Determining the Effectiveness of PCMS on Reducing Vehicle Speed in Rural Highway Work Zones

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ABSTRACT
Due to the rising needs in highway maintenance and construction, the number of work zones is increasing throughout the United States. Highway work zones disrupt normal traffic flow and create safety problems. With a total of 1,010 fatalities and more than 40,000 injuries in the work zones in 2006, more improvements in safety are needed. The objective of this research project was to measure the effectiveness of a Portable Changeable Message Sign (PCMS) in reducing vehicle speeds in the upstream of the one-lane, two-way work zones on rural highways. The effectiveness of the PCMS was evaluated under three different conditions during field experiments: (1) PCMS switched on; (2) PCMS switched off, but still visible; (3) PCMS removed from the road and out of sight. Based on the data analysis results, the authors concluded that the presence of PCMS was effective in reducing the vehicle speeds in these work zones. The major contribution of this research project was to quantify the effectiveness of PCMS in rural one-lane, two-way work zones which had previously not been studied in detail.

INTRODUCTION

Across the United States, most highways in the nation's highway system need maintenance; it is inevitable that more work zones will appear on the highways. Work zones on highways create serious disruptions in the normal traffic flow and result in major inconveniences for the traveling public. Since the 1960s, researchers have been studying work zone safety (*1*). A significant number of relevant studies have been published to unveil safety problems and propose safety improvements in work zones (*2*). Over the last 10 years, the annual number of people killed in motor vehicle crashes in work zones has increased by 45% (up to 1,010 in 2006) (*3*). In addition, more than 40,000 people are injured each year due to motor vehicle crashes in work zones (*3*).

With the growth of technology, the use of new traffic control devices and adapting to new procedures have improved work zone safety; nevertheless, crashes still occur in highway work zones. Some factors have been extensively cited as the main causes of traffic crashes in highway work zones, including excessive vehicle speeds, variation of speeds between different vehicles, and driver inattention and erratic maneuvers (*4-13*). Researchers are most concerned with reducing traffic speeds in work zones, and believe a reduction in speed will ultimately be most effective for reducing crashes and fatalities (*5*). Until recently, static regulatory and advisory signage had been utilized in the work zones; however, these types of signage are known to be minimally effective in decreasing the number of crashes (*8*). As a result, the signage system needs to be enhanced and studies of the speed control measures have been conducted. Previous research shows that work zone speeds can be controlled in a number of ways including: 1) police presence; 2) changeable message signs; 3) rumble strips; 4) drone radar; 5) radar activated speed trailers; 6) temporary traffic control devices; and 7) increased fines. In addition, these speed control methods could prevent common human errors that can lead to severe crashes such as overlooking traffic control devices, careless driving, following too closely, exceeding the speed limit, or driving too fast for work zone conditions. This paper reports the results of a field study conducted on rural highway work zones to evaluate the effectiveness of a Portable Changeable Message Sign (PCMS) on reducing vehicle speeds under three conditions: (1) PCMS switched on; (2) PCMS switched off, but still visible; (3) PCMS removed from the road and out of sight.

LITERATURE REVIEW

According to the Manual on Uniform Traffic Control Devices for streets and highways, a Changeable Message Sign (CMS) is a sign that is capable of displaying more than one message and can be changed manually or by remote or automatic control (*14*). Such kind of the sign is referred to as the Dynamic Message Sign (DMS) in the national intelligent transportation systems (ITS) architecture. A DMS is commonly used to indicate road information to drivers such as traffic flow, weather, speed limits, individual speed, alternative-route guidance systems, and conditions of the highway. A DMS can also be referred to as a PCMS if the device is portable and easily transferred from one location to another.

Richards and Dudek (1985) proposed the implementation of CMS as a speed control device in the work zones. They outlined the advantages and disadvantages of CMS based on the results of field studies and observations at numerous street and highway work zones in Texas. On average, the vehicle speeds were reduced by 7 mph by utilizing the CMS in urban arterial and rural freeway (*15*). Since then, a few research projects have been conducted to evaluate the effectiveness of CMS. Previous research projects reported in the literature using CMSs to improve work zone safety were briefly reviewed as follows.

