MIDWEST SMART WORK ZONE DEPLOYMENT INITIATIVE

MwSWZDI

FHWA POOLED FUND STUDY

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Adaptir

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Supplemental Notes

Abstract

The ADAPTIR is a portable, condition-responsive work zone traffic control system which is capable of providing drivers with real-time information about work zone traffic conditions via VMS and highway advisory radio (HAR). It was deployed in a work zone on I-80 between Lincoln and Omaha during the summer of 1999. The system is intended to provide warning to drivers of slower speeds and delays within the work zone, and encourage them to use caution and take alternate routes if possible. Various measures of effectiveness were employed to characterize the effect of the system on traffic and driver decisions. Traffic speed and lane distribution on the approach to the work zone were measured before and after the deployment of the ADAPTIR. The number of forced merges were obtained from video footage near the taper. Speeds were compared with advisory speeds to determine compliance. Diversion point volumes were logged to determine if drivers took alternate routes because of the system. Finally, a driver survey was conducted. Crash data was also examined, using a regression technique to compare crashes with and without the system. The systems use did not significantly affect any of the parameters with the exception of speed. The speed advisory message did have a effect on speeds, and the effect was stronger for signs located closer to the work zone.

NEBRASKA

Three technologies were evaluated in Nebraska. They were the following:

- SpeedGuard Radar Speed Reporting System provided by Speed Measurement Laboratories, Inc.;
- Portable Traffic Management System provided by Brown Traffic Products, Inc.; and
- ADAPTIR Traffic Control System provided by the Scientex Corporation.

The technologies were deployed in a work zone on I-80 between Lincoln and Omaha in the vicinity of the Highway 63 interchange near Greenwood as shown in Figure 5-1. The work zone was for an interstate reconstruction project which involved the closing of one roadway for reconstruction and head-to-head operation on the other roadway. The 1998 average daily traffic volume on this section of I-80 was approximately 38,000 vehicles per day, of which 21 percent were trucks. The normal speed limit on I-80 is 75 mph, the speed limit in the work zone was 55 mph.

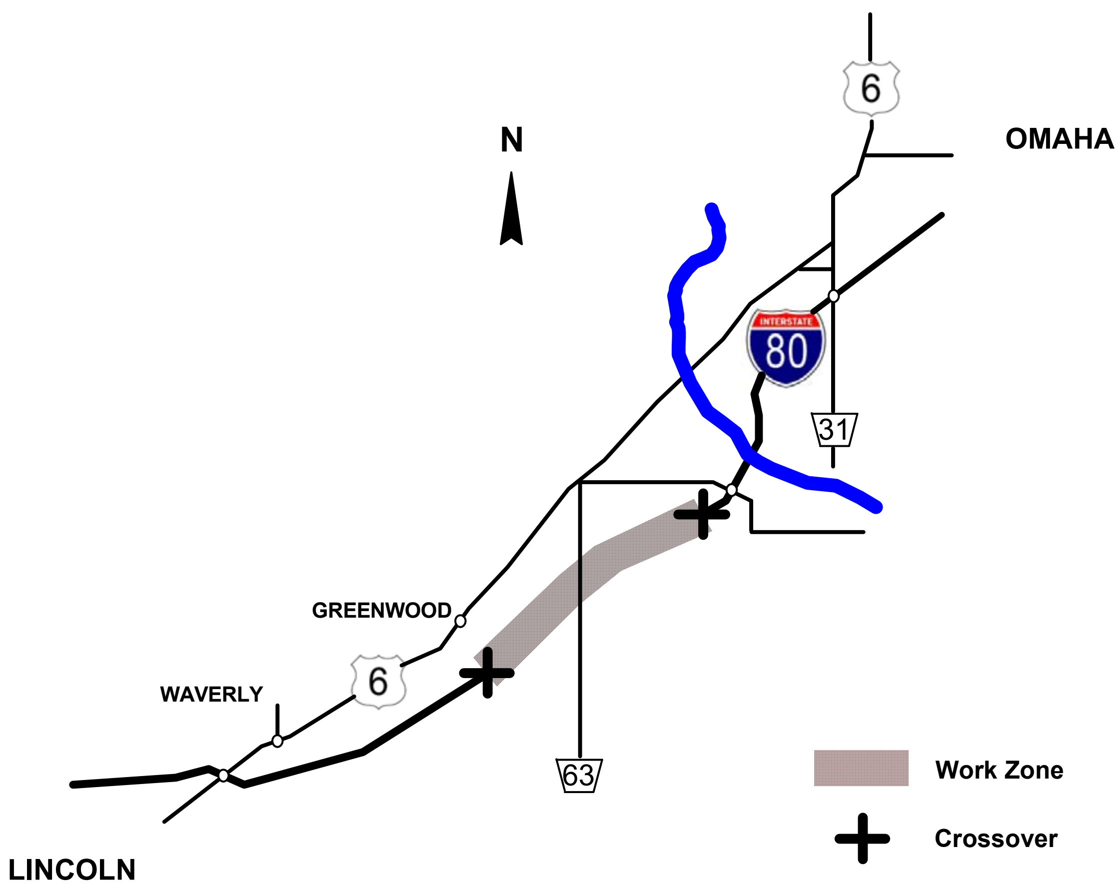


FIGURE 5-1 Location of work zone where technologies evaluated in Nebraska were deployed.

ADAPTIR

Description

ADAPTIR is a portable, condition-responsive work zone traffic control system which is capable of providing drivers with real-time information about work zone traffic conditions via VMS and highway advisory radio (HAR). The objective of the system is to improve the safety and efficiency of traffic operations in advance of the work zone by advising drivers of slower speeds and delays ahead and encouraging them to use alternate routes.

ADAPTIR has the following basic components:

- one or more VMSs deployed upstream of the work zone to display real-time traffic information to drivers;
- HAR to provide drivers with more detailed information than can be conveyed on the VMSs;
- Central system controller (CSC), which is an off-the-shelf IBM-compatible PC, to run the control software;
- radar sensors to continuously measure speeds at multiple locations upstream of the work zone; and
- roadside remote stations (RRS) to receive data from the radar sensors and, under the control of the CSC, program the VMSs and HAR to display and broadcast the appropriate messages.

When ADAPTIR is operating, the RRSs continuously receive speed data from the radar sensors. At regular intervals, the CSC acquires the data from the RRSs via radio modem and analyzes it to estimate delays and detect high speed differentials upstream of the work zone. When the delays and/or speed differentials are above preselected thresholds, the CSC directs the RRSs to cause the VMSs and HAR to display and broadcast the appropriate messages.

The deployment of ADAPTIR evaluated in this study did not include HAR. Driver information was provided on four VMSs in advance of the work zone. Three types of messages were displayed on these signs: (1) speed advisory messages, (2) delay messages, and (3) diversion messages. The speed advisory messages were time-stamped and displayed in the following two-phase sequential format:

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

The delay messages were also time-stamped and displayed in the following two-phase sequential format:

Phase 1	Phase 2
I-80 (E) ADVISORY XX:XX XM	XX MIN DELAY AHEAD

The diversion message was also displayed in a two-phase sequential format as follows:

Phase 1	Phase 2
30 MIN DELAY AHEAD	CONSIDER ALT. ROUTE

The three VMSs farthest upstream of the work zone were blank when traffic conditions did not warrant the display of speed advisory, delay, or diversion messages. The VMS closest to the work zone displayed the following lane closure message when none of the other messages were displayed:

RIGHT LANE CLOSED

The logic used by the CSC to select the message to display is shown in Figure 5-8. The CSC analyzed the data from the RRSs at 8-minute intervals throughout the day, except when 4-minute intervals were used during the period of higher traffic volume between 1:00 and 8:00 pm. As long as the speed of traffic measured downstream of a VMS was no more than 10 mph below the speed measured at the VMS, the VMS remained blank. However, if the speed difference was greater than 10 mph, the speed advisory message was displayed indicating the speed downstream to the nearest 5 mph.

When the CSC estimated delays greater than 5 minutes, the delay message was displayed to the nearest 5 minutes up to a maximum value of 30 minutes. When delays were more than 30 minutes, the diversion message was displayed on the VMSs upstream of the diversion point. The speed advisory message had priority over the delay and diversion messages because of the accident potential associated with high speed differentials.

ADAPTIR was developed through a cooperative agreement with the FHWA and the Maryland State Highway Administration by The Scientex Corporation, 2000 14th Street North, Suite 300, Arlington, Virginia 22201; PH: 703-276-3377; FX: 703-276-0996.

