 75.3 | 107.1 | 76.6 | 76.6 |
| 64 East | 95-103 | 99.1 | 93.8 | 93.8 | 98.5 | 88.4 | 85.8 | 99.3 | 91.6 | 92.7 | 99.5 | 88.5 | 85.3 | 99.1 | 89.3 | 88.5 |
| Shadwell | ≥ 104 | 107.5 | 95.8 | 95.4 | 107.5 | 94.1 | 88.0 | 107.8 | 97.8 | 98.5 | 106.7 | 89.0 | 85.8 | 106.7 | 93.5 | 91.6 |

1 km = 0.6 mi.

¹ Two lanes open.

² Reduced to 72.4 km/hr.

-- Indicates that speeds were incalculable because a problem was encountered with the videotapes and travel times were unavailable.

reach Station 3 suggests that the CMS had a positive impact on reducing speed variance.

Figures 4 and 5 show the average and 85th percentile speeds calculated for the high-speeding vehicles (using the camera data) at the work zone on I-81 South at Buffalo Gap. This site was chosen to illustrate some of the trends that were observed at nearly all of the sites. The graphs in Figure 4 show that vehicle speeds reduced at Stations 2 and 3 for all of the messages that were used on the CMS. In addition, the messages HIGH SPEED SLOW DOWN and YOU ARE SPEEDING SLOW DOWN appear to have had a greater impact on vehicle speeds than the other two messages. Figure 5, which illustrates the 85th percentile speeds at this site, confirms this finding.

As shown in Figure 5, the 85th percentile speeds did decrease for all of the messages; however, the two messages mentioned previously were more effective in that they reduced these speeds to values that were *at or below the posted speed limit*.

ANOVA Results

Before these results are presented, it should be noted that the data for the work zone at I-81 North in Abingdon could not be used in the analysis, as this was the only study site where the normal speed limit of 104.6 km/hr (65 mi/hr) was reduced to 72.4 km/hr (45 mi/hr), and these data could not be compared with the data for the remaining sites as they were all reduced from 104.6 km/hr to 88.5 km/hr (65 to 55 mi/hr).

Camera Data

The average and 85th percentile speeds at Stations 2 and 3 were tested, and no significant difference was found between any of the messages with regard to these statistics. Based on the results of all of the tests, which indicated that there was no significant difference at $\alpha = .05$ among the average and 85th percentile speeds for the four different messages, Null Hypotheses 1 and 2 were not rejected for both Station 2 and station 3 speed comparisons.

Whole Population Data

In the first set of tests, ANOVA was used to determine whether there were significant differences in the data obtained when the data collection team was present and not present at the work zone. At a significance level of $\alpha = .05$, it was found that there was no difference in the average speeds, 85th percentile speeds, and speed variances at either Station 2 or 3 under the two different conditions. In light of these results, the presence of the data collection team was not considered a bias in favor of the CMS when judging its effectiveness. Null Hypotheses 3 through 6 were therefore not rejected for each of the speed characteristics at both Stations 2 and 3.

The results of the ANOVA conducted to assess the effect of each message on speeds as compared with speeds when not using the CMS indicate that the messages YOU ARE SPEEDING SLOW DOWN and HIGH SPEED SLOW DOWN are the most effective

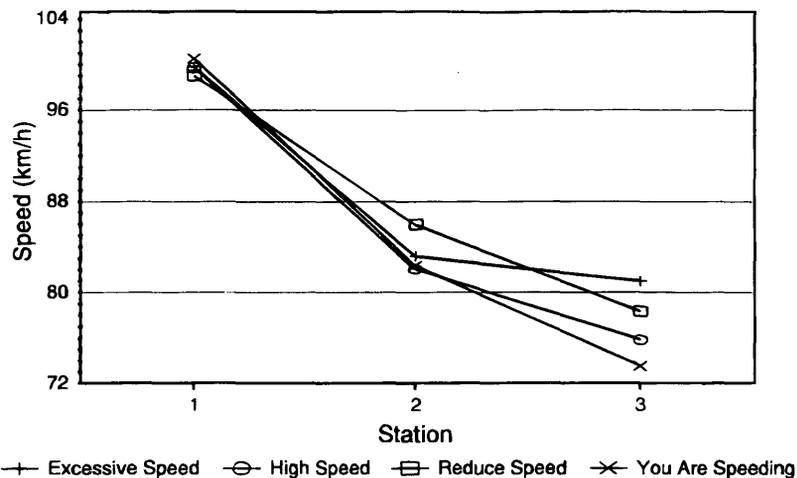


FIGURE 4 Average speeds calculated from camera data for I-81, South Buffalo Gap (threshold speed limit = 93.3 km/hr; posted speed limit = 88.5 km/hr; 1 km = 0.6 mi).

