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Title: **Effect of Condition-Responsive, Reduced-Speed-Ahead Messages on Speeds in Advance of Work Zones on Rural Interstate Highways**

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## ABSTRACT

Condition-responsive, reduced-speed-ahead messages were evaluated as part of the Midwest States Smart Work Zone Deployment Initiative, a pooled-fund study sponsored by Iowa, Kansas, Missouri, Nebraska, and the Federal Highway Administration. The messages were displayed on three portable changeable message signs (PCMSs) placed approximately 1, 3, and 8 miles in advance of a work zone on rural interstate highway in Nebraska. The messages were intended to advise drivers of the speed of slower traffic ahead and thereby encourage them to slow down. Speeds downstream of the PCMSs were measured and compared to the speeds displayed in the messages. The results of the analysis indicated that the messages were somewhat effective in reducing speeds. It was concluded that their effectiveness could have been improved if the distances between the PCMSs had been shorter so that the locations where the messages were displayed would have been closer to the points where traffic speeds were actually lower. Driver interviews revealed that the reduced-speed-ahead messages were understood and thought to be useful by most drivers who recalled seeing them. However, some drivers questioned their usefulness and doubted their reliability, because they hadn’t seen any reason to slow down.

key words: work zones, speed control

## INTRODUCTION

A primary safety concern associated with work zones on rural interstate highways is the increased crash potential when congestion occurs on the approach to a work zone. Depending on the traffic volume and capacity of the work zone, the queue of slow-moving or stopped vehicles caused by the congestion may extend rapidly upstream creating a high speed differential between the end of the queue and approaching traffic. The unexpectedly sudden encounter with congestion often makes it very difficult for some drivers to safely reduce their speeds and avoid colliding with other vehicles as they approach the end of the queue.

Condition-responsive, work zone traffic control systems are available to address this problem. These systems detect the presence of slow-moving or stopped traffic on the approach to the work zone and provide advance warning to drivers via portable changeable message signs (PCMS), highway advisory radio (HAR), and/or flashing beacons on fixed-message signs. The messages used to convey this warning vary. Some messages simply advise drivers of the presence of slow-moving or stopped traffic ahead. Others warn drivers of the presence of slow-moving or stopped traffic and advise them to slow down or proceed with caution. Another type of message used for this purpose is a reduced-speed-ahead message, which merely tells drivers the speed of traffic ahead. The objective of the research presented in this paper was to evaluate the effectiveness of a condition-responsive, reduced-speed-ahead message in advance of a work zone on a rural interstate highway.

## STUDY SITE

The study site was a work zone on I-80 between Lincoln and Omaha, Nebraska, shown in Figure 1. The work zone was for an interstate resurfacing project, which involved the closing of one roadway for reconstruction and two-lane, two-way operation on the other roadway. The average daily traffic volume on the four-lane section of I-80 was approximately 40,000 vehicles per day with

21 percent trucks. The normal speed limit on I-80 was 75 mph, and the speed limit in the work zone was 55 mph.

The evaluation was conducted on the eastbound approach to the work zone. On this approach, the right lane was closed, reducing the two eastbound lanes of I-80 to one lane in advance of the median crossover. The traffic control plan on the approach is shown in Figure 2. It included the following sequence of signs on each side of the roadway:

1. ROAD WORK 2 MILES sign;
2. FINES FOR SPEEDING DOUBLED IN WORK ZONES sign about 9,500 feet before the merging taper;
3. SPEED LIMIT 65 sign with FINES DOUBLE sign plate about 8,500 feet before the merging taper;
4. RIGHT LANE CLOSED 1 MILE sign;
5. DO NOT PASS sign about 3,600 feet before the merging taper;
6. RIGHT LANE CLOSED ½ MILE sign;
7. REDUCED SPEED AHEAD sign about 1,500 feet before the merging taper;
8. Symbolic "lane reduction on the left" transition sign about 1,000 feet before the merging taper;
9. SPEED LIMIT 55 sign with FINES DOUBLE sign plate about 500 feet before the merging taper; and
10. DETOUR AHEAD at the beginning of the taper.

In addition to the signs, there were two flashing arrow panels. One arrow panel was located at the outside edge of the right shoulder about 4,800 feet in advance of the merging taper, and the other arrow panel was located on the right shoulder just downstream of the beginning of the merging taper. The merging taper was 900 feet long. It was delineated by reflectorized plastic drums spaced at 50-foot intervals and monodirectional yellow raised pavement markers at 5-foot centers.

