PAPER NO. 01-2261

EVALUATION OF SPEED DISPLAYS AND RUMBLE STRIPS AT RURAL MAINTENANCE WORK ZONES

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Paper prepared for the 80th Annual Meeting of the
Transportation Research Board
Washington, D.C.,
January 7-11, 2001

ABSTRACT

This paper describes an evaluation of the effectiveness of speed displays and portable rumble strips at reducing speeds in rural maintenance work zones. Speed displays are radar-activated signs that dynamically display oncoming vehicle speeds in large numerals. The devices were tested on low-volume, high-speed rural roads where maintenance activities were completed in a single day. All work zone sites were two-lane facilities with 3 m (10 ft) shoulders. Speed and volume data were collected for cars and trucks as they traveled through four work zones. These data were collected when no work zone traffic control was present, when normal work zone traffic control was set up, and when the speed display or portable rumble strips were installed.

The results for the portable rumble strips were mixed, with passenger cars experiencing less than a 3.2 km/h (2 mph) reduction in mean speed approaching the temporary traffic control zone. The impact of the rumble strips on trucks was more pronounced, with significant mean speed reductions approaching the temporary traffic control zone of up to 11.6 km/h (7.2 mph) less than normal traffic control. The percent of vehicles exceeding the speed limit in the advance warning area was also reduced when the rumble strips were in place.

The speed display was generally more effective than the rumble strips at reducing vehicle speeds in the advance warning area. Mean speeds were often significantly reduced as both cars and trucks approached the work zone, with speed reductions of up to 16.1 km/h (10 mph) being achieved. The percentage of vehicles exceeding the speed limit was also reduced in the advance warning area from when only normal work zone traffic control was used.

INTRODUCTION

The Texas Department of Public Safety reported that 10,273 crashes occurred in Texas work zones in 1998, representing 6 percent of all collisions that occurred on the state road system. These crashes resulted in 132 deaths and 11,514 injuries. As part of their continuing effort to improve safety in work zones, the Texas Department of Transportation (TxDOT) initiated a project to evaluate the effectiveness of innovative traffic control devices in rural maintenance work zones.

Most rural maintenance work zones in Texas occur on low volume roads that have a regulatory speed limit of 112.7 km/h (70 mph). Activities at these work zones typically last no more than a day, with traffic control being removed each day by dusk. The short duration of these work zones also makes it difficult to coordinate with law enforcement agencies for work zone speed control. Maintenance crews need devices that effectively reduce speeds in these work zones and can be installed by the work crew. Devices should be able to be installed in a minimal amount of time so as not to provide an impediment to the completion of the maintenance activities.

Two devices that may be suitable for application in rural maintenance work zones are speed displays and portable rumble strips. A recent study performed by the Texas Transportation Institute (TTI) evaluated the effectiveness of speed displays at a short-term work zone on a four-lane divided highway (*1*). Speed displays are radar-activated signs that display the speed of approaching vehicles. Figure 1 shows an example of a speed display. The TTI study found that the display created speed reductions of about 8.0 km/h (5 mph) within the activity area when compared to normal traffic control. Another recent study performed in Kansas examined the effectiveness of portable rumble strips upstream of the temporary traffic control zone with a portable traffic signal (*2*). This study found that mean speeds decreased between 0 to 3.2 km/h (2 mph) when the rumble strips were installed, although site conditions may have had an impact on speeds. The Kansas study also found that the rumble strips that were tested were probably spaced too closely together and were not thick enough to create significant speed reductions.

This evaluation expanded upon these previous studies of speed displays and rumble strips in rural work zones. The speed display was re-examined to determine if its effectiveness on two lane roads rather than four lane roads. The dimensions of the rumble strips tested in this study were different from those used in the Kansas evaluation. The rumble strips tested were double the thickness of those used in Kansas (64 mm vs. 32 mm thick), and were also spaced further apart (45.7 cm vs. 30.5 cm).

