# Speed Reduction Effects of Speed Monitoring Displays with Radar in Work Zones on Interstate Highways

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The speed monitoring display is a traffic control device that uses radar to measure the speeds of approaching vehicles and shows these speeds to traffic on a digital display panel. It is intended to slow traffic by making drivers aware of how fast they are traveling. In addition, it is expected that its radar will also cause some drivers using radar detectors to slow down. The effectiveness of this device was evaluated at a work zone on an interstate highway in South Dakota. The speed monitoring display reduced mean speeds and excessive speeds on the approach to the work zone. Mean speeds were reduced by 6 to 8 km/hr (4 to 5 mi/hr), and the percentages of vehicle exceeding the advisory speed limit of 72 km/hr (45 mi/hr) were reduced by 20 to 40 percentage points. These speed reductions are greater than those reported for the use of radar alone.

The safety of workers and the traveling public in highway work zones is a major concern of highway agencies. Several studies (*1*) have found that the rate and severity of traffic accidents in highway work zones are significantly higher than those on normal roadway sections. Excessive speed is among the contributing circumstances most often reported for work zone accidents (*1,2*). Likewise, the accident experience in highway work zones in South Dakota has been a concern of the South Dakota Department of Transportation (SDDOT). During the 9-year period between 1983 and 1992, nearly 1,600 accidents occurred in work zones, which resulted in 18 fatalities and more than 800 injuries (*3*). Again, excessive speed was frequently cited as a contributing factor in these accidents.

In an effort to address the problem of excessive speeds in highway work zones, the SDDOT initiated a study to evaluate traffic control devices designed to reduce traffic speeds in work zones. The first task of the research was to conduct a review of the literature and current practice to identify traffic control devices with the potential to reduce speeds in work zones. In addition, the accident experience in work zones on highways in South Dakota was reviewed to identify the types of work zones that represented the most serious safety problems. Based on the findings of the review and the results of the accident data analysis, candidate traffic control devices were ranked according to their potential effectiveness, ease of implementation, advantages and disadvantages, cost, and applicability in work zones that represent the greatest safety problems in South Dakota. The traffic control devices with the highest rankings were selected by SDDOT for field testing. The speed monitoring display was among the devices selected for testing in work zones on interstate highways.

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## SPEED MONITORING DISPLAY

The speed monitoring display is a device that measures and displays the speeds of approaching vehicles. The objective is to reduce traffic speeds by making drivers aware of how fast they are traveling. The speeds are measured by radar and presented to the drivers on a digital display panel. The application of the speed monitoring display found in the literature was on urban streets. Reductions in speeds of up to 32 km/hr (20 mi/hr) were observed with its use on streets in Berkeley, California (*4*). Although these observations were not substantiated statistically, they suggested that the speed monitoring display might be effective in reducing speeds in work zones.

The particular speed monitoring display evaluated in this study is shown in Figure 1. It was a portable, self-contained, solar-powered trailer unit that was fabricated by the SDDOT. The speed display panel was 508 mm (20 in.) high and 711 mm (28 in.) wide, and it had a three-digit readout with 229-mm (9-in.) high digits. The sign assembly mounted above the speed display panel included a WORK ZONE warning sign [914 mm (36 in.) by 914 mm (36 in.)], an advisory speed plate [W13–1, 610 mm (24 in.) by 610 mm (24 in.)], and a YOUR SPEED guide sign [305 mm (12 in.) by 1524 mm (60 in.)]. All of the signs in the assembly were orange with black legends. A Type I barricade panel [305 mm (12 in.) by 1524 mm (60 in.)] was mounted below the speed display panel.

## STUDY SITE

The speed monitoring display was tested at a bridge-replacement work zone on westbound Interstate 90 near Sioux Falls, South Dakota. The annual average daily traffic (AADT) on Interstate 90 at this location was 9,000 vehicles per day. The work zone was on an urban section of the interstate; therefore, the normal speed limit was 88 km/hr (55 mi/hr). The right lane of the two westbound lanes was closed in advance of a median crossover. Vehicles traveling in the westbound lanes were observed during the field study. A layout of the study site is shown in Figure 2.