Zech et al. measured the effectiveness of three commonly used CMS messages in reducing vehicle speeds and variance in highway work zones (*5*). The results of their research showed that properly selected CMS messages could significantly reduce speeds of all classes of vehicles in highway work zones. Researchers conducted a field study on Interstate 90 in western New York State and evaluated the speed measurements of nearly 180,000 vehicles. The three types of CMS messages tested were: (1) RIGHT|LANE|CLOSED ~ KEEP|LEFT; (2) WORK ZONE|MAX SPEED|45 MPH ~ BE|PREPARED|TO STOP; and (3) LEFT|LANE|CLOSED ~ KEEP|RIGHT. Of the three CMS messages tested, the second CMS message proved the most effective and significantly reduced vehicle speeds by 5.3-10.8 km/h (3.3-6.7 mph).

Dixon and Wang studied the potential of a CMS with radar for reducing speeds in highway work zones in Georgia. The research team collected speed data at the upstream of the work zone, in the advance warning area, and adjacent to the active work area before and after the installation of the CMS with radar. Data analysis results indicated that the CMS with radar significantly reduced vehicle speeds by 6 to 7 mph in the immediate vicinity of the sign and was not sensitive to a novelty effect (*17*).

Pesti and McCoy evaluated the long-term effectiveness of speed monitoring displays (SMDs) at two work zones on Interstate 80 in Nebraska. The SMDs were found to be effective in lowering mean speeds by 3 to 4 mph. Other improvements included 2 to 7 mph reduction in 85th percentage speed and a 20- to 40-point increase in the percentage of vehicles complying with the speed limit (60 mph) over a 5-week period (*18*).

Fontaine and Carlson evaluated the effectiveness of speed displays and the portable rumble strips in reducing vehicle speeds. The field studies were conducted in four sites in the Childress District in Texas. All four sites were rural-maintenance work zones on low-volume, two-lane roads with 112.7 km/h (70 mph) speed limits. Fontaine and Carlson found that the speed display effectively reduced vehicle speeds. Passenger car speeds were between 3.2 and 14.5 km/h (2 and 9 mph) lower in the advance warning area of the work zone than with only normal traffic control devices present. Also, the speed displays appeared to produce a greater speed reduction in commercial trucks than in passenger cars. Speeds were 4.8-16.1 km/h (3-10 mph) lower with the speed display for trucks in the advance warning area of the work zone (*8*).

Garber and Srinivasan conducted a research project using a CMS equipped with a radar unit on highways in Virginia. The CMS was placed within the work area at the beginning of the lane taper. Four different messages were evaluated during the course of the study, and researchers found that the message "YOU ARE SPEEDING. SLOW DOWN" was the most effective. They also concluded that the CMS equipped with a radar unit was effective for work zones with long durations (*19*).

Garber and Patel evaluated the effectiveness of the CMS with a radar unit in reducing speeds at seven work zones on two interstate highways in Virginia. The results indicated that the CMS with radar reduced the speeds of speeding drivers by 6 mph (*20*). McCoy et al. conducted a similar research project using the CMS at a work zone on an interstate highway in South Dakota. Analysis results indicated that mean speeds were reduced by 6 to 8 km/hr (4 to 5 mph), and the percentages of vehicles exceeding the advisory speed limit of 72 km/hr (45 mph) were reduced by 20 to 40 percentage points (*21*).

Benekohal and Shu observed the effectiveness of placing a single CMS in the advance area of work zones. Although the speed reductions were statistically significant in general, they were not practically significant for truck-speed reduction (*22*). Ullman evaluated the effectiveness of using a radar transmission sign to reduce vehicle speeds. Results showed that the installation of

the sign reduced speeds by 4.82 km/h (3 mph) on average and had a greater effect on commercial trucks than cars (*23*).

In summary, since 1985, several research projects have been conducted to evaluate the effectiveness of CMS based on the mean speed reduction, 85th percentile speed reduction, and the percentage of vehicles complying with the speed limit. Analysis results indicated that the CMS was effective in reducing vehicle speeds and increasing the percentage of drivers complying with the speed limit posted in the work zones. However, most of the previous studies were performed in the interstate highways. In addition, the vehicle speed reduction per certain distance (e.g., speed reduction per 500 feet) was not measured in the most of previous studies, which was important information for the traffic engineers to design the work zone layout.