**MESSAGE DEPLOYMENT**

The condition-responsive, reduced-speed-ahead messages were displayed on three PCMSs located at distances of 1.13, 3.13, and 7.83 miles in advance of the work zone. The messages were time-stamped and displayed in the following two-phase sequential format:

| Phase 1 | Phase 2 |
|---|---|
| I-80 (E)<br>ADVISORY<br>XX:XX XM | REDUCED<br>SPD AHD<br>XX MPH |

The two PCMSs farthest upstream of the work zone were blank when traffic conditions did not warrant the display of advisory speed messages. The PCMS closest to the work zone displayed the following lane closure message when it was not displaying an advisory speed message:

| |
|---|
| RIGHT<br>LANE<br>CLOSED |

The messages were deployed by means of the ADAPTIR™ system, which is a portable, condition-responsive work zone traffic control system developed by The Scientex Corporation through a cooperative agreement with the Federal Highway Administration and the Maryland State Highway Administration *(1)*. The system utilized radar sensors mounted on the three PCMSs and the arrow panel at the merging taper to continuously measure speeds at these four locations. At regular intervals (every 4 minutes during peak periods and every 8 minutes during off-peak periods), the system compared the average speeds at the four locations. Whenever the average speed at the next downstream radar sensor was found to be more than 10 mph lower than the average speed at a PCMS, the speed advisory message was displayed indicating the downstream speed rounded down to the nearest 5 mph. Otherwise, the PCMS remained blank, or in the case of the PCMS closest to the work zone, the RIGHT LANE CLOSED message was displayed.

The deployment of the PCMSs and the arrow panel is shown in Figure 3. The PCMSs were placed in the middle of median on I-80 at distances of 1.13, 3.13, and 7.83 miles upstream of the beginning of the merging taper. The spacing between the PCMSs was determined by three factors:

1. The number of PCMSs available for the purposes of the evaluation was limited to three.
2. The desire to place the PCMS, which was farthest upstream, in advance of the Highway 6 Interchange so that diversion messages could also be displayed on it when necessary.
3. The location of suitable vantage points for the radio communications between the PCMSs and the system controller.

The placement of one of the PCMSs displaying a reduced-speed-ahead message is shown in Figure 4.

## DATA COLLECTION

The data for evaluating the effect of the advisory speed messages included traffic volume, vehicle speeds and speed messages. Traffic volume and vehicle speeds were obtained by video cameras on overpasses downstream of each PCMS. The locations of the cameras and PCMSs are shown in Figure 3. The distance of the camera location downstream of each PCMS is given in Table 1. Traffic on eastbound I-80 was video taped at these locations during a 16-day period. A total of 46.5 hours of video was recorded at each camera location. The video tapes were analyzed with a video image processing system to obtain traffic counts and vehicle speeds.

Speed data measured by the radar units of the PCMSs were also used. They were available as average values over the time intervals (*i.e.*, 4 minutes during peak and 8-minutes during off-peak periods) used by the ADAPTIR™ system to evaluate traffic conditions and select the appropriate messages to be displayed. These average speeds were downloaded from the ADAPTIR™ system log.

In addition to the speed and volume data collection, drivers were interviewed at a rest area about one-half mile downstream of the work zone. The drivers were asked if they had seen the portable PCMSs. If they had seen them, they were asked to identify which messages they saw. For each message they identified, they were asked the following questions:

- Did you understand the message? If not, what was not understood?
- Was the message useful? If not, why not?
- Did the message increase your awareness of traffic conditions ahead? If not, why not?

As the survey was conducted, drivers were referred to a poster which displayed photographs of a PCMS and the messages.

## DATA ANALYSIS

Although speed data were collected before and after the installation of the ADAPTIR system, no congested periods were observed during the "before studies". All speed data collected before system installation were from free-flow conditions under which the speed messages of the PCMSs would not have been activated. Therefore, the effectiveness of the system could not be evaluated based on the before-after study results, and it was done using data from the after study period only.

Since the speed data measured by the radar units of the PCMSs were available as 4-minute and 8-minute averages, driver response to the reduced-speed-ahead messages could not be estimated by the speed changes of individual vehicles between the PCMSs and the downstream camera locations. Instead, regression equations were developed to assess the relationships between the speed messages displayed on the PCMSs and three speed parameters calculated from the speed data measured at the camera locations. The three speed parameters were the mean speed, $85^{th}$ percentile speed, and the mean speed of vehicles driving faster than the $85^{th}$ percentile speed. The intervals during which reduced-speed-ahead messages were displayed on the PCMSs were identified from the ADAPTIR™ system logs. The volumes and the three speed parameters at the downstream camera locations were then computed for the corresponding intervals, which were offset by the travel times from the PCMSs to the downstream camera locations. The travel times were estimated by dividing the distance between the PCMS and the camera by the average of the mean speeds at these two locations.

Since vehicle speeds also depend on the level of congestion, the density of traffic flow was also incorporated in the analysis. The mean density in each interval was estimated by dividing the volume by the mean speed during the interval.

A series of multiple regression analyses of the data was conducted to determine the effect of the reduced-speed-ahead messages and density on the three speed parameters. The dependent variable was one of the speed parameters for each relationship. The independent variables were the speed indicated by the advisory speed message and the density of traffic flow at the downstream camera location.