The traffic control plan was a typical SDDOT plan for a long-term lane closure on an interstate highway, which is consistent with the *Manual on Uniform Traffic Control Devices for Streets and Highways.* (*5*) The following sequence of traffic control devices was located on both sides of the westbound lanes:

1. ROAD CONSTRUCTION AHEAD signs about 1,434 m (4,700 ft) in advance of the lane closure taper.
2. RIGHT LANE CLOSED AHEAD signs about 671 m (2,200 ft) in advance of the lane closure taper.


**FIGURE 1 Speed monitoring display.**

3. RIGHT LANE CLOSED 1500 FT signs with warning lights about 534 m (1,750 ft) in advance of the lane closure taper.
4. Symbolic "lane transition reduction on the right" signs with 45 mi/hr advisory speed plates about 137 m (450 ft) in advance of the lane closure taper.

There was an advance warning arrow panel at the beginning of the 205 m (672 ft) lane closure taper. The taper was delineated by channelizing drums with warning lights spaced at approximately 15-m (50-ft) intervals and white raised pavement markers spaced at 1.5-m (5-ft) intervals. About 220 m (720 ft) beyond the end of the taper, symbolic "left reverse turn" warning signs with 30 mi/hr advisory speed plates were located on both sides of the roadway in advance of the median crossover.

Two speed monitoring displays were installed about 95 m (310 ft) in advance of the lane closure taper. The displays were positioned at the edge of the shoulder on each side of the roadway. The placement of the displays is shown in Figure 3.

Two photographs of the study site are shown in Figure 4. The photograph in Figure 4(*a*) was taken about 702 m (2,300 ft) in advance of the lane closure taper. It shows the approach to the lane closure, which was on a tangent, nearly level section of roadway. It also shows the exit ramp that was located on the approach about 183 m (600 ft) in advance of the lane closure taper. The photograph in Figure 4(*b*) was taken from the overpass at the beginning of the taper. It shows the taper and the entrance ramp located at the end of the taper.

It should be noted that the work area was not visible to traffic on the study approach. Therefore, the activity in the work area did not influence the speed of traffic on the study approach.

## DATA COLLECTION

Data were collected before and after the speed monitoring displays were installed. The before study was conducted on Monday, July 12, 1993. The speed monitoring displays were installed on Tuesday, July 13, 1993. In an effort to reduce the chances of simply observ-