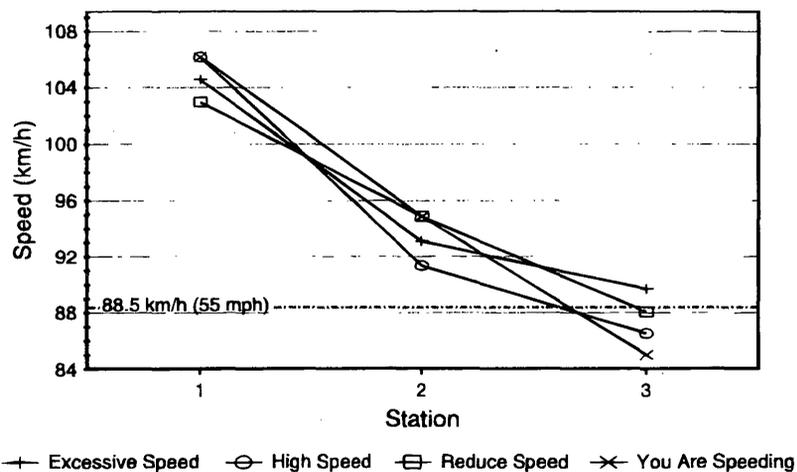


FIGURE 5 85th percentile speeds calculated from camera data for I-81, South Buffalo Gap (threshold speed limit = 93.3 km/hr; posted speed limit = 88.5 km/hr; 1 km = 0.6 mi).

of the four messages. They both show a significant reduction in average speeds at Stations 2 and 3 with the use of the CMS. Null Hypotheses 8 and 10 were therefore rejected for average speeds at both Stations 2 and 3.

Each of the remaining two messages had significant differences at one station only. For the message EXCESSIVE SPEED SLOW DOWN, there was a significant difference in average speeds at Station 3, and for REDUCE SPEED IN WORK ZONE, the significant difference in speed was at Station 2. These results might indicate that drivers are not responding to the messages in a consistent manner. In other words, the messages may not be as influential or forceful as the first two messages or make as strong an impression on all drivers as desired. For example, in using the message REDUCE SPEED IN WORK ZONE, there is a significant reduction in average speeds between Stations 1 and 2, but speeds rise

again before the end of the work zone. This occurrence suggests that the message may not have had a lasting impression on drivers as they traveled through the work zone. Based on these results, Null Hypothesis 7 for average speeds was rejected only at Station 3, and Null Hypothesis 9 for average speeds was rejected only at Station 2.

The results also show that all of the messages are effective in reducing the 85th percentile speeds of vehicles traveling through the work zone. When compared with the 85th percentile speeds for the control condition without the CMS, all of the differences were found to be significant at $\alpha = .05$. Thus, Null Hypotheses 7 through 10 were rejected for 85th percentile speeds.

For comparisons of speed variance between no CMS and the four messages, EXCESSIVE SPEED SLOW DOWN was the only message that did not have significant differences in variance at Stations 2 and 3. Thus, Null Hypothesis 7 was not rejected for speed

variance at both stations. When all of the results thus far are considered together, this message appears to be the least effective of the group. The remaining three messages were effective in significantly reducing speed variance when compared with conditions when the CMS was not in use. Thus, Null Hypotheses 8 through 10 were rejected for speed variance at both Stations 2 and 3.

The results of the comparisons of the percentage of vehicles speeding by any amount confirm the trends that were illustrated in the earlier results. All of the messages were effective in reducing the total number of speeding vehicles. Null Hypotheses 7 through 10 were therefore rejected for the percentage of vehicles speeding by any amount at both Stations 2 and 3.

CONCLUSIONS

The following conclusions are made based on the literature search and the results of the analyses.

- The changeable message sign with a radar unit is a dynamic speed control measure that is more effective than the static MUTCD signs in altering driver behavior in work zones. The use of personalized messages to the high-speed drivers makes these drivers more inclined to reduce vehicle speeds in these zones.
- Upon testing the CMS at seven sites on interstate highways in the state of Virginia, it was found that the CMS is an effective means of reducing vehicle speeds and speed variance, thereby increasing safety in work zones.
- When directly compared, it was found that there were no significant differences between the four messages with regard to their effect on high-speed vehicles as well as the whole population.

RECOMMENDATIONS

The CMS with radar unit is recommended as an effective speed control device to be used in work zones on interstate highways. In addition to reducing speeds, it is also effective in reducing speed variance, which could result in overall safer conditions in the work zone.

The following guidelines are suggested for using the CMS:

- The threshold speed should be set at approximately 3 mi/hr over the posted speed limit to warn drivers that they are exceeding the safe speed in the area.

- The CMS should be placed just before the beginning of the transition area, unobstructed by other signs so that it may be easily read and obtain drivers' full attention.

- When there is a taper and traffic is funneled into a single lane, it is suggested that the CMS be placed so the radar will detect only one vehicle at a time and the display be seen clearly by that one vehicle. If more than one lane of traffic is allowed through the activity area, the CMS should be placed so that drivers on both lanes can easily see the display board.

- The message **YOU ARE SPEEDING SLOW DOWN** is recommended for the display as it obtained the best response from the driving public. **HIGH SPEED SLOW DOWN** may also be used and will obtain virtually the same results.

- This study determined that the CMS is effective in work zones for short term applications, up to 1 week at a time. To assess its effectiveness for longer periods, it is recommended that a similar study be carried out to determine its effectiveness in long-term applications.

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