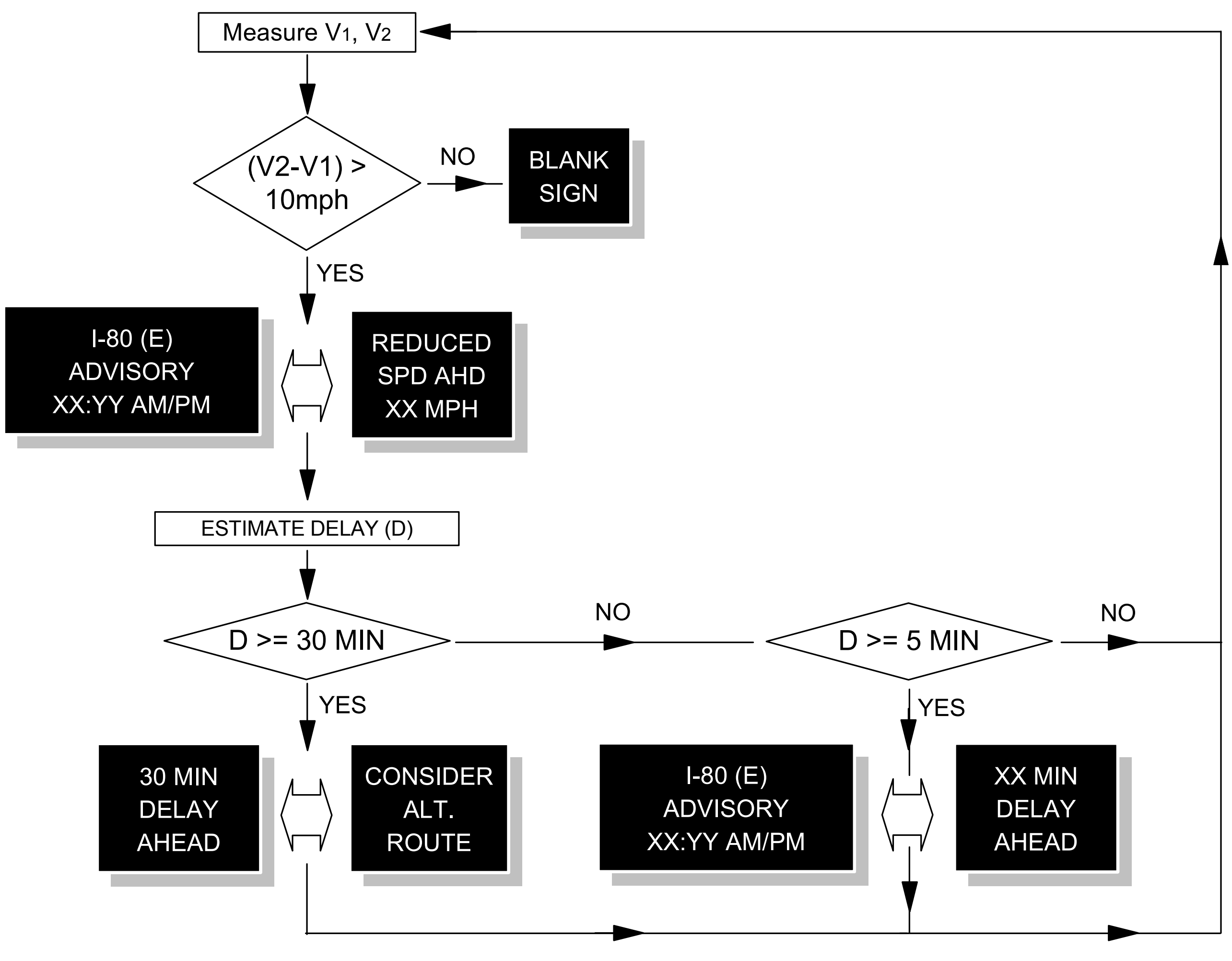


FIGURE 5-8 ADAPTIR VMS message selection.

Study Site

The study site for the evaluation of the ADAPTIR was the eastbound approach to the work zone in Figure 5-1. 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 and head-to-head traffic operation through the work zone. The traffic control plan on the approach is shown in Figure 5-9. 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 lane closure taper;
3. SPEED LIMIT 65 sign with FINES DOUBLE sign plate about 8,500 feet before the lane closure taper;
4. RIGHT LANE CLOSED 1 MILE sign;
5. DO NOT PASS sign about 3,600 feet before the lane closure taper;
6. RIGHT LANE CLOSED ½ MILE sign;
7. REDUCED SPEED AHEAD sign about 1,500 feet before the lane closure taper;
8. Symbolic "lane reduction on the left" transition sign about 1,000 feet before the lane closure taper;
9. SPEED LIMIT 55 sign with FINES DOUBLE sign plate about 500 feet before the lane closure taper; and
10. DETOUR AHEAD at the beginning of the taper.

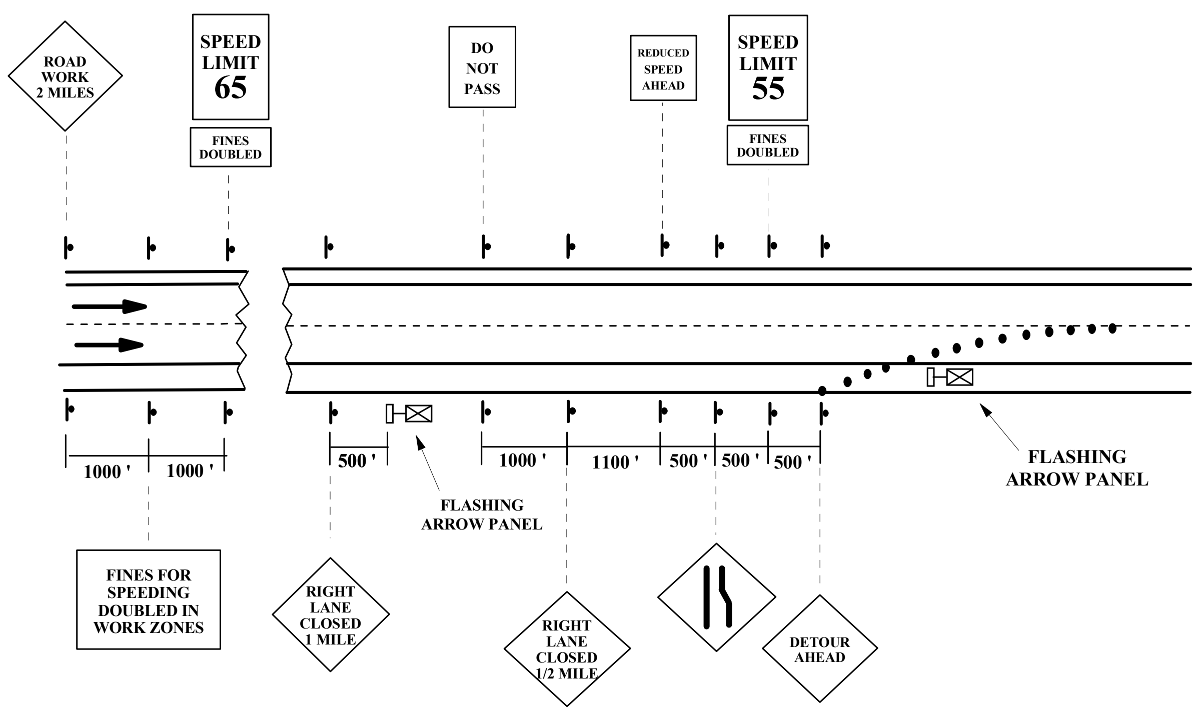


FIGURE 5-9 Traffic control plan at ADAPTIR study site.

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 lane closure taper, and the other arrow panel was located on the right shoulder just downstream of the beginning of the lane closure taper.

The lane closure 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.

The deployment of the VMSs is shown in Figure 5-10. Three of the four VMSs were placed in the middle of median on I-80 at distances of 1.1, 3.1, and 7.8 miles upstream of the work zone. The VMS farthest from the work zone was about one-half mile before the interchange with Highway 6, which provides an alternate route around the work zone on I-80 as shown in Figure 5-1. The fourth VMS was placed on eastbound Highway 6 about one mile before the I-80 interchange. The placement of one of the VMSs on I-80 is shown in Figure 5-11.