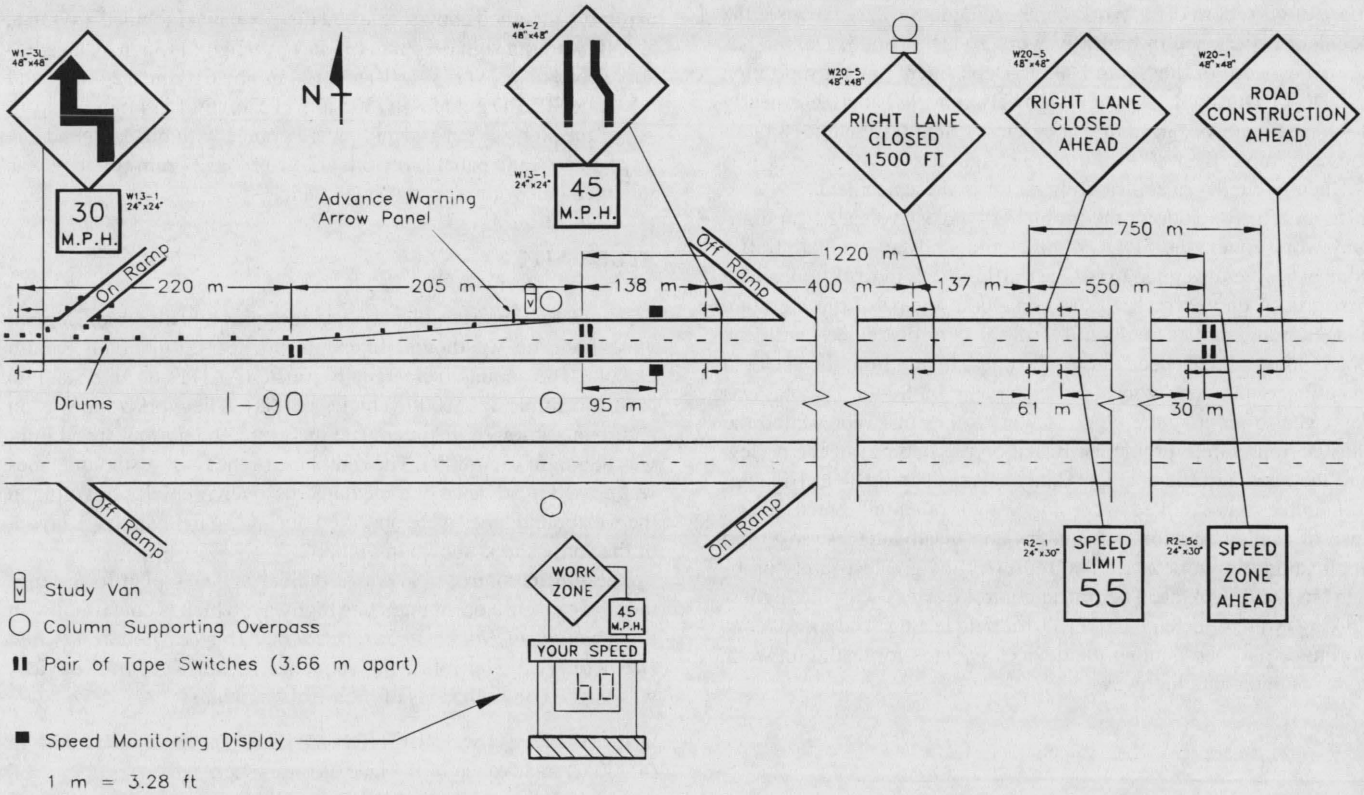



**FIGURE 2 Study site plan.**

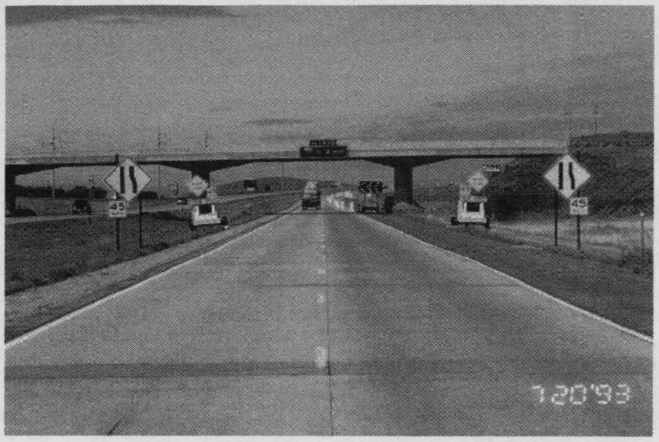


**FIGURE 3 Speed monitoring display installation.**

ing the novelty effects of the displays, the after study was not conducted until Tuesday, July 20, 1993, about 7 days after the displays had been installed.

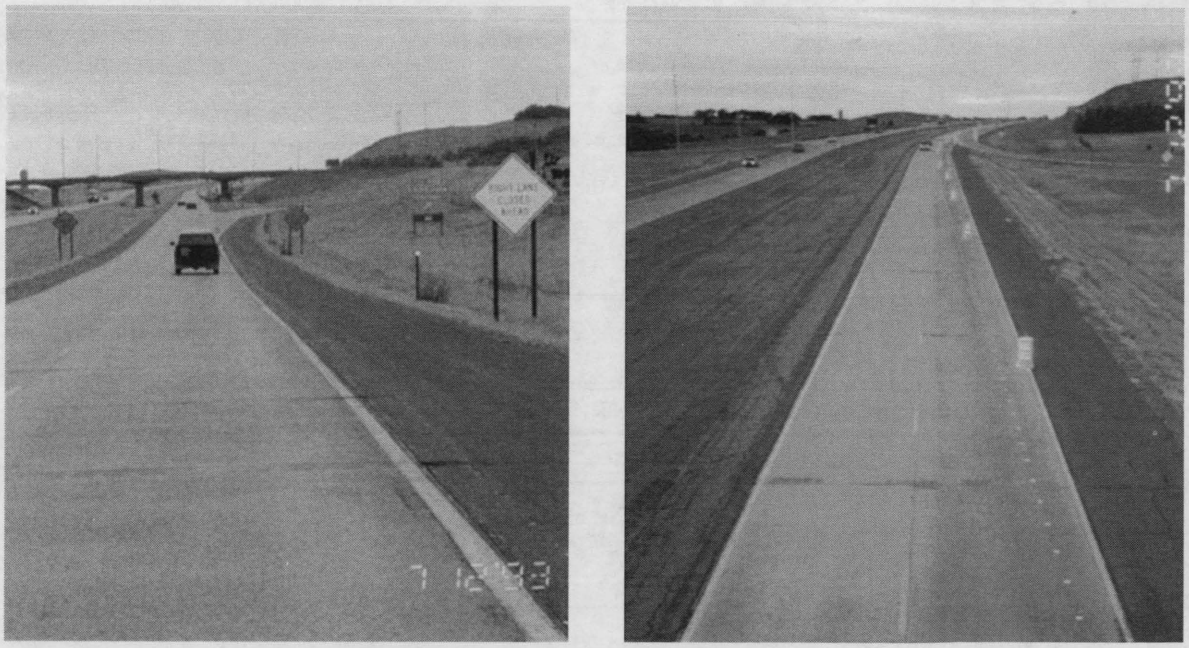
The data were collected during daylight between the hours of 9:00 a.m. and 5:00 p.m. The weather on both study days was fair to partly cloudy with no precipitation. The pavement surface was dry.