During congested flow conditions, the speed messages may appear more effective due to the combined effect of the increased density of traffic flow and driver response to the messages. It is difficult to determine what the actual contributions of these two factors are because a speed message displayed on a PCMS can often be a function of the density at the downstream camera location. However, in this particular case the density observed by a driver approaching the camera location is not the same density that occured in the moment when the driver noticed the speed message displayed on the upstrem PCMS. Depending on the travel time, the density in the vicinity of the camera location can change significantly. However, the correlation between density and speed messages was checked to avoid the existence of serious multicollinearity in the regression model.

The driver surveys were compiled. The percentages of drivers who noticed the PCMSs and the messages displayed were calculated. The percentages of drivers who understood and found the messages helpful were also computed. Reasons given by drivers for not understanding the messages, or finding them useful, were tabulated.

## RESULTS

### Speed Reduction

The reduced-speed-ahead messages were intended to warn drivers of slower traffic ahead and thus encourage, or at least prepare, them to slow down. A reduced-speed-ahead message was displayed on a PCMS whenever the speed of traffic passing by the PCMS was at least 10 mph higher than the speed of traffic at the next PCMS downstream. In the case of PCMS #1, which was closest to the work zone, the speed of traffic passing it was compared to the speed of traffic measured by the radar sensor on the arrow panel at the merging taper. The advisory speed displayed in the message was the speed (rounded down to the nearest 5 mph) at the downstream location. For example, if the average speed of traffic during the ADAPTIR™ control interval (either 4 or 8 minutes depending on the time of day) at PCMS #2 was 65 mph and the average speed of traffic at PCMS #1 during the same interval was 43 mph, a speed advisory message of 40 mph would be displayed on PCMS #2.

During the 46.5 hours of speed data collection in the 16-day collection period, a total of 323 reduced-speed-ahead messages were displayed on the three PCMSs. The frequency of the advisory speeds displayed on each PCMS is shown in Table 2. The closer the PCMS was to the work zone, the more messages it displayed. PCMS #1 displayed 130 reduced-speed-ahead messages, PCMS #2 displayed 102 reduced-speed-ahead messages, and PCMS #3 displayed 91 reduced-speed-ahead messages. The range in advisory speeds displayed was from 5 to 55 mph. The advisory speeds most frequently displayed were 20 and 25 mph. Although advisory speed messages of 50 and 55 mph were quite common. The least frequently displayed advisory speeds were 5 and 10 mph.

The 85$^{th}$ percentile speeds at the downstream camera location versus the average densities and the advisory speeds displayed are shown for each PCMS in Figure 5. Each point in the graphs corresponds to a 4-minute or 8-minute time interval when a reduced-speed-ahead message was displayed. These data suggest that the reduced-speed-ahead messages had little effect on the 85$^{th}$ percentile speeds, particularly at the camera location downstream of PCMS #3. As expected, a stronger relationship between density and 85$^{th}$ percentile speed can be observed. According to the Highway Capacity Manual (*3*), the critical density dividing uncongested and congested flow conditions is 45 vpm. Thus, a time period was considered uncongested when the average density was below 40 vpm, and congested when the density was above 40 vpm. The uncongested and congested periods are indicated with filled and empty circles, respectively.

The graphs in Figure 5 show in most cases, during uncongested flow conditions, the speed message had little or no effect on the 85$^{th}$ percentile speeds (i.e., most of the filled circles are well above the 45 degree line). However, the speed messages displayed on PCMS #1 were found to be effective in six cases under uncongested flow conditions (i.e., filled circles close or below the 45 degree line). The six cases are identified in the graph by an ellipse drawn around the points. There was only one occasion when the messages of the other two PCMSs were found effective during uncongested flow conditions.

During congested flow conditions, the apparent effectiveness of the speed messages was much better (i.e., the 85$^{th}$ percentile speeds are generally much closer to the 45 degree line), than during uncongested conditions. Note, however that this improved effectiveness is a composite effect of the speed messages and the higher density of traffic flow.

The graphs for the other two speed parameters are very similar to those shown in Figure 5, and therefore are not included among the figures.

The results of the multiple regression analysis of the data are presented in Table 3. The p-values indicate that all regression equations for the two camera locations closest to the merging taper downstream of PCMSs #1 and #2 accounted for a statistically significant amount of the variation, and the regression coefficients in each equation were statistically significant ($\alpha = 0.05$). At these locations all three speed parameters were found to be inversely related to density; the higher the density of traffic flow, the lower the speed at the camera location.

At the camera location closest to the work zone, the reduced-speed-ahead message displayed by the PCMS upstream also influenced all three speed parameters the camera location. Approximately 42 percent of the advisory speed indicated by the message was included in the mean speed actually realized. For the 85$^{th}$ percentile and the mean of the highest 15 percent speeds, it was about 20-25 percent at this location.

At the camera location downstream of PCMS #2, which was the second closest to the work zone, the speed messages did not have a statistically significant effect on any of the three speed parameters.