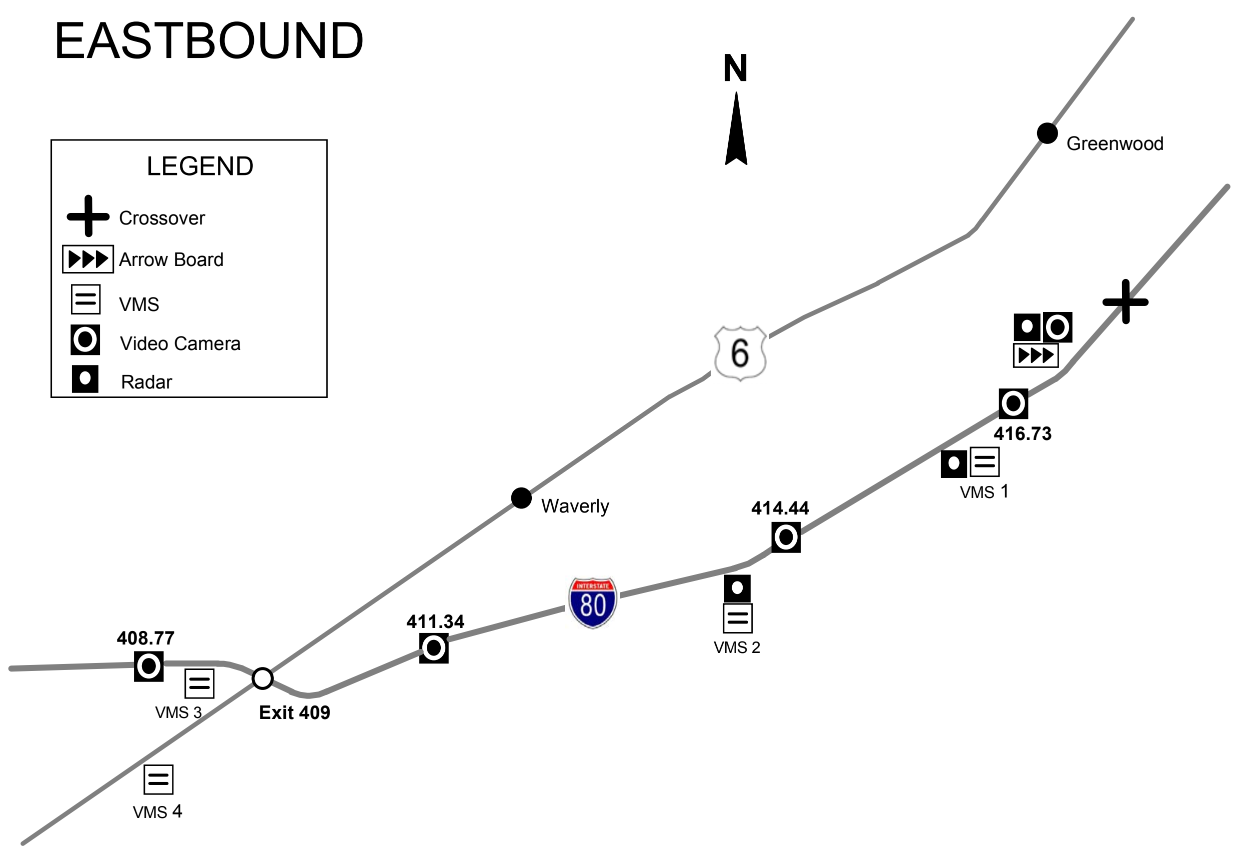


FIGURE 5-10 ADAPTIR VMS deployment.

FIGURE 5-11 ADAPTIR VMS placement.

As indicated in Figure 5-10, radar sensors were mounted on the three VMSs on I-80 and the arrow board at the lane closure taper to measure traffic speeds at these locations. Speeds were not measured on Highway 6 where the fourth VMS was located. When conditions warranted, speed advisory and delay messages were displayed on the three VMSs on I-80. The diversion message was only displayed on the two VMSs upstream of the diversion points on I-80 and Highway 6. Delay messages were also displayed on the VMS on Highway 6, but speed advisory messages were not displayed on Highway 6.

Data Collection

Five types of data collection were conducted to evaluate the effectiveness of the ADAPTIR: (1) traffic speed and lane distribution in advance of the lane closure taper, (2) number of forced merges in advance of the lane closure taper, (3) driver compliance with the advisory speed messages, (4) mainline and ramp volumes at the diversion point, and (5) driver survey.

Speed and Lane Distribution

Traffic speed and lane distribution on the approach to the work zone were measured before and after the deployment of the ADAPTIR. The data were collected with two video cameras. One camera was stationed on an overpass and used to video tape traffic at 2,000 feet before the lane closure taper. The other camera was mounted on the 30-foot telescoping mast of a University of Nebraska-Lincoln video recording trailer which was positioned behind the arrow board at the taper. This camera was used to record traffic at 500 feet before the taper. These cameras are shown in Figure 5-10.

The before data were collected from 2:30 to 6:30 pm on Monday and Tuesday, July 12 and 13, 1999. The after data were collected one week later from 2:30 to 6:30 pm on Monday and Tuesday, July 19 and 20, 1999. The ADAPTIR was deployed on July 15, 1999.

Forced Merges

The camera on the video recording trailer at the taper provided a clear view of the merging operations within 500 feet of the taper. The number of forced merges were obtained from the view recorded with this camera.

Speed Message Compliance

The data for evaluating drivers' compliance with the speed advisory messages were obtained by video cameras on overpasses downstream of each VMS on I-80. The locations of the cameras and VMSs are shown in Figure 5-10. The distance of the camera location downstream of each VMS is given in Table 5-12. Traffic on eastbound I-80 was video taped from these locations on 16 days between July 16 and August 22, 1999. A total of 46.5 hours of video was recorded at each camera location. The dates and times of the video taping sessions are shown in Table 5-13.

TABLE 5-12 Speed message compliance camera locations.

VMS	Distance Upstream of Taper (mi)	Distance Upstream of Camera (mi)
1	1.13	0.76
2	3.13	0.47
3	7.83	2.07

TABLE 5-13 Speed message compliance video taping sessions.

Date	Day	Time	Date	Day	Time
7-16-99	Friday	2:30 - 5:30 pm	7-30-99	Friday	3:41 - 6:01 pm
7-19-99	Monday	2:30 - 6:30 pm	8-1-99	Sunday	3:09 - 5:15 pm
7-20-99	Tuesday	2:30 - 6:30 pm	8-6-99	Friday	3:37 - 5:33 pm
7-21-99	Wednesday	2:00 - 6:00 pm	8-8-99	Sunday	2:43 - 6:02 pm
7-22-99	Thursday	2:00 - 6:00 pm	8-13-99	Friday	2:31 - 6:01 pm
7-23-99	Friday	3:50 - 5:25 pm	8-15-99	Sunday	2:29 - 6:17 pm
7-25-99	Sunday	3:39 - 6:30 pm	8-20-99	Friday	2:54 - 5:20 pm
7-29-99	Thursday	4:18 - 5:46 pm	8-22-99	Sunday	2:49 - 4:50 pm

Diversion Point Volumes

Traffic volumes on the mainline and ramps on eastbound I-80 and eastbound Highway 6 upstream of the Highway 6 interchange with I-80 were counted continuously throughout the study period from July 12 to August 30, 1999. The data were collected with four portable, recording traffic counter/classifier units, which were installed and maintained by the NDOR. One unit was installed on each of the following roadways at the Highway 6 interchange: (1) eastbound I-80 upstream of the exit ramp, (2) eastbound I-80 exit ramp, (3) eastbound Highway 6, and (4) eastbound I-80 entrance ramp. These locations are shown in Figure 5-12.

Driver Survey

Drivers were interviewed at the rest area on eastbound I-80 about one-half mile downstream of the work zone. The drivers were asked if they had seen the portable VMSs. 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 VMS and the messages.

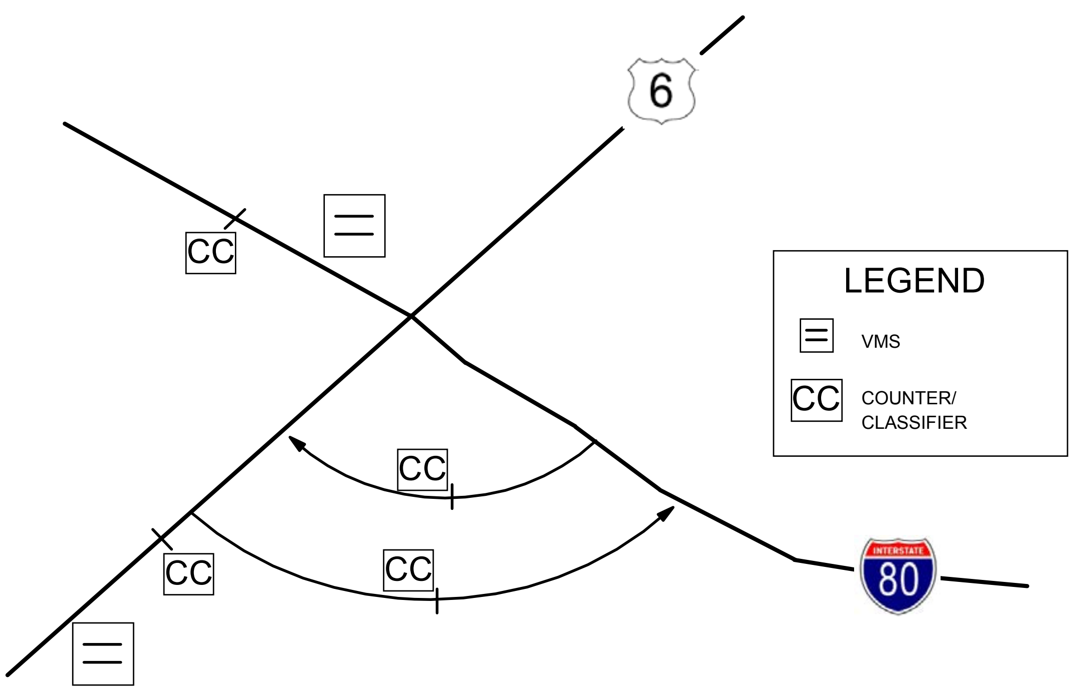


FIGURE 5-12 Traffic counter/classifier locations at Highway 6 interchange.