The data were collected with tape switches at three locations in advance of the work zone as shown in Figure 2. The first location (Station 1) was about 200 m (650 ft) downstream of the ROAD CONSTRUCTION AHEAD signs and 1,220 m (4,000 ft) in advance of the lane closure taper. The second location (Station 2) was at the beginning of the lane closure taper, and the third location (Station 3) was at the end of the taper. At each location, tape switches were installed in the open lanes. Two lanes were open to traffic at Stations 1 and 2, and only one lane was open to traffic at Station 3. Speed, volume, headway, and vehicle classification data were collected by the tape switches at each station.

Traffic operations on the entrance ramp and in the merge area immediately downstream of the taper were videotaped to record when entrance ramp vehicles may have influenced vehicles on the study approach. The video-camera clock was synchronized with the clock in the computer that recorded the tape switch data so that the two data sets could be coordinated during data analysis. Both the video camera and the computer were located in the study van where observers monitored their operation. The study van was parked behind a column of the crossroad overpass near the beginning of the taper as shown in Figure 5. Although a portion of the van could be seen by approaching traffic, the presence of the van was not observed to influence traffic behavior. It was parked in a "non-threatening" manner, facing away from the roadway so that it would not appear as though it was involved in speed-limit enforcement or about to enter the freeway. In addition, as can be seen in Figure 3, there was considerable visual stimuli provided by the advance warning arrow panel and the other traffic control devices on the approach, which reduced the conspicuity of the van. Also, because the same study van was located in exactly the same position during the before and after studies, its influence on traffic would be about the same in both studies. Therefore, its effect would be eliminated in the comparison of traffic speeds before and after the installation of the speed monitoring displays.

## DATA ANALYSIS

The speed monitoring displays were intended to slow traffic by making drivers aware of how fast they were traveling. Therefore,



(*a*) (*b*)

**FIGURE 4 Views of study site: (*a*) approach; (*b*) lane closure taper.**


**FIGURE 5 Location of data collection van.**

the data analysis examined the difference in approach speeds before and after the displays were installed. In particular, the reductions in mean speeds and excessive speeds were examined.

The speeds used in the analysis were those of "free flowing" vehicles, which were vehicles that were not influenced by other vehicles. A vehicle was determined to be free flowing if the following conditions existed when it traveled through the study site:

- There were no vehicles on the entrance ramp downstream of the taper.
- The headway between it and the vehicle ahead was more than 4 sec.

The sample sizes observed in the before and after studies are shown in Table 1. Station 1 was the farthest from the lane closure taper. It was 1,220 m (4,000 ft) in advance of the taper. Station 2 was at the beginning of the taper, and Station 3 was at the end of the taper. The sample sizes were smaller at Station 2 than they were at Station 1 because some vehicles left the interstate on the exit ramp between Stations 1 and 2. The sample sizes were slightly smaller at Station 3, because more vehicles at this location were traveling at headways that were less than 4 sec after the two approach lanes had merged into one lane at the end of the taper. Also, in a few cases, vehicles had arrived on the downstream entrance ramp by the time free-flowing vehicles at Station 2 had arrived at Station 3.