STUDY DESCRIPTION

Purpose and Scope

The purpose of this study was to evaluate the performance of speed displays and portable rumble strips at rural maintenance work zones. Throughout this paper, the term “rural maintenance work zone” will be used to refer to work zones on low-volume, two lane roads with

112.7 km/h (70 mph) speed limits where work is completed within a day. The following specific goals were established as part of this evaluation:

- Evaluate the usability of these devices for rural maintenance work zones.
- Determine if portable rumble strips produce lower speeds in rural maintenance work zones than normal work zone traffic control.
- Determine if speed displays produce lower speeds in rural maintenance work zones than normal work zone traffic control.
- Determine if portable rumble strips and speed displays impact cars and trucks differently.
- Determine if portable rumble strips and speed displays can reduce the percentage of speeding vehicles.

Speed Display

Speed displays create speed reductions in two ways. First, drivers tend to slow once they see their speed shown on the display. Second, the radar unit in the display will activate radar detectors far in advance of the work zone. This may influence drivers to slow down due to the perceived presence of a police officer.

This evaluation utilized a SPEEDGUARD trailer-mounted speed display provided by TxDOT. Figure 1 shows the speed display used in this evaluation. The SPEEDGUARD features a 61.0 cm (24-inch) LED display and uses Ka-band radar to detect oncoming vehicles. The display has a strobe lamp that flashes when a vehicle is detected traveling over a preset speed threshold. This feature is intended to simulate the operation of photo radar, possibly decreasing speeds through the threat of automated enforcement. During this evaluation, the speed threshold for the strobe light was set at 120.7 km/h (75 mph). The display also has a 130 dB siren that can be activated by vehicles traveling over a preset speed. This option is intended to warn workers when an extremely high-speed vehicle is approaching, but was not used in this evaluation due to concerns about battery drain.

Portable Rumble Strips

The rumble strips were used in this study to provide an additional warning to drivers that they were about to enter a work zone. The strips provide an auditory and vibratory warning to the driver of the upcoming work zone. The rumble strips tested were also bright orange, providing a visual cue that the driver is about to enter the work zone.

The portable rumble strips tested were manufactured by Advanced Traffic Markings. The rumble strips were shipped as pre-cut 3.7 m (12 feet) long rolls. Each strip was 10 cm (4 inches) wide and 0.32 cm (1/8 inch) thick. The rumble strips were orange in color, and were applied to the pavement by removing the protective back and adhering the strips to the pavement. Six individual strips were used at each location rumble strips were placed in the work zone. These strips were placed 45.7 cm (18 inches) from one another. A weighted tamping cart or roller can be used to better attach the strips to the pavement. Figure 2 shows the application of the strips to the pavement. For this study, 0.64 cm (¼ inch) thick rumble strips were created by applying rumble strips to each other.

Methodology

Data were collected at four short term, rural maintenance work zones. Prior to the set up of work zone traffic control, free flow speeds were collected using a LIDAR (light detection and ranging) gun. Data were then collected while the work was underway. First, traffic data were collected while the normal work zone traffic control was in place. Approximately halfway through the day, the test treatment (either the speed display or portable rumble strips) was installed, and additional data were collected. Since work was completed in one day at each site, both the before and after period data were collected in the same day.

Traffic counters were used to collect speed and volume data as vehicles approached the work zone. The counter data provided spot speeds and traffic volumes. Data were collected during the day, and weather conditions were clear each day. All vehicles were classified as either cars or trucks. Cars were defined to consist of passenger cars, minivans, sport utility vehicles, and pickup trucks. Trucks were characterized as consisting of tractor-trailers and single unit trucks. Data were collected at the following locations:

- Upstream of the temporary traffic control zone prior to traffic control being visible
- At the "Road Work – Traffic Fines Double" sign (R20-5)
- At the "Road Work Ahead Signs" (CW 20-1D)
- At the "Left Lane Closed Ahead" (CW 20-5R) or "Reverse Curve" (CW 1-4R) sign
- Within the work zone activity area

Due to equipment malfunctions, data were not always available at all of these points. The available speed data were used to compare the before and after speeds at each station to determine if the display has a significant effect on speeds.