The driver surveys were conducted on seven afternoons between July 23 and August 20, 2000. The days and times of these surveys are shown in Table 5-14.

TABLE 5-14 Driver survey times.

Date	Day	Time
7-23-99	Friday	2:30 - 5:55 pm
7-30-99	Friday	3:25 - 6:00 pm
8-06-99	Friday	4:00 - 5:59 pm
8-13-99	Friday	4:25 - 5:52 pm
8-18-99	Thursday	3:04 - 4:47 pm
8-19-99	Friday	4:57 - 5:00 pm
8-20-99	Saturday	3:25 - 5:12 pm

Data Analysis

Speed and Lane Distribution

The video tapes recorded by the video cameras during the before and after studies were processed with the Autoscope video processing system to determine the types and speeds of the vehicles and the volumes of traffic in each lane at 500 and 2,000 feet in advance of the lane closure taper. The tapes were examined to identify periods of congested flow conditions. These periods were defined as 15-minute periods with average speeds below 35 mph. However, there were no periods of congested flow during the before and after studies. Thus, the analysis was conducted for passenger cars and non-passenger cars during uncongested flow conditions.

The following speed parameters were computed from the speed data collected for passenger cars and non-passenger cars at 500 and 2,000 feet in advance of the lane closure taper during the before and after studies:

- mean speed,
- standard deviation,
- 85th-percentile speed,
- 10-mph pace,
- percentage of speeds within the pace,
- percentage complying with the speed limit, and
- mean of highest 15 percent of speeds.

The statistical significance of the differences in these speed parameters before and after the deployment of the ADAPTIR was determined. The t test was used to evaluate the differences between the before and after values of the mean speed, 10-mph pace, and mean of highest 15 percent of speeds. An analysis of covariance was also conducted to account for the effects of traffic volume in the comparison of mean speeds. The binomial test was used to evaluate the statistical significance of differences between the before and after values of the 85th-percentile speed, percentage of speeds within the pace, and percentage complying with the speed limit. The F test was used to check for statistically significant differences between the before and after values of the standard deviation of the speed distribution.

The lane volumes recorded by the video cameras were used to determine the lane distribution for each 2-minute period during the before and after studies. Lane distributions were computed for passenger cars and non-passenger cars. The t test was used to determine the statistical significance of the differences between the before and after values of the mean lane distributions for each data set.

Forced Merges

The video tapes of traffic in the merge area in advance of the lane closure taper were viewed to determine the number of forced merges occurring during each 15-minute period of the before and after studies. The rate of forced merges per 1,000 vehicle were computed for each period. The t test was used to determine the statistical significance of the differences between the before and after mean rates of forced merges.

Speed Message Compliance

The video tapes recorded by the video cameras located downstream of the three VMSs on I-80 were processed with the Autoscope video processing system to determine the mean speed and volume during each regular time interval (*i.e.*, 4 minutes between 1:00 and 8:00 pm and 8-minutes during the remainder of the day) used by the ADAPTIR CSC to evaluate traffic conditions and select the messages to be displayed. The mean density of traffic flow in each interval was estimated by dividing the volume by the mean speed during the interval.

The intervals during which speed advisory messages were displayed on the VMSs were identified from the CSC logs. The volumes and mean speeds at the downstream camera locations were then computed for the corresponding intervals, which were offset by the travel times from the VMSs to the downstream camera locations. A multiple regression analysis of the data were conducted to determine the effect of the speed advisory messages on the reduction in mean speed between the VMSs and the downstream camera locations. The independent variables were the speed reduction indicated by the advisory speed message and the density of traffic flow at the downstream camera location.

Diversion Point Volumes

The times when the diversion message was displayed on the two VMSs in advance of the diversion point at the Highway 6 interchange were identified from the CSC logs. The 5-minute traffic counts recorded during these times by the four traffic counter/classifiers deployed at the interchange as shown in Figure 5-12 were then determined for each 5-minutes. The percentages of traffic volume at each of the four locations when the two VMSs were blank and when they displayed the diversion message were computed for each 5-minute period. An analysis of covariance was conducted to determine the statistical significance of the effects of the diversion message and traffic volume on the 5-minute percentages of traffic at the four locations. The t test was used to determine the statistical significance of the differences between the percentages of the two messages when the two VMSs were blank and when they displayed the diversion message.

Driver Survey

The driver surveys were compiled. The percentages of drivers who noticed the VMSs and the messages displayed were calculated. A binomial proportions test was conducted to determine the statistical significant of differences between the percentages of drivers who saw the messages and the percentages of time the messages were displayed during the survey. 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 and Lane Distribution

The speed parameter values computed from the speed data are shown in Table 5-15. There were no statistically significant ($\alpha = 0.05$) differences between the before and after values of the speed parameters at 500 and 2,000 feet. Thus, ADAPTIR did not seem to affect the vehicle speeds in advance of the lane closure taper. This result is not unexpected because the data were collected during periods of uncongested flow when the speed advisory messages were seldom displayed.

The lane distributions before and after the deployment of ADAPTIR are shown in Table 5-16. These values indicate that the deployment of ADAPTIR did not affect the lane distributions at 500 and 2,000 feet in advance of the lane closure taper. None of the differences in the mean percentages of vehicles in the open (right) lane were found to be statistically significant ($\alpha = 0.05$), regardless of vehicle type. As noted above, these data were collected during periods of uncongested flow when the speed advisory and delay messages were seldom displayed. When these messages were not displayed, the VMS closest to the work zone displayed the message RIGHT LANE CLOSED. This VMS was 1.13 miles upstream of the work zone and only about 500 feet upstream of the RIGHT LANE CLOSED 1 MILE signs, which were installed on each side of the roadway as part of the traffic control plan. Therefore, it is not surprising that the ADAPTIR had no effect on the lane distribution in advance of the lane closure taper.

Forced Merges

The numbers and rates of forced merges observed before and after the deployment of ADAPTIR are shown in Table 5-17. A total of 150 forced merges at a rate of 20 per 1,000 vehicles were observed in the 8-hour before study. A total of 152 forced merges at a rate of 19 per 1,000 vehicles were observed in the 8-hour after study. The differences between the before and after forced-merge rates were not significantly different ($\alpha = 0.05$). Therefore, the ADAPTIR did not seem to affect the rate of forced merges in advance of the lane closure taper.

Speed Message Compliance

The speed advisory messages were intended to warn drivers of slower traffic ahead and thus encourage, or at least prepare, them to slow down. A speed advisory message was displayed on a VMS whenever the speed of traffic passing by the VMS was 10 mph or more higher than the speed of traffic at the next VMS downstream. In the case of VMS #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 board at the lane closure taper. The advisory speed displayed in the message was the speed (to the nearest 5 mph) at the downstream location.

TABLE 5-15 Before and after speed parameter values for ADAPTIR.

Speed Parameter	2,000 ft Before Taper [a]		500 ft Before Taper [b]	
	Before	After	Before	After
Passenger Cars				
Mean Speed (mph)	60.1	60.7	55.3	56.0
Standard Deviation (mph)	3.9	4.1	3.6	3.7
85th-Percentile Speed (mph)	64.2	65.1	58.9	59.6
10-mph Pace	56-66	56-66	52-62	51-61
Within in 10-mph Pace (%)	79	77	78	79
Speed Limit Compliance (%)	88	85	43	45
Mean Speed of Highest 15 % (mph)	65.4	67.3	60.5	61.4
Sample Size	5,574	6,169	3,021	6,598
Non-Passenger Cars				
Mean Speed (mph)	63.7	64.3	55.3	56.0
Standard Deviation (mph)	3.3	3.3	3.5	3.6
85th-Percentile Speed (mph)	66.6	67.9	59.3	59.7
10-mph Pace	59-69	60-70	51-61	51-61
Within in 10-mph Pace (%)	86	87	80	82
Speed Limit Compliance (%)	62	60	44	43
Mean Speed of Highest 15 % (mph)	68.4	69.4	60.7	61.1
Sample Size	1,368	1,854	869	1,457

[a] Speed limit is 65 mph.