In the before study, 83 to 86 percent of the vehicles were two-axle vehicles (e.g., passenger cars, vans, and pickup trucks), and 14 to 17 percent of them had more than two axles (e.g., passenger cars, vans, and pickup trucks with trailers, and trucks). In the after study, a slightly lower percentage of two-axle vehicles was observed. Only 81 to 84 percent of the vehicles had two axles, and 16 to 19 percent had more than two axles.

### Mean Speeds

The mean speeds observed before and after the installation of the speed monitoring displays are shown in Table 2. As expected, the speed of traffic decreased as it approached the work zone in both the

**TABLE 1 Sample Sizes**

| | Before Study | | | After Study | | |
|---|---|---|---|---|---|---|
| Station[a] | Vehicles With 2 Axles | Vehicles With > 2 Axles | All Vehicles | Vehicles With 2 Axles | Vehicles With > 2 Axles | All Vehicles |
| 1 | 1,820 | 298 | 2,118 | 1,668 | 312 | 1,980 |
| 2 | 1,338 | 261 | 1,599 | 1,197 | 281 | 1,478 |
| 3 | 1,285 | 266 | 1,551 | 1,161 | 267 | 1,428 |

[a]Station 1 is 1,220 m (4,000 ft) in advance of the taper.
Station 2 is at the beginning of the taper.
Station 3 is at the end of the taper.

**TABLE 2 Mean Speeds (km/hr)**

| | Vehicles With 2 Axles | | Vehicles With > 2 Axles | | All Vehicles | |
|---|---|---|---|---|---|---|
| Station[a] | Before | After | Before | After | Before | After |
| 1 | 105.6 | 105.5 | 100.2 | 100.2 | 104.8 | 104.7 |
| 2 | 98.1 | 92.3 | 93.6 | 85.5 | 97.4 | 91.0 |
| 3 | 97.3 | 91.3 | 92.3 | 84.4 | 96.5 | 90.0 |

1 km/hr = 0.62 mph.
[a] Station 1 is 1,220 m (4,000 ft) in advance of the taper.
Station 2 is at the beginning of the taper.
Station 3 is at the end of the taper.

**TABLE 3 Partial Sums of Squares at Station 2**

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Squares | F value | p value |
|---|---|---|---|---|---|
| Speed at Station 1 | 1 | 1,153 | 1,153 | 13.87 | 0.0002 |
| Number of Axles (2, 3, 4, 5, or 6) | 4 | 11,414 | 2,854 | 34.30 | 0.0001 |
| Study Type (Before or After) | 1 | 2,871 | 2,871 | 34.51 | 0.0001 |
| Interaction of Study Type and Number of Axles | 4 | 868 | 217 | 2.61 | 0.0339 |

**TABLE 4 Partial Sums of Squares at Station 3**

| Source of Variation | Degrees of Freedom | Sum of Squares | Mean Squares | F value | p value |
|---|---|---|---|---|---|
| Speed at Station 1 | 1 | 897 | 897 | 11.95 | 0.0006 |
| Number of Axles (2, 3, 4, 5, or 6) | 4 | 13,867 | 3,467 | 46.17 | 0.0001 |
| Study Type (Before or After) | 1 | 22,325 | 22,325 | 297.33 | 0.0001 |

before and after studies. In each vehicle class, the mean speeds at Station 1 were higher than those at Station 2, and the mean speeds at Station 2 were higher than those at Station 3. Also, at each station, the mean speed of vehicles with two axles was higher than that of vehicles with more than two axles in both the before and after studies.

The data in Table 2 also indicate that the speed monitoring displays did reduce the mean speeds at Stations 2 and 3. In each vehicle class, the mean speeds observed at these stations in the after study were lower than the mean speeds observed in the before study. The mean speeds of the two-axle vehicles were reduced by about 6 km/hr (4 mi/hr), and the mean speeds of the vehicles with more than two axles were reduced by about 8 km/hr (5 mi/hr).

An analysis of variance was conducted to determine the statistical significance of the differences in the before and after mean speeds at Stations 2 and 3. In the analysis, time of day and number of axles were used as blocking factors because they were expected to have influenced the vehicle speeds. In general, traffic speeds are lower during periods of higher traffic volumes, and because traffic volume varied throughout the day, time of day was used as a blocking factor in the analysis. The differences in mean speeds observed between the vehicle classes shown in Table 2 indicated that the number of axles may affect vehicle speeds and therefore should be used as a blocking factor.