Data Collection Sites and Test Configuration

Four test sites in the TxDOT Childress district were used in this evaluation. All four sites were rural maintenance work zones where the traffic control was set up in the morning and removed by dusk each day. Horizontal and vertical alignments were gentle at all locations. No regulatory or advisory speed limit signs were located within the study areas. The study site locations, devices tested, and dates of data collection were:

- US 83 NB, rumble strips, May 3, 2000 (Site 1)
- US 83 NB, rumble strips, May 4, 2000 (Site 2)
- US 62 EB, speed display, June 20, 2000 (Site 3)
- US 62 EB, speed display, June 22, 2000 (Site 4)

The US 83 sites were located in a rural area approximately 16 km (10 miles) north of a small city with a population of 5000. US 83 is a north-south two-lane road with 3.0 m (10 feet) wide shoulders. The average daily traffic (ADT) of the road is 1850 vehicles per day. The speed

limit was posted at 112.7 km/h (70 mph) for both cars and trucks. The maintenance crew was pouring hot-mix asphalt onto the southbound travel lane, and all northbound traffic was being diverted onto the shoulder. The activity area was approximately 1.0 km (0.6 miles) long both days.

Two sets of six rumble strips were installed each day. Each set of rumble strips was placed perpendicular to the direction of travel, and each of the six strips in each set were spaced 45.7 cm (18 inches) from one another. The first set of six rumble strips were located halfway between the "Road Work –Traffic Fines Double" and the "Road Work Ahead" signs. The second set of rumble strips were located halfway between the "Road Work Ahead" signs and the "Left Lane Closed Ahead" sign. The rumble strips were placed at the same location both days.

The US 62 sites were located in a rural area approximately 32 km (20 miles) from the nearest population center. US 62 is an east-west two lane road with 3.0 m (10 feet) wide shoulders and an ADT of approximately 1000 vehicles per day. The study sites were located about 16 km (10 miles) from the Texas border with Oklahoma. The speed limit was posted at 112.7 km/h (70 mph) for both cars and trucks. The maintenance crew was pouring hot mix asphalt onto the through travel lanes, and all through traffic was diverted onto the shoulders. A flagman was stationed at the taper of the work zone. He displayed the "SLOW" indication on his paddle, and never stopped traffic. The activity area was approximately 1 km (0.6 miles) long both days. The speed display was located 945 m (3100 feet) from the work zone taper (about halfway between the "Road Work – Traffic Fines Double" and the "Road Work Ahead" signs) at site 3, and 707 m (2320 feet) from the taper (about halfway between the "Road Work Ahead" and Reverse Curve signs) at site 4.

The locations of the data collection locations relative to the taper are shown in Table 1. Figure 3 shows the layouts of the study sites.

USE OF DEVICES FOR TEMPORARY MAINTENANCE ACTIVITIES

The speed display was quick and easy to install, making it appropriate for short-term maintenance activities. The display could be set-up within 10 minutes, and positioning was quick and easy. The speed thresholds for the strobe light were set by dialing the proper speed on an indicator. Battery drain was not a problem, and TxDOT personnel indicated that the device could operate for at least 3 days without recharging the battery. Removal of the display involved opening the cabinet, turning the power off, and attaching the display to a towing vehicle.

Installation and removal of the rumble strips was more complicated than for the speed display. The rumble strips were firmly applied to the pavement using a tamping cart at 45.7 cm (18 inch) intervals. The strips were applied to a dry road in 32 °C (90°F) temperatures. The adhesive immediately bonded to the road, and the strips remained firmly attached to the road throughout the data collection. It took three workers about 20 minutes to install each set of rumble strips, yielding a total installation time of approximately 40 minutes for both sets. After data collection was completed, the rumble strips were removed from the road by grabbing a corner of the strip and peeling it from the pavement. The strips were not reusable.

The impact of these devices on the behavior of traffic was also observed. While the majority of the vehicles exposed to the speed display reduced speed, occasionally the display would cause drivers to accelerate. These drivers accelerated in an effort to see how high they could get the display to read. One driver was observed to do this at the two test sites. Erratic maneuvers in the vicinity of the rumble strips were also observed. During the two days of data collection, two vehicles attempted to go around the rumble strips. Both vehicles went into the southbound lane to go around the rumble strips. These maneuvers happened in a passing zone when there was no oncoming traffic.