At the camera location downstream of PCMS #3, none of the regression equations accounted for a statistically significant amount ($\alpha = 0.05$) of the variation in the three speed parameters. Therefore it was not included in Table 3.

The regression equations indicate that the reduced-speed-ahead messages were somewhat effective in reducing speeds. The closer the PCMS was to the work zone, the more effective the messages were. PCMS #1 was 1.13 miles upstream of the work zone and within the traffic control plan in advance of the work zone. Therefore, drivers at this location should have been well aware of the work zone and very likely to perceive the need to slow down. PCMS #2 was 3.13 miles upstream of the work zone and more than one mile upstream of the first work zone sign (*i.e.*, ROAD WORK 2 MILES). However, the advance work zone signing was in full view from the camera location downstream of PCMS #2, which was less than one mile from the advance work zone signing. Therefore, at least some of the drivers should have been aware of the work zone and likely to perceive the need to slow down. PCMS #3 was 7.83 miles upstream of the work zone and more than 5 miles in advance of the first work zone sign. The camera location downstream of PCMS #3 was nearly 4 miles before the work zone. In addition, PCMS #3 was 4.7 miles upstream of PCMS #2, where the lower speeds displayed on PCMS #3 were being measured. Drivers traveling at the speed limit (75 mph) would travel nearly 4 minutes before reaching the location of PCMS #2. Therefore, many drivers may have been unaware of the work zone and not likely to perceive the need to slow down.

## Driver Survey

A total of 264 drivers were surveyed. Most (215) of the drivers were driving passenger cars, 41 were driving trucks, and eight were in recreational vehicles. Two-hundred-eighteen (218) of the drivers were male and 46 were female. Over 65 percent (175) had not driven through the work zone before, whereas 89 of the drivers said that they had. Sixty (60) of the drivers were from Nebraska. The rest of the drivers were from 35 states and Canada.

Of the 264 drivers surveyed, 209 (79 percent) saw at least one of the PCMSs. Of the 209 drivers who saw a PCMS, the number of drivers who recalled seeing the messages displayed by the

PCMSs is shown in Table 4. Also shown is the percentage of the time each message was displayed while the driver survey was conducted. For example, the speed advisory message was displayed 17 percent of the time. Therefore, one would have expected 36 (17 percent) of the 209 drivers who saw this message. The p-value in Table 4 indicate that the difference between the percentage of time the speed advisory message was displayed and the percentage of drivers seeing the message was not statistically significant.

The percentages of drivers seeing the PCMS messages, who understood the messages and thought they were useful, are shown in Table 5. The I-80 (E) ADVISORY XX:XX XM message was not understood by some drivers. They did not understand the term ADVISORY and wondered why the time of day was given. These drivers also did not believe the message was useful.

The REDUCED SPD AHD XX MPH messages was understood by nearly all drivers, who also thought it was useful. The drivers who did not understand this message wondered why the speed was lower ahead or didn't believe the message because they didn't see any reason to slow down. Therefore, these drivers did not believe the message was useful.

The meaning of a blank PCMS was only understood by 24 percent of the drivers. About 28 percent of the drivers thought it meant that the PCMS was not working. The other drivers simply didn't know what a blank PCMS meant.

## CONCLUSION

Reduced-speed-ahead messages displayed during periods of uncongested flow were not effective in reducing speeds. However, when traffic flow approached congestion levels, these messages were effective in reducing speeds at locations where drivers were aware of the presence of the work zone ahead and likely to perceive the need to slow down. Reduced-speed-ahead messages displayed on the PCMS farthest upstream of the work zone were not effective in reducing speeds, because the PCMS was too far in advance of the location of the slower speeds so that drivers did not perceive the need to slow down. Thus, the 4.7-mile spacing between the PCMS farthest upstream of the work zone and the next PCMS was too long. Also, the effectiveness of the two PCMSs closer to the work zone could have possibly been improved if the 2-mile spacing between them would have been shorter. The 1.1-mile spacing between the PCMS closest to the work zone and the arrow panel at the taper, where the speeds for its reduced-speed-ahead messages were measured, may have also been too long. It was apparent that the spacing between the PCMSs influenced the effectiveness of the messages. Further research is needed to determine the optimum spacing of the ADAPTIR PCMSs, which may vary with traffic and roadway conditions.

The I-80 (E) ADVISORY XX:XX XM message was the least-often noticed message relative to the percentage of the time it was displayed. Also, it was the message least-understood by drivers, and its usefulness was often questioned by drivers. Although it was intended to add credibility to the advisory speed message with which it was displayed, it was not seen or understood by drivers.

The reduced-speed-ahead message was understood by most drivers. However, some questioned its usefulness and doubted its reliability, because they hadn't seen any reason to slow down.