Another factor that would be expected to influence a vehicle's speeds at Stations 2 and 3 was its speed at Station 1. The faster a vehicle is traveling at Station 1, the faster it would be expected to be traveling at Stations 2 and 3. However, it was not possible to accurately track vehicles over the 1,220 m (4,000 ft) between Stations 1 and 2. Therefore, the average speed at Station 1 during the same hour of the time of day when the vehicle's speeds were recorded at Stations 2 and 3 was used as a covariate to account for the possible effect of speed at Station 1.

Thus, the effects of time of day, number of axles, and speed at Station 1 were accounted for in the analysis. In addition, all two-factor interactions were considered, and those that were not significant were eliminated. The analysis was performed using the General Linear Analysis Procedure of the Statistical Analysis System. (*6*)

The partial sums of squares from the analysis of variance at Stations 2 and 3 are shown in Tables 3 and 4, respectively. These results indicate that the speed monitoring displays had a significant effect on the mean speeds at both stations because the effect of study type (before or after) was significant ($p$-value = 0.0001). The effects of the average speed at Station 1 during the same hour of the day and the number of axles were also significant at both stations. In addition, the effect of the interaction of study type and number of axles was significant at Station 2 (the beginning of the taper). As shown in Figure 6, this interaction indicated that vehicles with more than two axles, especially those with more than four, reduced their speeds more in response to the speed monitoring displays.

The experimental design used in this study was not balanced, because the sample sizes in the cells defined by the experimental factors were not equal and the covariate did not have the same mean value in every cell. Therefore, the best estimate of effect of the speed monitoring displays would be the least-square mean speeds, which account for differences in cell sample sizes and covariate mean values. They are the mean speeds that would be expected if the mean values of the blocking factors and the average speed at Station 1 were the same in the before and after studies. The least-square mean speeds are shown in Table 5. These data indicate that the speed monitoring displays reduced the mean speed of traffic by 7.6 km/hr (4.7 mi/hr) at Station 2 and 6.1 km/hr (3.8 mi/hr) at Station 3.

**TABLE 5 Least-Square Mean Speeds (km/hr)**

| Station[a] | Before | After | Difference |
|---|---|---|---|
| 2 | 95.2 | 87.6 | -7.6 |
| 3 | 93.2 | 87.1 | -6.1 |

1 km/hr = 0.62 mph.
[a] Station 2 is at the beginning of the taper. Station 3 is at the end of the taper.

## Excessive Speeds

Previous studies(*7–9*) have found that speed reduction measures involving radar have a more pronounced effect on vehicles exceeding the speed limit. These studies have also found that truck speeds are usually reduced more than passenger car speeds, which has been attributed to the higher percentage of trucks using radar detectors.

The speed distributions at Station 1 are shown in Figure 7. At this location, 1,220 m (4,000 ft) in advance of the taper, where the speed limit was 105 km/hr (65 mi/hr), the speed distributions within each vehicle class were about the same before and after the speed monitoring displays were installed. The results of chi-square tests indicated that there was no significant difference between the distributions within each vehicle class at the 0.05 level of significance.

The percentages of vehicles exceeding the advisory speed limit of 72 km/hr (45 mi/hr) at Stations 2 and 3 are shown in Figure 8. At each station, the percentages of vehicles traveling at excessive speeds within each vehicle class were reduced after the speed monitoring displays were installed. The results of chi-square tests of these percentages within each vehicle class, at each station, indicated that these reductions were significant at the 0.05 level of significance. Comparison of the percentages between vehicle classes suggests that the reductions in excessive speeds at Stations 2 and 3 were greater for vehicles with more than two axles than they were for two-axle vehicles.