SPEED RESULTS

The speed reduction benefits of the speed display and the rumble strips compared to normal work zone traffic control were evaluated. Table 2 summaries the average speeds collected at each site. Column A shows the free flow speeds at the site without any work zone traffic control present. Free flow speeds were consistent throughout each site, so the same free flow speeds for cars and trucks were used at each data collection station. Column B represents the speeds that were collected when only normal traffic control was in place at the site. Column C shows the speeds collected when either the rumble strips (at sites 1 and 2) or the speed display (at sites 3 and 4) were present. The next three columns represent the difference in speeds between normal work zone traffic control and free flow speeds Δ(B-A), between the speed display/rumble strips and free flow speeds Δ(C-A), and between the speed display/rumble strips and normal work zone traffic control Δ(C-B). The speeds with normal traffic control were compared to the speeds obtained when either the rumble strips or speed display were in place. Analysis of Variance (ANOVA) tests were conducted at a 0.05 level of significance at each location at each site. Differences in the Δ(C-B) that are shown in bold exhibit a statistically significant difference in mean speeds.

Table 3 shows the percentage of vehicles exceeding the 112.7 km/h (70 mph) speed limit at each site. The column headings on this table have the same meaning as those on Table 2. The percentage of speeders at each data collection station for normal work zone traffic control were compared to the percentage present when the rumble strips or speed display were set up. Chi square tests were conducted at a 0.05 level of significance. The differences in the Δ(C-B) column that are shown in bold and shaded are have statistically significant differences in the percentage of speeding vehicles.

Reduction in Mean Speeds

Figures 4 and 5 show the mean speeds collected for cars and trucks at each site. The approximate locations of the speed displays and rumble strips are noted on the figures. On these figures, the dark horizontal line represents the free flow speed at the site when the work zone is not present.

Rumble Strips

Figure 4 shows that vehicle speeds were usually reduced below their free flow levels once traffic entered the temporary traffic control zone. The exception was at site 1, where truck

speeds under normal work zone traffic control exceeded free flow levels until after the "Road Work Ahead" sign. This indicates that both normal traffic control and the rumble strips provide some measure of speed control from free flow levels.

The rumble strips did not appear to significantly impact the speeds of passenger cars. As Figure 4a shows, the initial speeds of passenger cars entering the work zones at sites 1 and 2 were higher than when only normal work zone traffic control was present. The only location where car speeds were lower was at the "Left Lane Closed Ahead" sign. Speed reductions at this point were between 1.8 to 3.2 km/h (1 to 2 mph).

Trucks experienced a greater speed reduction is response to the rumble strips than the cars did. As Figure 4b shows, truck speeds were consistently lower than the speeds with normal work zone traffic control once the trucks had passed the first rumble strip. Truck speeds were between 3.7 and 11.6 km/h (2 and 7 mph) lower in the advance warning area, and were between 4.7 to 6.6 km/h (3 to 4 mph) slower in the activity area.

Speed Display

Figure 5 shows that speeds were consistently reduced below their free flow levels as vehicles entered the work zones at sites 3 and 4. This indicates that normal traffic control does offer some speed reduction benefit, although it may not be as great as the reduction with the speed display present.

The speed display caused some speed reductions for passenger cars. Figure 5a shows that the average speeds with the speed display present were consistently lower than those collected when the display was not active. Speed reductions were greater at site 3 than at site 4. At site 3, passenger car speeds were between 8.4 and 14.5 km/h (5 and 9 mph) slower than with the normal work zone traffic control. These reductions were statistically significant at the "Road Work Ahead" and Reverse Curve signs. Speed reductions for cars at site 2 were smaller than at site 3, ranging from between 2.3 to 3.9 km/h (1.5 to 2.5 mph).

The speed display seemed to impact mean truck speeds more than mean car speeds. Figure 5b shows that truck speeds were consistently reduced when the display was activated. Truck speeds were 11.4 to 15.3 km/h (7 to 9 mph) slower for than with normal traffic control at site 3, and were between 4.8 and 15.1 km/h (3 and 10 mph) slower at site 4.