OBJECTIVES AND SCOPE

The primary objective of this research was to determine the effectiveness of a PCMS in reducing vehicle speeds in the upstream of one-lane, two-way work zones on rural highways, which have not been studied in detail. Three different conditions were designed for the field experiments including: (1) PCMS switched on with the message "Slow Down;" (2) PCMS switched off, but still visible; and (3) PCMS removed from the road and out of sight.

The research team conducted the experiments in two one-lane, two-way rural highway work zones located on US-36 and US-73 in Kansas. The traffic volumes for US-36 and US-73 were 3,630 volumes per day (vpd) and 3,400 vpd, respectively. Both US-36 and US-73 had a statutory speed limit of 104.6 km/h (65 mph) and a posted work zone speed limit of 72.4 km/h (45 mph). The roadway surfaces were being paved during the construction operations. While construction operations were underway, the two lane highways were reduced to one-lane, two-way work zones that required temporary traffic signs, flaggers, and a pilot car to coordinate vehicles entering and leaving the work zones.

DATA COLLECTION

The free-flow vehicle speeds were collected at the upstream of the work zones by using two speed measurement sensor systems (SmartSensor HD Model 125) from 9:00 a.m. to 5:00 p.m. during a two-week period in June 2008. The sensor systems are capable of collecting vehicles' speed up to ten lanes and use microwave radar technology to detect speeds with minimal influence from environmental conditions. Sensors were mounted on a 3.6 meter (12 feet) tall tripod which was installed 2.4-3.6 meters (8-12 feet) away from the traffic lane. This distance provided a relatively safe lateral clearance for the sensor systems and the researchers away from passing traffic. In addition, this distance also complied with the manufacturer-recommended installation requirements. Field tests showed that this installation configuration enabled accurate speed collection, especially when the speeds of the passing vehicles were greater than 32.2 km/h (20 mph). Figure 1 shows the setup of one sensor system in a work zone and Figure 2 presents the PCMS used in the field experiments.

FIGURE 1 The sensor system for vehicle speed measurement

FIGURE 2 The PCMS used in field experiments

In order to determine the speed change of the vehicles, two sensor systems were utilized. The first system (Sensor 1) was installed 320 meters (1,050 feet) away from the first temporary traffic sign (TTS) with the message *Road Work Ahead*. The second system (Sensor 2) was

installed 168 meters (550 feet) away from the first TTS. The *Road Work Ahead* Sign was about 457 meters (1,500 ft) away from the actual beginning of the lane closure. Both sensors were utilized to measure vehicle speeds at the upstream of the work zones. The PCMS was located between the two sensors and was positioned 70 meters (200 feet) away from Sensor 2. The layout of the sensors, PCMS, and the first TTS are showed in Figure 3. This layout was used for experiments 1 (PCMS ON) and 2 (PCMS OFF, but still visible). Similarly, for experiment 3 (PCMS absent) the layout remained the same except there was no PCMS present as shown in Figure 4.