When there was no reduced-speed-ahead message to display, the PCMSs were left blank in order to preserve the primacy of messages displayed. Only about 14 percent of the drivers, who reported seeing any of the PCMSs, recalled seeing a blank PCMS. But, only about 24 percent of those seeing a blank PCMS understood what it meant. The remaining drivers thought that the PCMS was not working or simply didn't know what it meant. However, the consequences of drivers' misunderstanding blank PCMSs seem minor compared to those of drivers failing to notice real-time, condition-responsive messages because they had become accustomed to seeing some general work zone messages displayed on the PCMSs. Further research would be needed to examine the trade-offs between leaving PCMSs blank when there is no real-time, condition-responsive message to display versus displaying a general message.

## ACKNOWLEDGMENT

This paper was based on the results of Project No. SPR-3(075), *Midwest States Smart Work Zone Deployment Initiative*, which is a pooled-fund study to test and evaluate new technologies for improving the safety and efficiency of traffic operations in highway work zones *(2)*. Agencies participating in the study are the Iowa Department of Transportation, Kansas Department of Transportation, Missouri Department of Transportation, Nebraska Department of Roads, Federal Highway Administration, and University of Nebraska Mid-America Transportation Center.

## DISCLAIMER



## REFERENCES

1. *User's Manual for the Condition Responsive Work Zone Traffic Control System*, The Scientex Corporation, Arlington, Virginia, April, 9, 1997.
2. P.T. McCoy and G. Pesti, *Midwest Smart Work Zone Deployment Initiative: Technology Evaluations - Year One,* Chapter 5, Mid-America Transportation Center, University of Nebraska-Lincoln, Lincoln, Nebraska, May, 2000.
3. *Highway Capacity Manual: Chapter 3, Basic Freeway Sections*, Special Report 209, Third Edition, Transportation Research Board, National Research Council, Washington, D.C. 1998.

**TABLE 1 Camera locations.**

| PCMS | Distance Upstream of Taper (mi) | Distance To Downstream Camera (mi) |
|---|---|---|
| 1 | 1.13 | 0.76 |
| 2 | 3.13 | 0.47 |
| 3 | 7.83 | 2.07 |

**TABLE 2 Frequency of reduced-speed-ahead messages.**

| | PCMS [a] | | | |
|---|---|---|---|---|
| Advisory Speed (mph) | 1 | 2 | 3 | Total |
| 55 | 20 | 0 | 14 | 34 |
| 50 | 20 | 1 | 17 | 38 |
| 45 | 11 | 2 | 9 | 22 |
| 40 | 10 | 7 | 5 | 22 |
| 35 | 9 | 8 | 10 | 27 |
| 30 | 12 | 11 | 5 | 28 |
| 25 | 17 | 13 | 12 | 42 |
| 20 | 23 | 21 | 7 | 51 |
| 15 | 6 | 18 | 5 | 29 |
| 10 | 0 | 10 | 1 | 11 |
| 5 | 2 | 11 | 6 | 19 |
| Total | 130 | 102 | 91 | 323 |

[a] PCMS #'s 1, 2, and 3 were 1.13, 3.13, and 7.83 miles upstream of the work zone, respectively.

**TABLE 3 Regression analysis of speed parameters at camera locations.**

$$\text{Model}^{a}: \ SP = \beta_o + \beta_{SM}\, SM + \beta_D\, D$$

Camera 0.76 Mile Downstream of PCMS #1 (0.4 mile upstream of work zone)

| Speed Parameter (SP) | | $\beta_o$ | $\beta_{SM}$ | $\beta_D$ | Model | $R^2$ |
|---|---|---|---|---|---|---|
| Mean Speed | Estimate | 62.663 | 0.421 | -0.964 | | 89.1 |
| | p-value | 0.0000 | 0.0000 | 0.0000 | 0.0000 | |
| $85^{th}$ percentile speed | Estimate | 76.568 | 0.241 | -0.987 | | 89.5 |
| | p-value | 0.0000 | 0.0007 | 0.0000 | 0.0000 | |
| V-mean-upper 15% | Estimate | 79.972 | 0.206 | -0.972 | | 86.7 |
| | p-value | 0.0000 | 0.0080 | 0.0000 | 0.0000 | |

Camera 0.47 Mile Downstream of PCMS #2 (2.7 mile upstream of work zone)

| Speed Parameter (SP) | | $\beta_o$ | $\beta_{SM}$ | $\beta_D$ | Model | $R^2$ |
|---|---|---|---|---|---|---|
| Mean Speed | Estimate | 69.928 | 0 | -0.875 | | 53.8 |
| | p-value | 0.0000 | - | 0.0000 | 0.0000 | |
| $85^{th}$ percentile speed | Estimate | 78.877 | 0 | -0.877 | | 52.7 |
| | p-value | 0.0000 | - | 0.0000 | 0.0000 | |
| V-mean-upper 15% | Estimate | 80.207 | 0 | -0.788 | | 50.5 |
| | p-value | 0.0000 | - | 0.0000 | 0.0000 | |

[a] SP = speed parameter
SM = reduced-speed-ahead message at PCMS (mph);
D = density at camera location (vpm).