Reduction in Percent of Vehicles Exceeding the Speed Limit

Figures 6 and 7 summarize the percentage of vehicles that exceeded the speed limit at each site. In both of these figures, the percentage of vehicles exceeding the speed limit under free flow conditions is marked with a heavy horizontal line. The locations of the rumble strips and speed display are noted on the figures.

Rumble Strips

The percentage of passenger cars that exceeded the 112.7 km/h (70 mph) speed limit was reduced by the implementation of the rumble strips. As shown in Figure 6a, the percentage of

vehicles traveling more than 112.7 km/h (70 mph) was lower than with normal traffic control at the "Road Work Ahead", "Right Lane Closed Ahead", and Activity Area data collection stations. This indicates that drivers reduced their speeds after they drove over the rumble strips. The percent of passenger cars exceeding the speed limit was between 3.8 and 7.2 percent lower at site 1 and between 0.3 and 1.8 percent lower at site 2.

The rumble strips also created truck speed reductions. Figure 6b shows the percent of trucks that were found to be speeding at each data collection station. The percentage of trucks exceeding the speed limit declined at the data collection stations occurring immediately after the first rumble strip installation. Reductions in the percentage of trucks speeding were also observed upstream of the temporary traffic control zone when the rumble strips were installed. This may have resulted from warnings transmitted by truckers over the CB radio.

Speed Display

The speed display was also effective at reducing the percentage of cars that exceeded the speed limit. Figure 7a shows that the percent of cars traveling over the speed limit declined at all data collection stations at site 3 when the display was active. The percentage of cars exceeding the speed limit at site 4 declined when the display was active at all locations except the Reverse Curve sign.

The percentage of trucks exceeding the speed limit was also reduced when the speed display was operational. Figure 7b shows that no trucks were detected traveling over the speed limit at any of the data collection sites at site 4 when the display was active. No trucks were speeding at any of the data collection stations that followed the speed display at site 3. It is difficult to draw conclusions on the effectiveness of the speed display on trucks because no trucks were found to be speeding at either site from the "Road Work Ahead" sign through the activity area when only normal traffic control was present.

Comparison of Rumble Strips and Speed Display

Figure 8a shows the passenger car speed reductions that the rumble strips and speed display created at all four sites. At sites 1 and 2, the passenger car speeds collected when the rumble strips were in place were lower than the speeds with normal work zone traffic control at the "Left Lane Closed Ahead" sign only. The speed reduction at this point is about 3.2 km/h (2 mph), and occurred after the second set of rumble strips. Inside the activity area, the car speeds with and without the rumble strips present were extremely close to one another. At site 3, speeds for passenger cars were up to 14.5 km/h (9 mph) less when the display was active than the speeds with normal traffic control present. Car speeds at site 4 when the display was operation were consistently about 3.2 km/h (2 mph) less than speeds with work zone traffic control. The speed display appears to produce larger speed reductions than the rumble strips for passenger cars.

Figure 8b shows the speed reductions for trucks at all four sites. At site 1, truck speed reductions within the temporary traffic control zone varied from 4.2 to 11.6 km/h (2.6 to 7.2 mph), with the largest differences in speed occurring after the rumble strips. At site 2, speed reductions were about 3.8 km/h (2 mph) lower after the rumble strips. Truck speeds were

between 4.7 and 6.6 km/h (3 and 4 mph) lower inside the activity area when the rumble strips were in place. Truck speeds at site 3 were between 11.3 and 14.5 km/h (7 and 9 mph) when the display was active. Speeds at site 4 were between 4.8 and 16.1 km/h (3 and 10 mph) slower than when normal traffic control was in place. Truck speed reductions varied from 15.0 km/h (9.3 mph) at the "Road Work Ahead" sign to 4.8 km/h (3 mph) at the Reverse Curve sign. The rumble strips appear to be more effective on trucks than on passenger cars. However, the speed display still seems to be more effective than rumble strips at reducing truck speeds in work zones.