[b] Speed limit is 55 mph.

☐ Difference between before and after values is significant ($\alpha = 0.05$).

For example, if the average speed of traffic during the CSC control interval (either 4 or 8 minutes depending on the time of day) at VMS #2 was 65 mph and the average speed of traffic at VMS #1 during the same interval was 43 mph, a speed advisory message of 45 mph would be displayed on VMS #2.

Table 5-16 Lane distribution before and after deployment of ADAPTIR.

Vehicle Type	Percentage of Vehicles in the Open (Right) Lane			
	2,000 ft Before Taper [a]		500 ft Before Taper [b]	
	Before	After	Before	After
Passenger Cars	86.0	87.4	96.6	97.9
Non-passenger cars	96.8	95.8	99.4	99.2
All Vehicles	88.1	89.3	97.0	98.2
Sample Size [c]	6,942/237	8,023/238	1,462/44	2,172/60

[a] Speed limit is 65 mph.
[b] Speed limit is 55 mph.
[c] Number of vehicles/number of 2-minute lane distribution values.
☐ Difference between before and after values is significant (α = 0.05).

TABLE 5-17 Forced merges before and after deployment of ADAPTIR.

Forced Merges	Before	After
Total Number Observed	150	152
Hours of Observation	8	8
Mean Rate (number/1,000 vehicles)	20	19
Standard Deviation (number/1,000 vehicles)	9.2	9.9
Sample Size [a]	32	32

[a] Number of 15-minute intervals for which mean rates were computed.
☐ Difference between before and after values is significant (α = 0.05).

During the 46.5 hours of observation on the 16 days between July 16 and August 22, 1999, a total of 323 speed advisory messages were displayed on the three VMSs on I-80. The frequency of the advisory speeds displayed on each VMS is shown in Table 5-18. The closer the VMS was to the work zone, the more speed advisory messages it displayed. VMS #1 displayed 130 speed advisory messages, VMS #2 displayed 102 speed advisory messages, and VMS #3 displayed 91 speed advisory 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.

TABLE 5-18 Frequency of advisory speed messages.

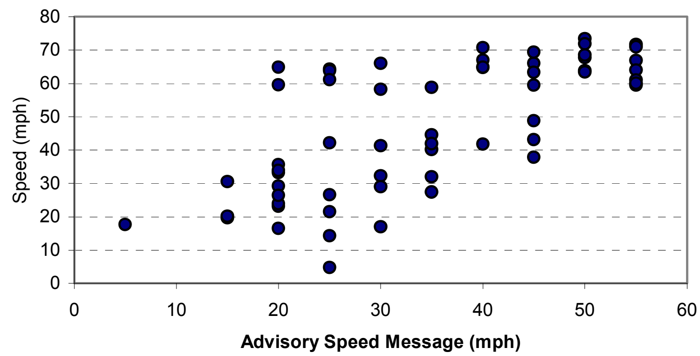
Advisory Speed (mph)	VMS [a]			Total
	1	2	3	
55	20	0	14	34
50	20	1	17	38
45	11	2	9	22
40	10	7	5	22
35	9	8	10	27
30	12	11	5	28
25	17	13	12	42
20	23	21	7	51
15	6	18	5	29
10	0	10	1	11
5	2	11	6	19
Total	130	102	91	323

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

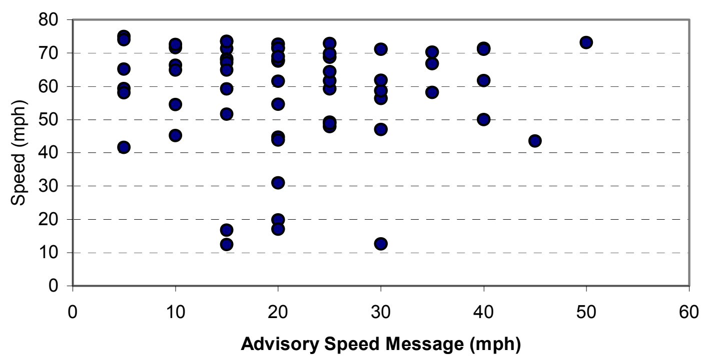
The average speeds at the downstream camera location versus the advisory speeds displayed are shown for each VMS in Figure 5-13. These data suggest the advisory speed messages had little or no effect on the average speeds at the downstream camera locations. However, the density of traffic flow must be considered because of its effect on speed as illustrated by the speed-density curves for the camera locations shown in Figure 5-14. The volume-density relationships at the camera locations in Figure 5-14 indicate that densities below 25 vehicles per mile were representative of uncongested flow conditions. Densities above 25 vehicles per mile were indicative of congested flow conditions.

The difference between the mean speed at a VMS and the speed in the advisory speed message it displays was the speed reduction indicated by the message. The difference between the mean speed at the VMS and the mean speed at the downstream camera location was the actual speed reduction. The actual speed reductions versus the speed reductions indicated by the speed advisory messages are shown for each camera location in Figure 5-15. These plots indicate that during uncongested flow conditions the actual speed reductions were typically at or below zero, regardless of the speed reduction indicated by the speed advisory message. However, during congested flow conditions, the actual speed reductions were usually above zero, and in some cases, equal or greater than the speed reduction indicated by the speed advisory message.

Camera 0.76 mile downstream of VMS #1



Camera 0.47 mile downstream of VMS #2



Camera 2.10 miles downstream of VMS #3

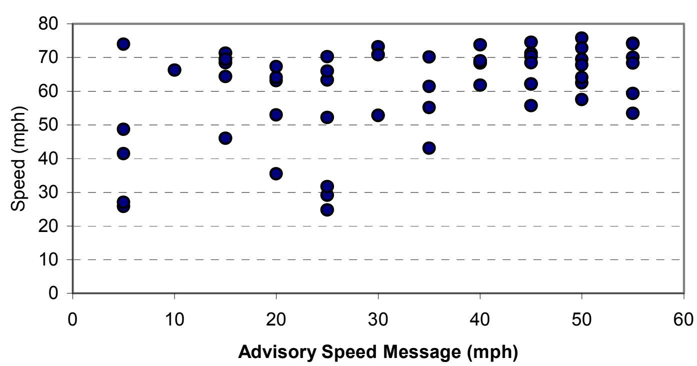
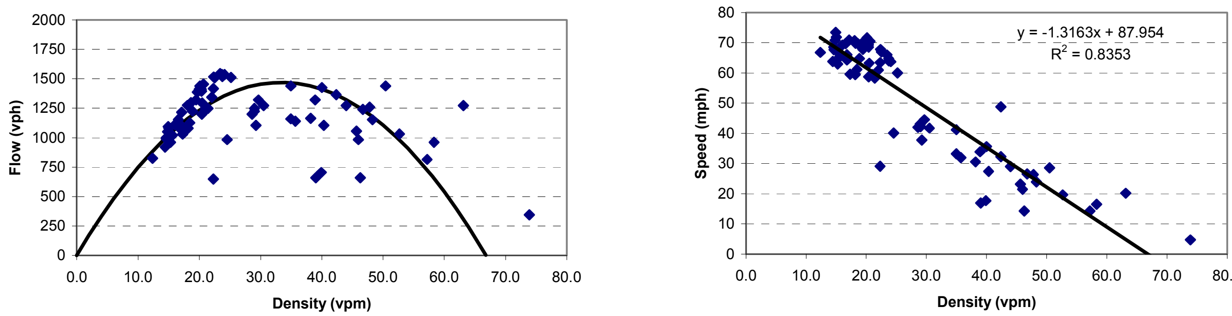
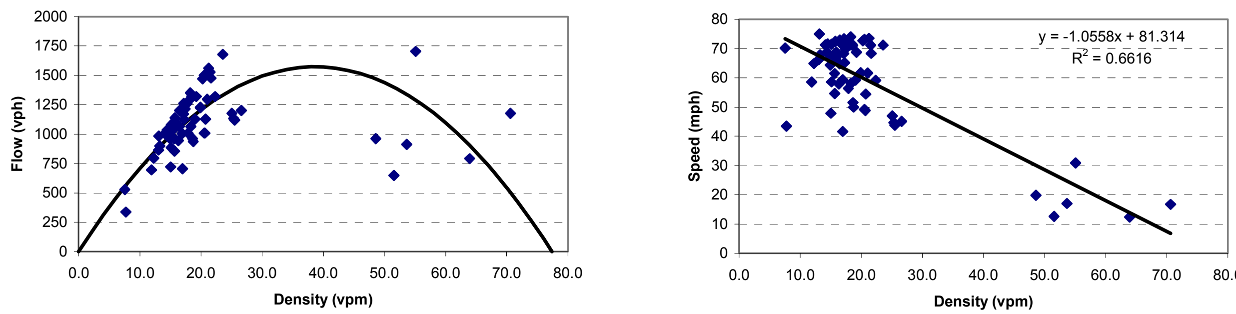