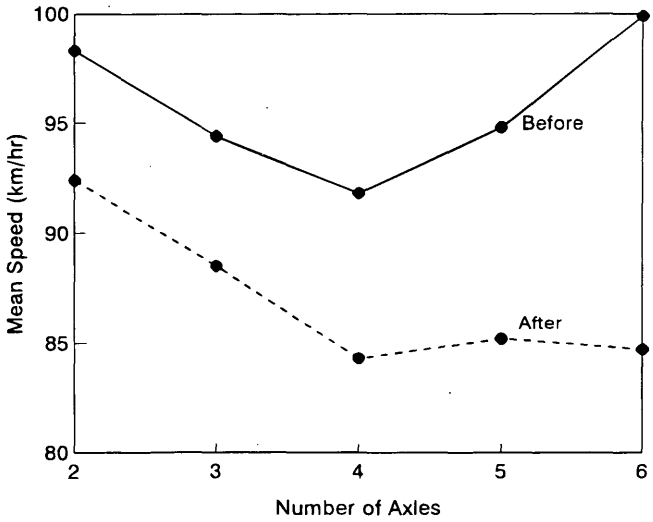



**FIGURE 6 Mean speeds at Station 2.**

The percentages of vehicles exceeding the speed limit by more than 16 km/hr (10 mi/hr) are shown in Table 6. At Station 1, where the speed limit was 105 km/hr (65 mi/hr), the before and after percentages were nearly the same. The results of chi-square tests indicated that there were no significant differences between the before and after percentages within each vehicle class. However, at Stations 2 and 3, the differences between the before and after percentages within each vehicle class were significant. After the speed