FINDINGS

Rumble Strip Effectiveness

- Installation time for the rumble strips was approximately 40 minutes. This may be too lengthy for rural maintenance applications.
- Some vehicles attempted to avoid the rumble strips by driving into the opposing lane.
- The portable rumble strips generally did not have a significant impact on average passenger car speeds. Speed reductions of 3.2 km/h (2 mph) were seen near the "Left Lane Closed Ahead" sign when the rumble strips were installed, but there was little difference in passenger car speeds within the activity area.
- The rumble strips had a greater impact on mean truck speeds than on passenger car speeds. Average truck speeds declined between 3.2 and 11.3 km/h (2 and 7 mph) at the data collection stations after the rumble strip installation. The average truck speed within the activity area was between 4.7 and 6.6 km/h (3 and 4 mph) less than with normal work zone traffic control.
- The percentage of passenger cars exceeding the speed limit declined by between 1-7 percent after each set of rumble strips as compared to normal work zone traffic control.
- The percentage of trucks exceeding the speed limit declined after the first set of rumble strips, but mixed results were achieved after the second set of rumble strips.
- Speed reductions for passenger cars appear to be consistent with those achieved using the thinner rumble strips in the Kansas study. Speed reductions for trucks are larger than those observed in the Kansas study.

Speed Display Effectiveness

- The speed display could be set up in under 10 minutes.
- One vehicle accelerated dramatically as it approached the speed display, in an effort to see how high the speed display would read. This represented less than 1 percent of vehicles entering the advance warning area.
- Average passenger car speeds were reduced by the speed display. Car speeds were between 2.6 and 14.5 km/h (2 and 9 mph) lower in the advance warning area than with normal traffic control.
- The speed display usually resulted in a reduction in the percentage of passenger cars speeding at each data collection station, with reductions of 15 to 20 percent observed at site 3.

- The speed display seemed to produce greater speed reductions in trucks than in passenger cars. Speeds were 4.8 to 15.3 km/h (3 to 10 mph) lower with the speed display for trucks in the advance warning area.
- The percentage of trucks exceeding the speed limit was lower than with normal traffic control entering the activity area. No trucks were found to be speeding with or without the display from the "Road Work Ahead" sign through the activity area.
- The speed reductions achieved by the speed display at the two sites were different. The positioning of the speed display may be a factor in the magnitude of speed reductions achieved.
- Speed reductions observed tended to be slightly larger than those observed in the TTI study performed on a four-lane divided highway.

CONCLUSIONS

Rumble Strips

- Installation of the rumble strips may be too lengthy for the rumble strips to be applied at rural maintenance work zones.
- The rumble strips produce minimal speed reductions for cars, but provide a 4.8 to 6.4 km/h (3 to 4 mph) speed reduction for trucks inside the activity area.
- The rumble strips had a greater impact on trucks than cars.
- The rumble strips produced mixed results on reducing the percentage of speeding vehicles.

Speed Display

- The speed display can be quickly set up, making it appropriate for application in rural maintenance work zones.
- The speed display usually produces speed reductions between 3.2 to 14.5 km/h (2 to 9 mph) for cars, and between 11.3 to 16.1 km/h (7 to 10 mph) for trucks.
- The speed display appeared to have a greater impact on truck speeds.
- The percentage of vehicles speeding was usually reduced in the advance warning area when the speed display was operational.

RECOMMENDATIONS

- Portable rumble strips appear to have a limited application in rural maintenance work zones. The portable rumble strips produced minimal reductions in passenger car speeds, but produced some reduction in truck speeds in the activity area. The installation time for these rumble strips was too lengthy to recommend their use in rural maintenance work zones. Also, the rumble strips were not reusable once they had been installed, potentially making these devices too costly to apply on a widespread basis for these activities.
- The speed display appears to be an effective means of speed control for rural maintenance activities. The display reduces both car and truck speeds, and has a positive impact on the percentage of vehicles exceeding the speed limit. The displays were easily set-up and removed. While the high initial cost of these devices may act as a disincentive to their use, they appear to provide a portable, effective means of controlling speeds in rural maintenance work zones.

ACKNOWLEDGEMENTS

This paper is based on research sponsored by the Texas Department of Transportation. It was performed by the Texas Transportation Institute of the Texas A&M University System. The content of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or polices of the Federal Highway Administration or the Texas Department of Transportation. The authors wish to acknowledge the contributions of Danny Brown, the Childress area engineer, and the Childress and San Angelo maintenance sections.