FIGURE 5-13 Average speed at camera locations versus advisory speed message

Camera 0.76 mile downstream of VMS #1



Camera 0.47 mile downstream of VMS #2



Camera 2.10 miles downstream of VMS #3

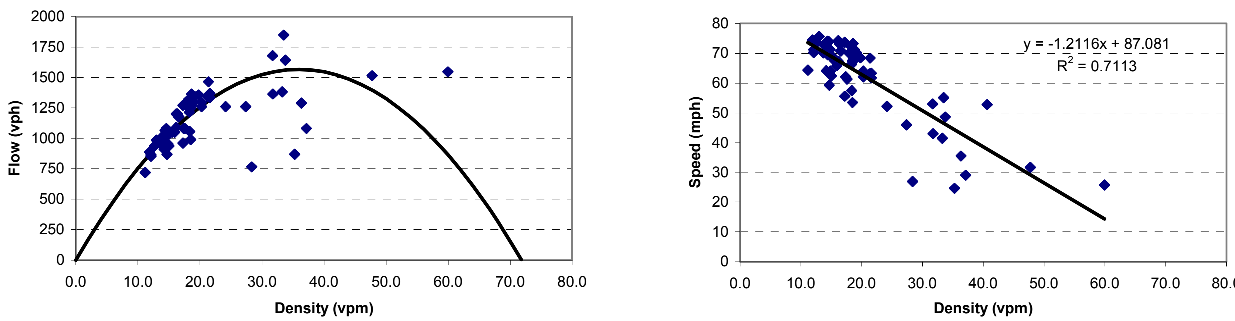


FIGURE 5-14 Speed-density and volume-density relationships at camera locations.

Camera 0.76 mile downstream of VMS #1

Camera 0.47 mile downstream of VMS #2

Camera 2.10 miles downstream of VMS #3

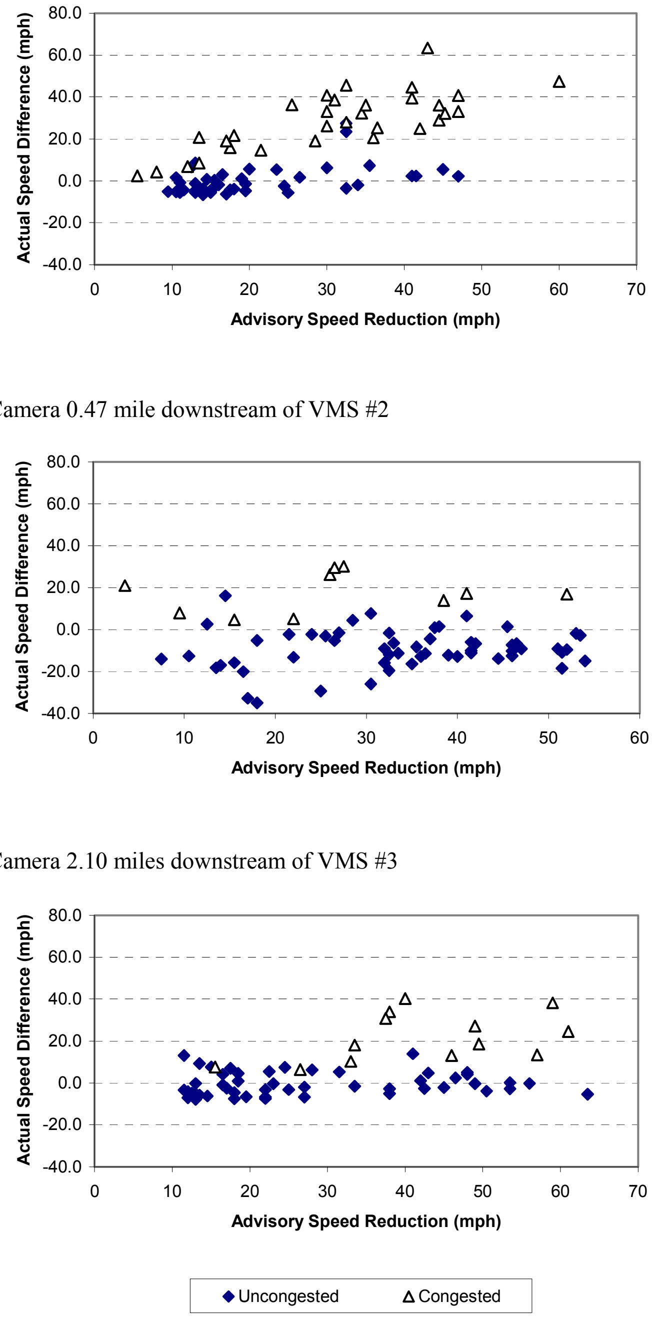


FIGURE 5-15 Actual speed reduction versus advisory message speed reduction.

The results of the multiple regression analysis of the data are presented in Table 5-19. The p-values indicate the regression equation for each location accounted for a statistically significant amount of the variation and the regression coefficients in each equation were statistically significant ($\alpha = 0.05$). The actual speed reduction at each location was found to be directly related to density; the higher the density of traffic flow at the camera location, the greater the difference between the average speed at the VMS and the camera location.

At the two camera locations closest to the work zone, the speed reduction indicated by the advisory speed message displayed by the VMS upstream also influenced the actual speed reductions between the VMS and the camera location. At the camera location closest to the work zone, approximately 50 percent of the speed reduction indicated by the advisory speed message was included in the actual speed reduction. Therefore, if the speed advisory message displayed by VMS #1 was REDUCED SPD AHD 20 MPH when the average speed at VMS #1 was 60 mph, the speed reduction indicated by the speed advisory message would be 40 mph, which would increase the actual speed reduction by about 20 mph. At the camera location downstream of VMS #2, which was the second closest to the work zone, approximately 25 percent of the speed reduction indicated by the advisory speed message was included in the actual speed reduction according to the regression equation. Therefore, if the speed advisory message displayed by VMS #2 was REDUCED SPD AHD 20 MPH when the average speed at VMS #2 was 60 mph, the speed reduction indicated by the speed advisory message would be 40 mph, which would increase the actual speed reduction by about 10 mph. However, at the camera location downstream of VMS #3, which was farthest from the work zone, the speed advisory message on VMS #3 had no effect on the actual speed reduction.

The regression equations indicate the advisory speed messages were somewhat effective in reducing speeds. However, the messages were more effective the closer the VMS on which they were displayed was to the work zone. VMS #1, which was closest to the work zone, 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. VMS #2, which was the second closest to the work zone, 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 VMS #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. VMS #3, which was the farthest from the work zone, 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 VMS #3 was nearly 4 miles before the work zone. In addition, VMS #3 was 4.7 miles upstream of VMS #2, where the lower speeds displayed on VMS #3 were being measured. Drivers traveling at the speed limit (65 mph) would travel over 4 minutes before reaching the location of VMS #2. Therefore, many drivers may have been unaware of the work zone and not likely to perceive the need to slow down.

TABLE 5-19 Regression analysis of speed reductions at camera location.

Camera 0.76 Mile Downstream of VMS #1 (0.4 mile upstream of work zone)				
Equation [a]	$\Delta S^{actual} = -25.9 + 0.887D + 0.504\Delta S^{VMS}$			
R-Squared	p-Values			
	Constant	D	ΔS^{VMS}	Equation
83.0	0.0000	0.0000	0.0000	0.0000
Camera 0.47 Mile Downstream of VMS #2 (2.7 miles upstream of work zone)				
Equation [a]	$\Delta S^{actual} = -31.1 + 0.796D + 0.255\Delta S^{VMS}$			
R-Squared	p-Values			
	Constant	D	ΔS^{VMS}	Equation
45.3	0.0000	0.0000	0.0137	0.0000
Camera 2.1 Miles Downstream of VMS #3 (5.8 miles upstream of work zone)				
Equation [a]	$\Delta S^{actual} = -15.6 + 0.910D$			
R-Squared	p-Values			
	Constant	D	ΔS^{VMS}	Equation
59.2	0.0000	0.0000	-	0.0000

[a] ΔS^{actual} = actual speed reduction at camera location (mph);
D = density at camera location (vpm); and
ΔS^{VMS} = speed reduction indicated by speed advisory message (mph).