**TABLE 4 Drivers' recall of PCMS messages.**

| Message | Percent Time Displayed | Drivers Seeing Message | | p-Value [a] |
|---|---|---|---|---|
| | | Number | Percent [b] | |
| I-80 (E) ADVISORY X:XX XM | 22 | 12 | 6 | 0.00000000 |
| REDUCED SPD AHD XX MPH | 17 | 45 | 12 | 0.147 |
| blank | 55 | 29 | 14 | 0.00000000 |

[a] Binomial proportions test of the difference between the percent time displayed and percent of drivers seeing message.
[b] Percent of the 209 drivers who recalled seeing at least one of the PCMSs.

**TABLE 5 Drivers' understanding, and opinion of PCMS messages.**

| Message | Understood Message | | Thought Message Useful | |
|---|---|---|---|---|
| | Number | Percent [a] | Number | Percent [a] |
| I-80 (E) ADVISORY X:XX XM | 9 | 75 | 9 | 75 |
| REDUCED SPD AHD XX MPH | 43 | 96 | 43 | 96 |
| blank | 7 | 24 | - | - |

[a] Percent of the drivers who recalled seeing the message.

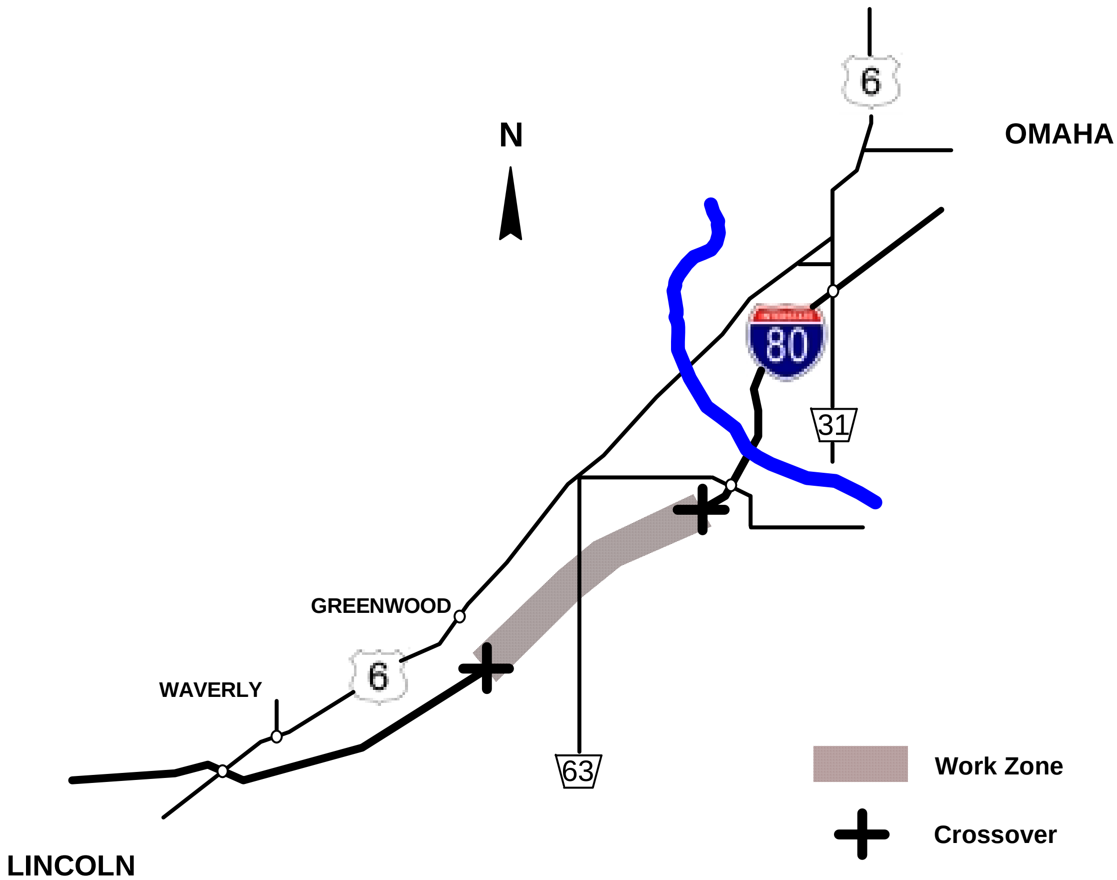


**FIGURE 1 Study site.**

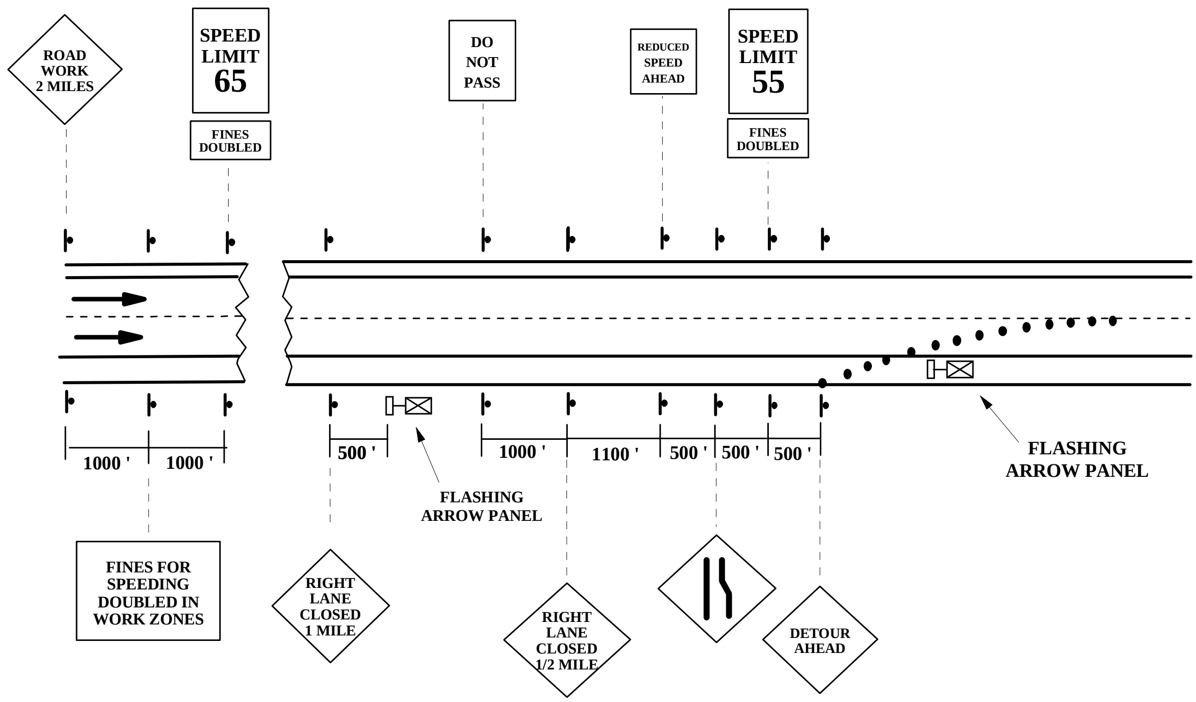


**FIGURE 2 Traffic control plan in advance of work zone.**

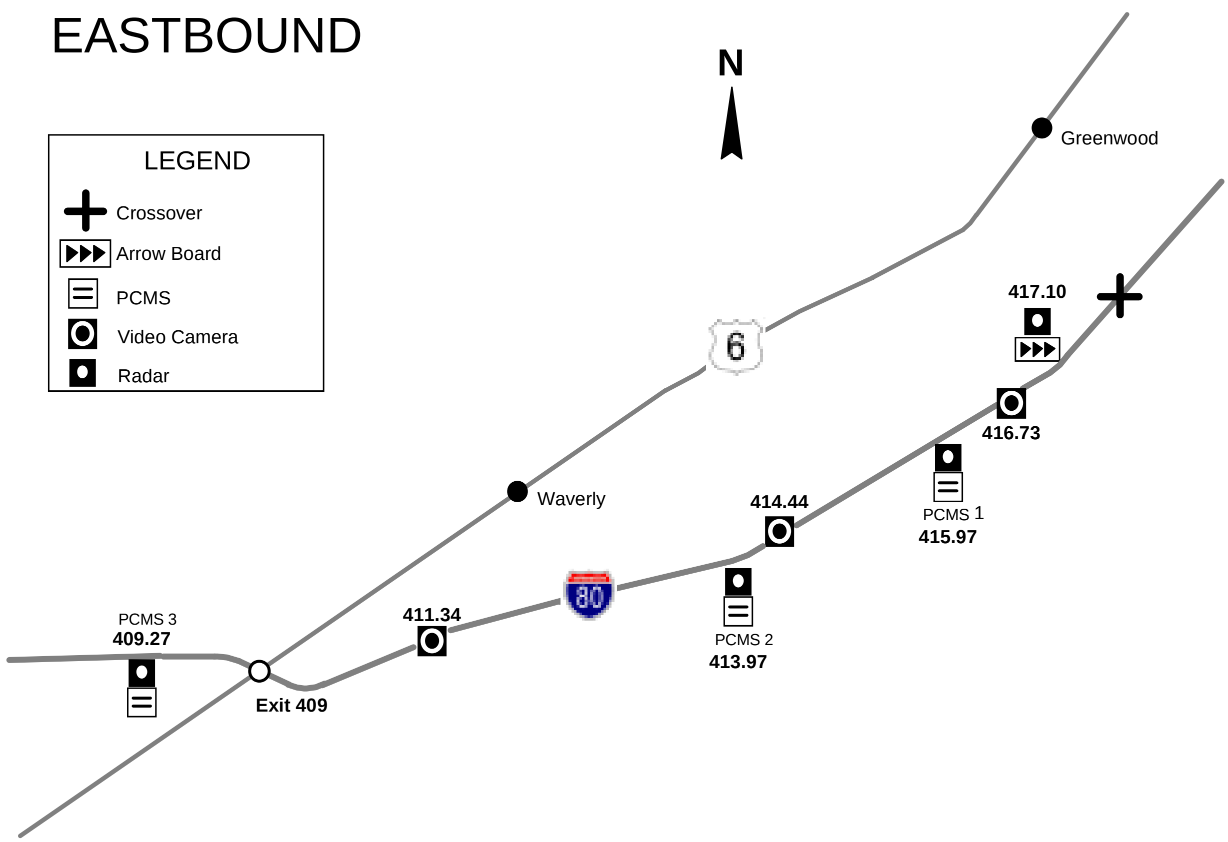


**FIGURE 3 PCMS deployment.**


**FIGURE 4 PCMS placement.**

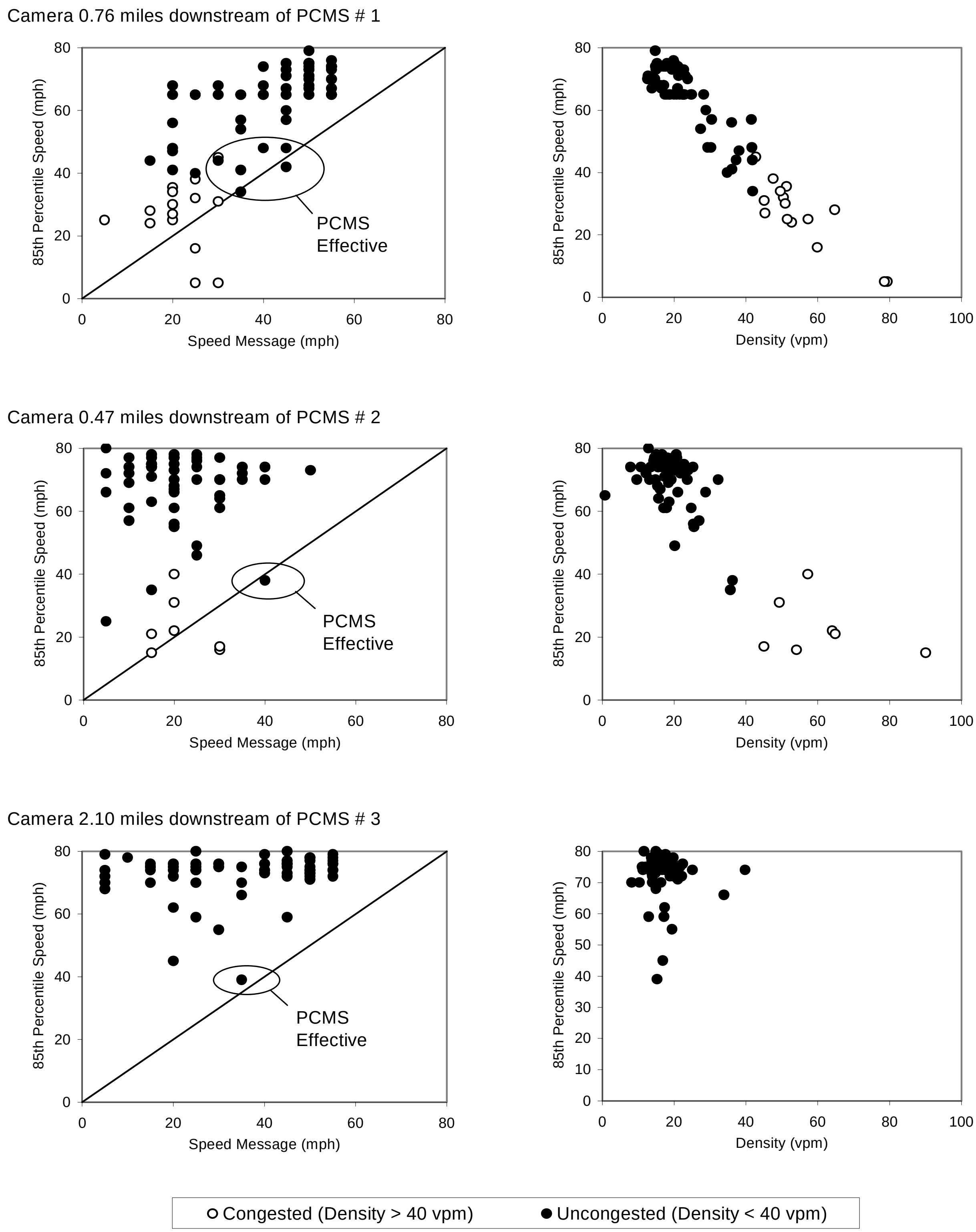


**FIGURE 5 85$^{th}$ percentile speed at camera locations vs. speed message and density**