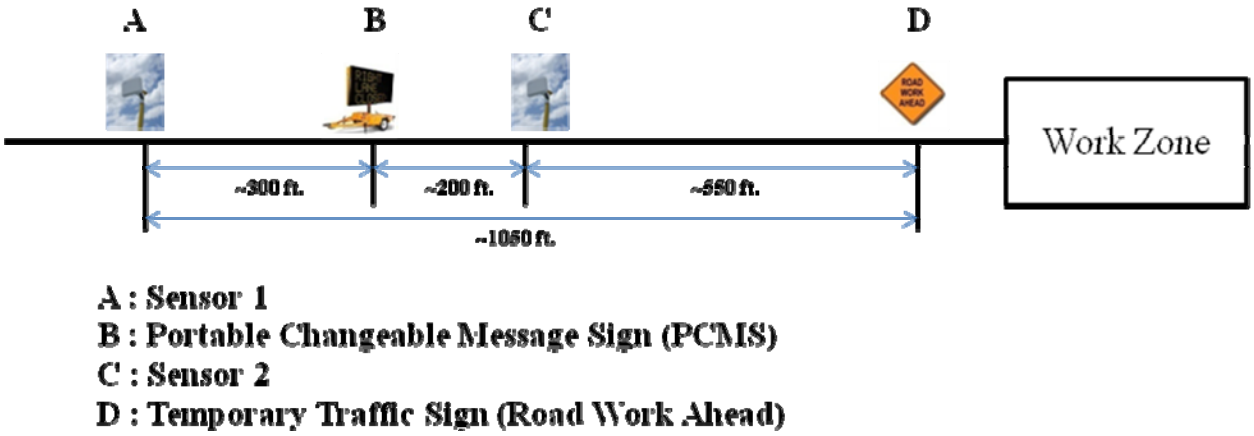

FIGURE 3 Site layout for experiments 1 and 2

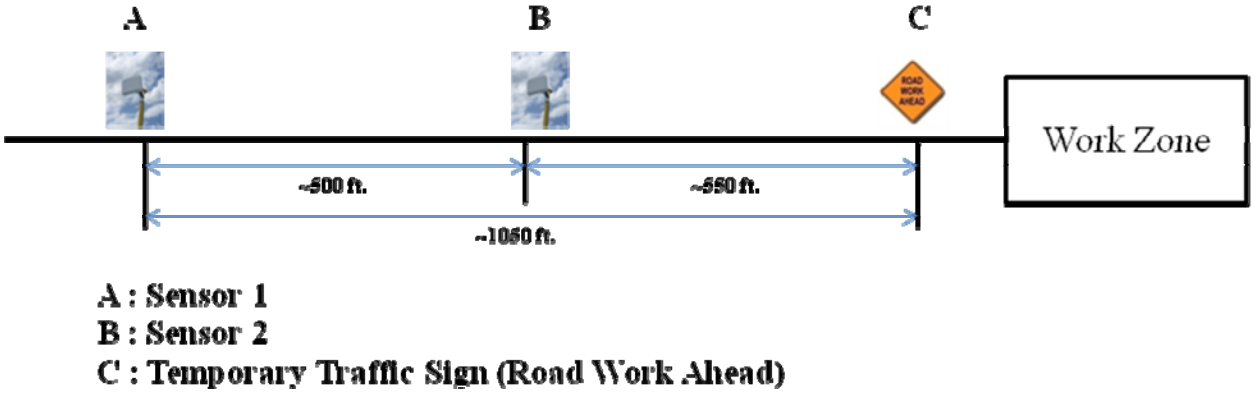

FIGURE 4 Site layout for experiment 3

A complete experimental trial occurred when both sensors successfully collected the speed of a vehicle at the sensor locations during the experiment. A total of 976 vehicle speed data were collected including passenger cars and trucks. Of these, 358 speed data were collected with the PCMS switched on, 435 were collected with the PCMS switched off, and 183 were collected when the PCMS was removed from the highway. Table 1 shows the list of data collected from two work zones in June 2008. Field experiments were started in the US-36 (a short-term work zone project). When the construction work finished in the US-36, researchers were only able to

collect 31 data for the Without PCMS situation. Clearly, 31 data were not enough to do the statistical analysis. Thus, additional data were collected in a work zone at the US-73, a nearby highway identical to the US-36. This was a situation (construction progress) that researchers had no control when they conducted the field experiments.

TABLE 1 Numbers of Speed Data by Different Experimental Conditions

Work Zone	Daily Traffic Volumes	Speed Limit (mph)	PCMS ON	PCMS OFF	Without PCMS
US-36	3,630	65	358	435	31
US-73	3,400	65	0	0	152
Total			358	435	183

DATA ANALYSIS

The effectiveness of the PCMS was measured based on the correlation of the vehicle speed change or the difference in speed between Sensor 1 and Sensor 2 under the three conditions. The tasks that were accomplished in the analyses of speed data include: (1) analyses of the vehicle speed difference between Sensor 1 and Sensor 2 when the PCMS was turned on and off; (2) a comparison of the change in vehicle speed when the PCMS was on and when the PCMS was removed from the highway; and (3) a comparison of the change in vehicle speed when the PCMS was off and when the PCMS was absent.