Diversion Point Volumes

The results of the analysis of covariance of the effects of the VMS diversion message and traffic volume on the percentage of traffic on the mainline and ramps are shown in Table 5-20. These results indicate the VMS on eastbound I-80 upstream of the Highway 6 interchange had a statistically significant effect on the percentage of traffic exiting eastbound I-80 at the interchange; whereas, the effect of traffic volume was not statistically significant ($\alpha = 0.05$). However, the effect of the VMS on eastbound Highway 6 upstream of the Highway 6 interchange did not have a statistically significant effect on percentage of traffic entering eastbound I-80 from eastbound Highway 6 at the interchange; whereas traffic volume did have a statistically significant effect ($\alpha = 0.05$).

The means of the 5-minute volume percentages on the mainline and ramps at the Highway 6 interchange are shown in Table 5-21. When the diversion message was displayed on the VMS on

TABLE 5-20 Analysis of covariance of effects of VMS diversion message and traffic volume.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F-Ratio	p-Value
VMS #3 on Eastbound I-80 Upstream of Highway 6 Interchange					
Volume	0.00054324	1	0.00054324	0.25	0.6148
VMS	0.057436	1	0.057436	26.86	0.0000
Residual	0.425591	199	0.00949272		
Total	0.48871	201			
VMS #4 on Eastbound Highway 6 Upstream of Highway 6 Interchange					
Volume	0.0788859	1	0.0788859	8.36	0.0045
VMS	0.00027977	1	0.00027977	0.03	0.8635
Residual	1.26399	134	0.0094328		
Total	1.34343	136			

TABLE 5-21 Mainline and ramp volume distributions at Highway 6 interchange.

Variable	Message	
	blank	CONSIDER ALT. ROUTE
VMS #3 on Eastbound I-80 Upstream of Highway 6 Interchange		
EB I-80 (%)	92	89
Exit Ramp (%)	8	11
Sample Size [a]	126	76
VMS #4 on Eastbound Highway 6 Upstream of Highway 6 Interchange		
Highway 6 (%)	56	57
Entrance Ramp (%)	44	43
Sample Size [a]	126	11

[a] Number of 5-minute volumes.

▢ Difference between messages is significant (α = 0.05).

eastbound I-80 upstream of the Highway 6 interchange, the percentage of traffic on the exit ramp increased by 3 percent and the percentage of traffic remaining on the eastbound I-80 decreased by 3 percent, which was statistically significant (α = 0.05). When the diversion message was displayed on the VMS on eastbound Highway 6 upstream of the Highway 6 interchange, the percentage of the traffic entering eastbound I-80 from eastbound Highway 6 decreased by 1 percent and the percentage of traffic remaining on Highway 6 increased by 1 percent. However, the difference was not statistically significant ($\alpha = 0.05$).

Thus, the results are mixed. The diversion message displayed by the VMS on eastbound I-80 accounted for a 3-percent diversion of traffic from I-80 to avoid delays in the work zone. However, the diversion message displayed by the VMS on eastbound Highway 6 was not effective in encouraging traffic to remain on Highway 6 to avoid delays in the work zone.

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. The states in which the drivers resided are shown in Table 5-22.

Of the 264 drivers surveyed, 209 (79 percent) saw at least one of the VMSs. Of the 209 drivers who saw a VMS, the number of drivers who recalled seeing the messages displayed by the VMSs is shown in Table 5-23. Also shown is the percentage of the time each message was displayed while the driver survey was conducted. For example, the message I-80 (E) ADVISORY X:XX XM was displayed 22 percent of the time. Therefore, one would have expected 46 (22 percent) of the 209 drivers who saw a VMS to have seen this message. Likewise, the VMSs were blank 55 percent of the time. Therefore, one would have expected about 115 (22 percent) to have seen a blank VMS.

The p-values in Table 5-23 indicate the difference between the percentage of time each message was displayed and the percentage of drivers seeing the message was statistically significant, except in the case of the speed advisory message. The percentage of drivers seeing the I-80 (E) ADVISORY X:XX XM message or a blank VMS were much lower than the percentages of the time they were displayed. On the other hand, the percentage of drivers seeing the delay or diversion message was much higher than the percentages of the time these messages were displayed.

The I-80 (E) ADVISORY XX:XX XM message was the first phase of the two-phase speed advisory and delay messages. It provided the time stamp for these messages, which were displayed in sequential format. Each phase was displayed for 2 seconds with no delineation between them. Thus, in order for drivers to see the entire message twice as suggested by VMS guidelines *(1)*, a viewing time of 8 seconds was required. The VMS character height was 18 inches, which provided a nominal legibility distance of 650 feet. As shown in Figure 5-11, the VMSs on I-80 were placed in the center of the median about 30 feet from the edge of the travel way. In this position, the VMSs

TABLE 5-22 Drivers' states of residence.

State	Number of Drivers	State	Number of Drivers	State	Number of Drivers	State	Number of Drivers
AR	1	KY	2	NJ	3	TX	7
AZ	4	LA	1	NM	1	UT	5
CA	13	MA	1	NV	1	VT	2
CO	24	ME	2	NY	2	WA	1
FL	3	MI	16	OH	8	WI	8
IA	35	MN	11	OK	3	WY	1
ID	3	MO	2	OR	1	Canada	2
IL	24	NC	1	PA	1		
IN	5	NE	60	SC	2		
KS	6	NH	1	SD	1		

TABLE 5-23 Drivers' recall of ADAPTIR VMS messages.

Message	Percent Time Displayed	Drivers Seeing Message		p-Value [a]
		Number	Percent	
I-80 (E) ADVISORY X:XX XM	22	12	6	0.00000000
REDUCED SPD AHD XX MPH	17	45	12	0.147
XX MIN DELAY AHEAD	5	30	14	0.00200
CONSIDER ALT. ROUTE	1	12	6	0.00500
blank	55	29	14	0.00000000

[a] Binomial proportions test of the difference between the percent time displayed and percent of drivers seeing message.

were no longer within the drivers' cone of vision when drivers were within 200 to 270 feet, depending on their travel lane. Therefore, available reading distance was about 380 to 450 feet. Drivers traveling at the speed limit (65 mph) would only have about 4.0 to 4.7 seconds to read the message, which would not have allowed them to read the message twice.

This limited reading time may have accounted for the low percentage of drivers seeing the I-80 (E) ADVISORY XX:XX XM message. But, this is unlikely since expected, or higher, percentages of drivers saw the other three messages, which were also portions of two-phase messages. Instead, it seems that drivers were simply more likely to recall the units of information in a message that describe the traffic condition ahead and what action is recommended. Time stamp information and blank signs were not as memorable.

The differences between the percentages of time the messages were displayed and the percentages of drivers seeing them also suggest that drivers were more likely to stop at the rest area where the driver survey was conducted when the delay and diversion messages were displayed. These messages, especially the diversion message, were displayed when there was congestion and delay in the work zone. After traveling through the congestion and delay, drivers may have been more inclined to stop at the rest area, which was about one-half mile downstream of the work zone. Consequently, the percentages of drivers surveyed who saw the delay and diversion messages were higher than the percentages of time they were displayed. Likewise, the percentages of drivers who were exposed to the other messages and blank VMSs were under represented by the drivers who stopped in the rest area while the survey was being conducted.

The percentages of drivers seeing the VMS messages, who understood the messages and thought they were useful, are shown in Table 5-24. 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 drivers who did not understand the XX MIN DELAY AHEAD were confused because did not know the location of the delay or the reason for it. Some drivers did not believe the message was useful because the delay they had actually experienced was much different (longer or shorter) than the delay displayed in the message. Others did not consider the message useful because they were already delayed before they saw the message.

The diversion message CONSIDER ALT. ROUTE was understood by all of the drivers who saw it. However, less than half of them thought it was useful. They did not believe the message was useful because it did not indicate or describe the alternate route to take.

TABLE 5-24 Drivers' understanding and opinion of ADAPTIR VMS messages.

Message	Drivers Who Understood Message		Drivers Who Thought Message Useful	
	Number	Percent	Number	Percent
I-80 (E) ADVISORY X:XX XM	9	75	9	75
REDUCED SPD AHD XX MPH	43	96	43	96
XX MIN DELAY AHEAD	26	87	25	83
CONSIDER ALT. ROUTE	12	100	5	42
blank	7	24	-	-

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

Conclusion

ADAPTIR had no effect on the speed and lane distribution of traffic within 2,000 feet of the lane closure taper. Also, ADAPTIR had no effect on the numbers and rates of forced merges in advance of the lane closure taper. However, it must be noted that, by coincidence, the before and after data for these performance measures were collected during periods of uncongested flow when messages were seldom displayed by the ADAPTIR VMSs. Consequently, the failure to observe significant differences in these performance measures before and after the deployment of ADAPTIR was not surprising.