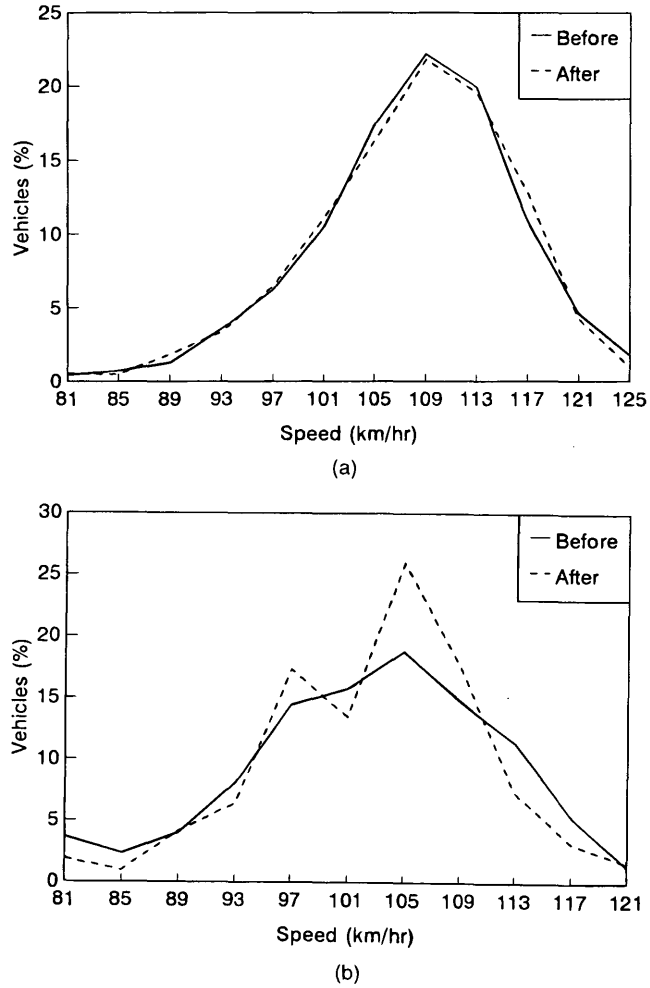



**FIGURE 7 Speed distributions at Station 1: (*a*) two-axle vehicles; (*b*) vehicles with more than two axles.**

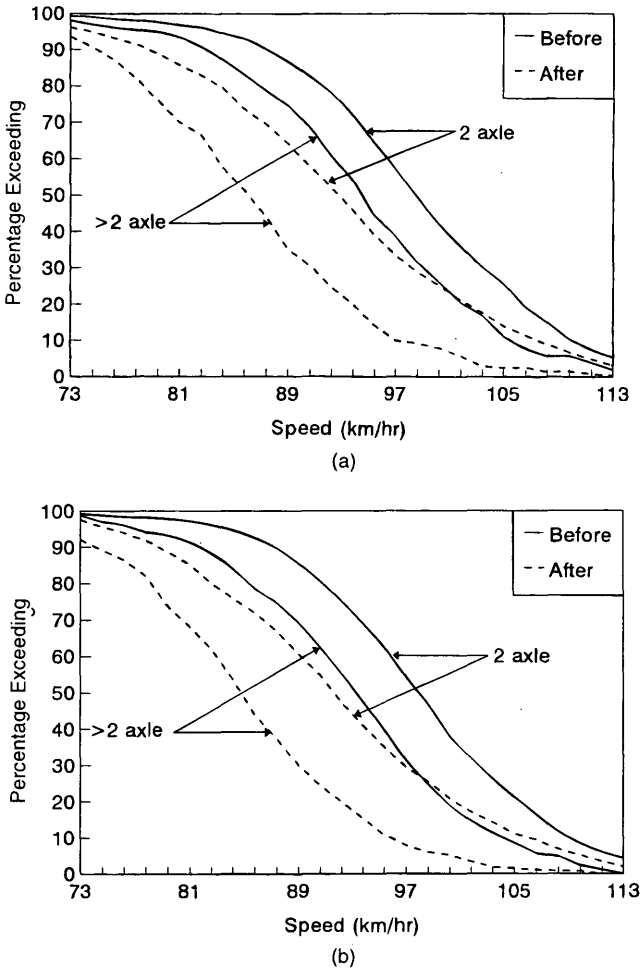



**FIGURE 8 Percentage of vehicles exceeding advisory speed limit: (*a*) Station 2; (*b*) Station 3.**

monitoring displays were installed, the percentages of two-axle vehicles exceeding the advisory speed limit of 72 km/hr (45 mi/hr) at Stations 2 and 3 were reduced by about 20 to 25 percentage points. The reductions in the percentages of vehicles with more than two axles were much higher. They were reduced by about 40 percentage points.

## CONCLUSION

The data indicate that the speed monitoring displays with radar were effective in reducing the speed of traffic approaching the work zone. The mean speeds were about 6 to 8 km/hr (4 to 5 mi/hr) lower after the speed monitoring displays were installed. In addition, the speeds of vehicles exceeding the advisory speed limit of the work zone were reduced significantly, and the percentages of vehicles exceeding the advisory speed limit by more than 16 km/hr (10 mi/hr) were reduced by as much as 40 percentage points.

These reductions are greater than those found in previous studies of radar alone (*7–9*). In long-term work zones on interstate highways, radar alone has been found to reduce mean speeds by only about 2 to 3 km/hr (1 to 2 mi/hr), and the percentages of vehicles exceeding the speed limit by more than 16 km/hr (10 mi/hr) have been reduced by only about 10 percentage points. Therefore, the speed monitoring displays with radar seem to be more effective than radar alone.

However, it should be noted that the effectiveness of the speed monitoring displays may have been limited by the design of its sign assembly and its close proximity to other work zone traffic control devices on the study approach. The sign assembly included a WORK ZONE warning sign and a 45 mi/hr advisory speed plate in addition to the speed display panel. Thus, the sign assembly may have contained too much information for some drivers to comprehend. Also, according to SDDOT guidelines, the spacing between the speed monitoring displays and the other traffic control devices on the approach to the lane closure should have been about 180 m (600 ft). However, as shown in Figure 2, the speed monitoring displays were only 43 m (140 ft) downstream from the symbolic "lane transition reduction to the right" signs with 45 mi/hr advisory speed plates and only 95 m (310 ft) upstream from the advance warning arrow panel at the beginning of the lane closure taper. These relatively short distances may have reduced the conspicuity of the speed monitoring displays and may not have been sufficient for some drivers to comprehend the speed monitoring displays. Therefore, the SDDOT is planning further study to determine the optimum design and location of the speed monitoring displays.

## ACKNOWLEDGMENT

This work was performed under the supervision of the SDDOT Technical Panel SD93–10. Members of the panel were Jim Cooper

**TABLE 6 Percentage of Vehicles Exceeding Speed Limit by More Than 16 km/hr**

| | Vehicles With 2 Axles | | Vehicles With > 2 Axles | | All Vehicles | |
|---|---|---|---|---|---|---|
| Station[b] | Before | After | Before | After | Before | After |
| 1 | 2.3 | 1.5 | 0.0 | 1.0 | 2.0 | 1.4 |
| 2 | 86.8 | 65.1[b] | 74.7 | 35.2[b] | 84.8 | 59.4[b] |
| 3 | 85.5 | 60.7[b] | 69.2 | 30.0[b] | 82.7 | 55.0[b] |

1 km/hr = 0.62 mph.
[a] Station 1 is 1,220 m (4,000 ft) in advance of the taper.
Station 2 is at the beginning of the taper.
Station 3 is at the end of the taper.
[b] Significantly different than the before percentage (0.05 level of significance).

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