The sensor systems produced raw data files in a text file format (.txt file) and classified the data by lanes, length of vehicle, speed, vehicle class, range, date, and time as shown in Figure 5. Researchers sorted the data collected from Sensors 1 and 2 based on the individual vehicle. The data collected for each experimental condition followed a normal distribution pattern based on the results of the Kolmogorov-Smirnov Test. Figures 6, 7, and 8 show the graphs of the normally distributed data for each condition.

```
#######################################################################
#                                                                     #
#             DATE          : June 03, 2008                           #
#             SERIAL NUMBER: SS125 U100000378                         #
#             DESCRIPTION   : SS125 ITS Radar                         #
#             LOCATION      : US-36                                   #
#             ORIENTATION   : North                                   #
#_____________________________________________________________________#
#           |         |        |        |        |      SENSOR TIME    #
# LANE      | LENGTH  | (MPH)  | CLASS  | RANGE  | YYYY-MM-DD HH:MM:SS.sss #
#           |         |        |        |        |                     #
#######################################################################
  LANE_01       76      48       4       36     2008-06-03 10:28:50.200
  LANE_01       45      38       3       35     2008-06-03 10:30:35.195
  LANE_01       20      37       2       37     2008-06-03 10:31:30.457
  LANE_01       21      47       2       38     2008-06-03 10:31:48.408
  LANE_01       22      49       2       37     2008-06-03 10:31:56.469
  LANE_01       19      46       1       37     2008-06-03 10:33:07.094
```

FIGURE 5 Example of the text file.