Speed advisory messages displayed during periods of uncongested flow were not effective in reducing speeds. However, when traffic flow approached congestion levels, the speed advisory 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. Speed advisory messages displayed on the VMS farthest upstream of the work zone were not effective in reducing speeds because the VMS 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 VMS farthest upstream of the work zone and the next VMS was too long. Also, the effectiveness of the two VMSs 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 VMS closest to the work zone and the arrow board at the taper, where the speeds for its speed advisory messages were measured, may have also been too long. It was apparent the spacing between the VMSs influenced the effectiveness of the speed advisory messages. Further research is needed to determine the optimum spacing of the ADAPTIR VMSs, which may vary with traffic and roadway conditions.

The ADAPTIR diversion message was effective in encouraging about 3 percent of the drivers to divert from I-80 to an alternate route when there was more than 30 minutes of delay ahead. However, it was not effective in encouraging drivers not to enter I-80 when there was 30 minutes or more of delay ahead. Results of the driver survey suggest that its effectiveness could be improved if the diversion message specified the alternate route drivers should take. Nearly 80 percent of the drivers surveyed were not from Nebraska and were probably not familiar with the alternate route.

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 speed advisory and delay messages with which it was displayed, it was not seen or understood by drivers.

The speed advisory 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.

The delay and diversion messages were the messages most often noticed by drivers relative to the percentages of time they were displayed. However, the credibility of the delay message was questioned by some drivers who experienced delays much longer or shorter than those given in the message. Revising the message to include reason for delay and its location would improve its credibility and usefulness to drivers.

When there was no speed advisory, delay, or diversion to display, the VMSs 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 VMSs recalled seeing a blank VMS. But, only about 24 percent of those seeing a blank VMS understood what it meant. The remaining drivers thought the VMS was not working or simply didn’t know what it meant. However, the consequences of drivers’ misunderstanding blank VMSs seems 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 VMSs. Further research would be needed to examine the trade-offs between leaving VMSs blank when there is no real-time, condition-responsive message to display versus displaying a general message.

CRASH DATA ANALYSIS

Crash data during the period of the technology evaluations on I-80 in 1999 were compared to crash data for the same period during the three previous years in order to assess the overall safety impacts of the technologies. Copies of the driver's and investigator's motor vehicle accident reports were obtained from the NDOR for crashes that occurred on I-80 and the alternate routes between July 12 and August 29 in 1996, 1997, 1998, and 1999. The section of I-80 between the Highway 6 and Highway 31 interchanges was included in the analysis. The alternate routes included the following highway sections:

- Highway 6 between I-80 and Highway 31;
- Highway 31 between I-80 and Highway 6;
- Highway 63 between I-80 and Highway 6; and
- Highway 66 between I-80 and Highway 6.

In 1996, there was a long-term work zone on I-80 between the Highway 6 and Highway 31 interchanges during the evaluation period. But, there were no long-term work zones on this section of I-80 during this period in 1997 and 1998.

I-80

The number of crashes on I-80 during the evaluation period in each year is shown in Table 5-25. In 1999, the total number of crashes was 45, which was much higher than the 27 and 25 crashes occurring in 1997 and 1998, when there were no work zones on the section of I-80 between the Highway 6 and Highway 31 interchanges. The number of crashes in 1999 was only slightly higher than the 40 crashes in 1996, when there was a work zone on this section of I-80.

TABLE 5-25 Crashes on I-80.

	Type		Severity		
Year	Rearend	Other	PDO [a]	Other	Total
1996	20	20	18	22	40
1997	7	20	12	15	27
1998	4	21	11	14	25
1999	24	21	31	14	45

[a] Property-damage-only crashes.

The average daily traffic (ADT) between July 12 and August 29 in each year is shown in Table 5-26. The ADT increased by 4.5 percent, from 46,400 to 48,500 vehicles per day, between 1996 and 1999. In each year, the ADT was about 1,000 vehicles per day higher in the eastbound direction than it was in the westbound direction.

TABLE 5-26 Average daily traffic on I-80.

Year	ADT [a]		
	EB	WB	Total
1996	23,600	22,800	46,400
1997	23,900	22,900	46,800
1998	24,200	23,300	47,500
1999	24,700	23,800	48,500

[a] Average daily traffic between July 12 and August 29.

An analysis of covariance was conducted to determine the significance of the effects of the year and ADT on the number of crashes. The results of the analysis indicated the effect of year was statistically significant (α = 0.05). But, the effect of ADT was not significant.

The mean number of daily crashes on I-80 during the evaluation period in each year is shown in Table 5-27. A t test was used to determine the statistical significance of the differences among the mean values. As shown in the table, the results indicated the mean number of daily rearend, property-damage-only, and total crashes on I-80 in 1999 were significantly (α = 0.05) higher than the corresponding mean values in 1997 and 1998, when there were no work zones on this section of I-80. Also, there were no statistically significant (α = 0.05) differences between the corresponding mean values of crashes in 1999 and 1996 when there was a work zone on this section of I-80.

TABLE 5-27 Mean number of daily crashes on I-80.

Year	Type		Severity		Total
	Rearend	Other	PDO [a]	Other	
1996	0.408	0.408	0.367	0.449	0.816
1997	0.143	0.408	0.245	0.306	0.551
1998	0.082	0.429	0.224	0.286	0.510
1999	0.490	0.429	0.633	0.286	0.918

[a] Property-damage-only crashes.

(shaded) Significantly different from value for 1999 (α = 0.05).

The number of crashes by direction on I-80 in 1999 is shown in Table 5-28. The number of crashes (29) in the eastbound was about twice the number (16) in the westbound direction. However, the results of an analysis of covariance indicated the effects of direction and volume were not statistically significant (α = 0.05).

TABLE 5-28 Crashes by direction on I-80 in 1999.

Direction	Type		Severity		Total
	Rearend	Other	PDO [a]	Other	
Eastbound	15	14	21	8	29
Westbound	9	7	10	6	16
Total	24	21	31	14	45

[a] Property-damage-only crashes.

The mean number of daily crashes by direction on I-80 in 1999 is shown in Table 5-27. The results of t tests indicated there were no statistically significant ($\alpha = 0.05$) differences between the directional mean values.

TABLE 5-29 Mean number of daily crashes by direction on I-80 in 1999.

Direction	Type		Severity		Total
	Rearend	Other	PDO	Other	
Eastbound	0.306	0.286	0.426	0.163	0.592
Westbound	0.184	0.143	0.204	0.122	0.327

[a] Property-damage-only crashes.

▢ Significant difference between directional values ($\alpha = 0.05$).

Alternate Routes

The number of crashes on the alternate routes during the evaluation period each year is shown in Table 5-30. In 1999, the total number of crashes was 11, which was within the range of the numbers of the nine and 14 crashes occurring in 1997 and 1998, when there were no work zones on the section of I-80 between the Highway 6 and Highway 31 interchanges. The number of crashes on the alternate routes in 1999 was about twice the five crashes in 1996, when there was a work zone on this section of I-80.

The ADT between July 12 and August 29 on the alternate routes was not available. However, the ADT at a NDOR continuous traffic counting station on Highway 6 near Gretna increased by 25 percent, from 6,900 to 8,600 vehicles per day, between 1996 and 1999.

TABLE 5-30 Crashes on alternate routes.

Year	Type		Severity		Total
	Rearend	Other	PDO [a]	Other	
1996	3	2	3	2	5
1997	0	9	4	5	9
1998	3	11	7	7	14
1999	3	8	6	5	11

[a] Property-damage-only crashes.

The mean number of daily crashes on the alternate routes during the evaluation period in each year is shown in Table 5-31. A t test was used to determine the statistical significance of the differences among the mean values. As shown in the table, the results indicated there were no statistically significant ($\alpha = 0.05$) differences between the mean values in 1999 and the corresponding mean values in 1997 and 1998, when there were no work zones on the section of I-80 between the Highway 6 and Highway 31 interchanges. Also, there were no statistically significant ($\alpha = 0.05$) differences between the mean values in 1999 and the corresponding mean values in 1996, when there was a work zone on this section of I-80.

TABLE 5-31 Mean number of daily crashes on alternate routes.

Year	Type		Severity		Total
	Rearend	Other	PDO [a]	Other	
1996	0.061	0.041	0.061	0.041	0.102
1997	0	0.184	0.082	0.102	0.184
1998	0.061	0.224	0.143	0.143	0.286
1999	0.061	0.163	0.122	0.102	0.224

[a] Property-damage-only crashes.

▢ Significantly different from value for 1999 ($\alpha = 0.05$).

Conclusion

The presence of long-term work zones on I-80 in 1996 and 1999 significantly increased the number of crashes occurring on I-80 between the Highway 6 and Highway 31 interchanges. The work zones significantly increased the number of rearend and property-damage-only crashes. Other types and severities of crashes were not significantly affected by the presence of the work zones. However, the technologies evaluated in 1999 did not significantly affect the number or rate of crashes associated with long-term work zones on this section of I-80.