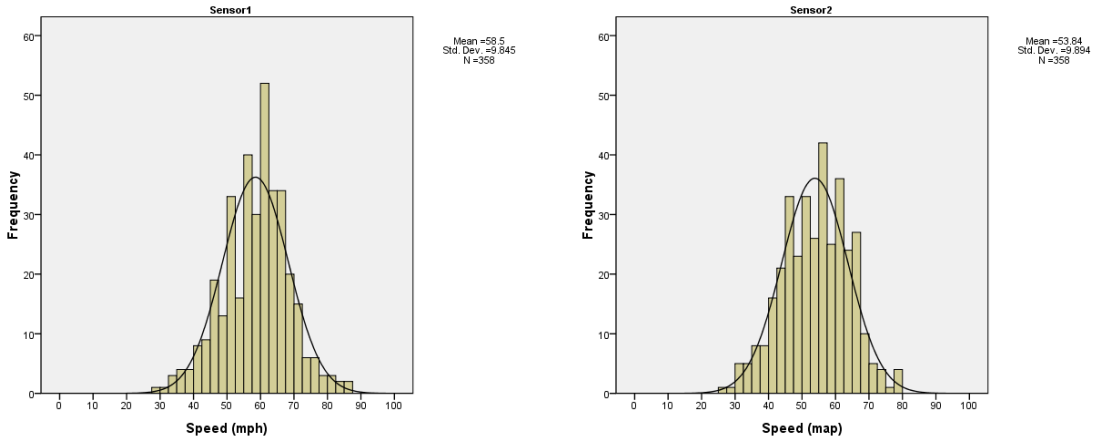

FIGURE 6 Speed data distributions of Sensors 1 and 2 with PCMS on

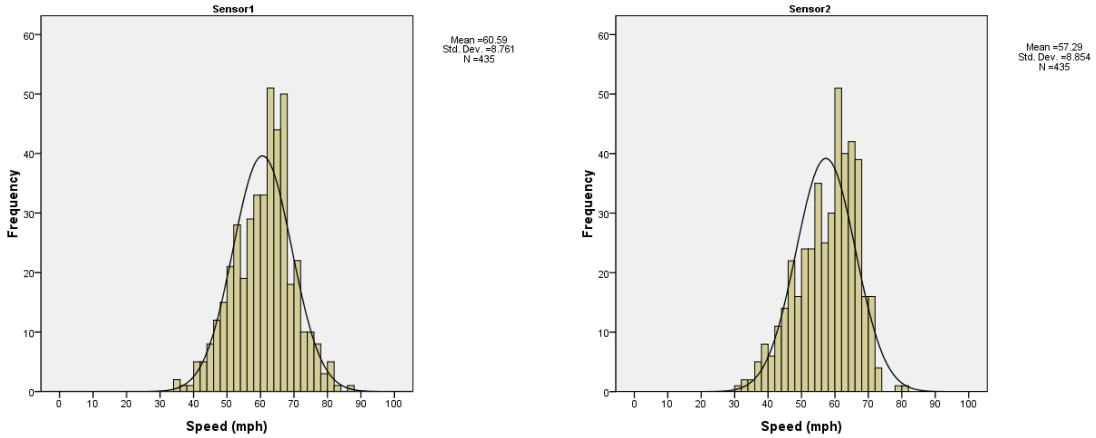

FIGURE 7 Speed data distribution of Sensors 1 and 2 with PCMS off

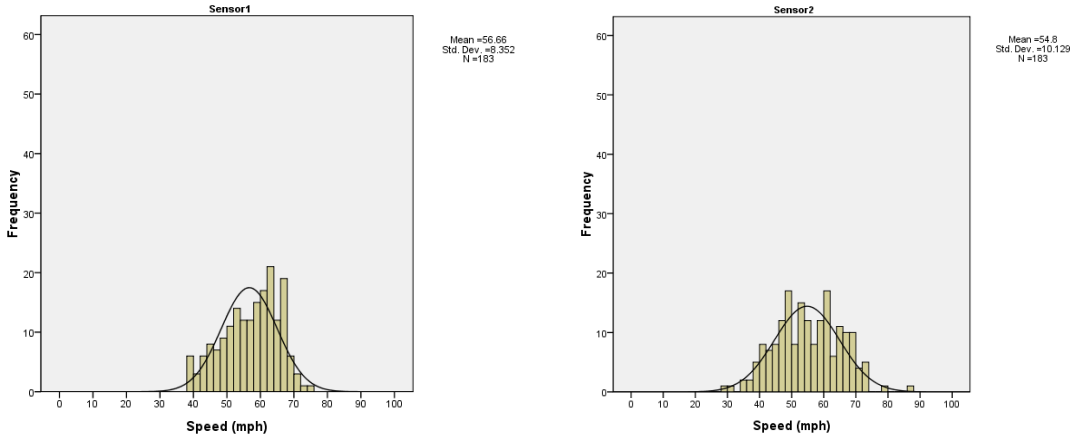

FIGURE 8 Speed data distribution of Sensors 1 and 2 without PCMS

A statistical software package, SPSS (Statistic Package for Social Science), was used to calculate the statistical values of all the data including the mean and standard deviation. The

average vehicular speed reduction from the position of Sensor 1 to the position of Sensor 2 (over 500 feet) is displayed in Table 2.

TABLE 2 Average Speed Reduction from Sensor 1 to Sensor 2

Conditions	Sample Size	Mean Sensor 1	Std. Dev. Sensor 1	Mean Sensor 2	Std. Dev. Sensor 2	Speed Reduction from Sensor 1 to Sensor 2 (mph)
PCMS ON	358	58.5	9.8	53.8	9.9	4.7
PCMS OFF	435	60.6	8.8	57.3	8.8	3.3
Without PCMS	183	56.7	8.4	54.8	10.1	1.9

In addition to the comparison analyses mentioned above, three null hypotheses (H_0) and alternative hypotheses (H_1) were defined. The null hypotheses and the alternative hypotheses tested are as follows:

(Case 1)

$$H_0 : (\mu_{O1} - \mu_{O2}) \leq (\mu_{F1} - \mu_{F2})$$
$$H_1 : (\mu_{O1} - \mu_{O2}) > (\mu_{F1} - \mu_{F2})$$

(Case 2)

$$H_0 : (\mu_{O1} - \mu_{O2}) \leq (\mu_{N1} - \mu_{N2})$$
$$H_1 : (\mu_{O1} - \mu_{O2}) > (\mu_{N1} - \mu_{N2})$$

(Case 3)

$$H_0 : (\mu_{F1} - \mu_{F2}) \leq (\mu_{N1} - \mu_{N2})$$
$$H_1 : (\mu_{F1} - \mu_{F2}) > (\mu_{N1} - \mu_{N2})$$

where μ_{O1} or μ_{O2} = mean vehicle speed at Sensor 1 or Sensor 2 when the PCMS was on (PCMS ON); μ_{F1} or μ_{F2} = mean vehicle speed at Sensor 1 or Sensor 2 when the PCMS was off (PCMS OFF); and μ_{N1} or μ_{N2} = mean vehicle speed at Sensor 1 or Sensor 2 when the PCMS was removed from the highway (Without PCMS). If the probability of the three conditions was below the threshold at a statistical level of significance of 5 percent, then a null hypothesis (H_0) was rejected in favor of an alternative (H_1) hypothesis.

The normally distributed speed data and equality variances allowed researchers to test the significances using the t-test for each case. Utilizing the independent two-sample t-test in the SPSS software to calculate the p-values, results were 0.002 for the first case, 0.000 for the second case, and 0.005 for the third case. Table 3 shows the computed values generated by SPSS. These values were significantly less than 0.05. As a result, researchers concluded that all three null hypotheses were confidently rejected. Thus, all three alternative hypotheses were statistically true.

TABLE 3 Results of Independent Two-Sample T-Test

Cases	p-values	Effectiveness? α = 0.05
1	0.002	YES
2	0.000	YES
3	0.005	YES

CONCLUSIONS

Highway statistics data indicate that a majority of the public roadways are rural and most of the major rural roadways (interstates, principal and minor arterials, and major collectors) are two-lane highways in the United States. Preserving, rehabilitating, expanding, and enhancing these highways require the assembly of a large number of one-lane, two-way work zones. This research project evaluated the effectiveness of a PCMS in reducing vehicle speeds on one-lane, two-way work zones on rural highways under three different situations: (1) PCMS switched on; (2) PCMS switched off, but still visible; and (3) PCMS removed from the road and out of sight. The findings of this research project provided valuable information for traffic engineers to design the work zone layout.

The research results revealed that the PCMS was effective in reducing vehicle speeds in the studied work zones. The PCMS turned on was significantly more effective than the PCMS turned off or was absent. The results also indicated that the PCMS, whether turned on or off, was significantly more effective than the PCMS was absent from the highway. When the PCMS was turned on, vehicle speeds were reduced by 7.6 km/h (4.7 mph) over a distance of 152.4 meters (500 foot). When the PCMS was turned off but still on the road, vehicle speeds were reduced by 5.3 km/h (3.3mph) over a distance of 152.4 meters (500 foot). When the PCMS was absent from the road, a mere 3.1 km/h (1.9 mph) speed reduction occurred over a distance of 152.4 meters (500 foot). In addition, three two-sample t-tests indicated that the speed reductions were statistically significant. Based on the results of the data analyses, researchers concluded that a visible and active PCMS in work zones will significantly reduce the speeds of vehicles approaching the work zones. A slower vehicular speed allows for greater reaction time to avoid crashes, and potentially creates a safer environment for drivers and workers in the work zones.

The major finding of this project, which was that the PCMS was effective in reducing vehicle speeds, was in line with the outcomes from previous research projects. However, most of the previous studies were conducted in the interstate highways. This project was performed in one-lane, two-way work zones on rural highways. In addition, since two speed detection sensors were used at the same time, researchers of this project were able to measure the speed reduction over certain distance (e.g., speed reduction per 500 feet), which were not analyzed in the previous studies.

There was a weakness in the field experiments for this research project, which was that the Without PCMS data were collected from two work zones located on the US-36 and the US-73, respectively. Field experiments were started in US-36 (a short-term work zone project). When the construction work finished in US-36, researchers were only able to collect 31 data points for the Without PCMS situation. Clearly, 31 data were not enough to conduct the statistical analysis. Thus, additional data were collected in a work zone at US-73, a nearby highway identical to US-36. Although researchers had no control on the construction progress when they conducted the field experiments, there is a need to improve the quality of data by collecting the vehicle speed data from the same work zone in the future research.

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