REFERENCES

1. Carlson, P.J., M Fontaine, H.G. Hawkins, K. Murphy, and D. Brown. Evaluation of Speed Trailers at High-Speed Temporary Work Zones. *Transportation Research Board 79th Annual Meeting Preprint CD-ROM*, January 2000.

2. Meyer, E. Evaluation of Orange Removable Rumble Strips for Highway Work Zones. *Transportation Research Board 79th Annual Meeting Preprint CD-ROM*, January 2000.

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TABLE 1 Location of Data Points in Relation to Taper

Location	Distance from Taper, m (ft)			
	Site 1	**Site 2**	**Site 3**	**Site 4**
Upstream of Temporary Traffic Control Zone	3267 (10718)	3267 (10718)	1883 (6177)	n.a.
Road Work - Traffic Fines Double	966 (3170)	966 (3170)	1043 (3421)	1106 (3630)
Road Work Ahead	646 (2120)	646 (2120)	769 (2522)	834 (2736)
Left Lane Closed Ahead	332 (1090)	332 (1090)	n.a.	n.a.
Reverse Curve	n.a.	n.a.	493 (1618)	574 (1883)
Speed Display	n.a.	n.a.	945 (3100)	707 (2320)
Rumble Strip Set 1	806 (2645)	806 (2645)	n.a.	n.a.
Rumble Strip Set 2	489 (1605)	489 (1605)	n.a.	n.a.
Taper	0	0	0	0
Activity Area	-231 (-758)	-231 (-758)	-241 (-792)	-241 (-792)

TABLE 2 Average Speeds

Site	Location	Vehicle Type	Average Speed (km/h)[c]					
			Free Flow (A)	Normal Traffic Control (B)	Treatment (C)	Δ (B-A)	Δ (C-A)	Δ [b] (C-B)
Site 1	Upstream	Car	109.4	106.1	111.0	-3.4	-1.6	**+5.0**
		Truck	108.5	113.6	107.8	+5.1	-0.6	-5.8
	Road Work – Traffic Fines Double	Car	109.4	103.5	108.1	-6.0	-1.3	**+4.7**
		Truck	108.5	110.2	106.1	+1.8	-2.4	-4.2
	Road Work Ahead	Car	109.4	101.1	102.7	-8.4	-6.8	+1.6
		Truck	108.5	112.0	100.4	+3.5	-8.0	**-11.6**
	Left Lane Closed Ahead	Car	109.4	98.0	94.8	-11.4	-14.6	**-3.2**
		Truck	108.5	100.9	92.2	-7.6	-16.3	**-8.7**
	Activity Area	Car	109.4	83.0	83.0	-26.4	-26.4	0.0
		Truck	108.5	83.5	78.9	-24.9	-29.6	-4.7
Site 2	Upstream	Car	109.4	108.6	112.0	-0.8	+2.6	**+3.4**
		Truck	108.5	111.7	109.8	+3.2	+1.3	-1.9
	Road Work – Traffic Fines Double	Car	109.4	105.4	109.0	-4.0	-0.5	**+3.5**
		Truck	108.5	106.4	107.5	-2.1	-1.0	+1.1
	Road Work Ahead	Car	109.4	100.1	103.0	-9.3	-6.4	+2.9
		Truck	108.5	105.7	102.0	-2.7	-6.4	-3.7
	Left Lane Closed Ahead	Car	109.4	97.7	95.9	-11.7	-13.5	-1.8
		Truck	108.5	98.2	94.1	-10.3	-14.3	-4.0
	Activity Area	Car	109.4	83.4	85.6	-26.1	-23.8	+2.3
		Truck	108.5	86.6	80.0	-21.9	-28.5	**-6.6**
Site 3[a]	Upstream	Car	108.5	113.1	112.0	+4.5	+3.4	-1.1
		Truck	109.6	113.1	104.8	+3.5	-4.8	**-8.4**
	Road Work – Traffic Fines Double	Car	108.5	104.0	95.6	-4.7	-13.0	-8.4
		Truck	109.6	105.6	90.3	-4.0	-19.3	-15.3
	Road Work Ahead	Car	108.5	102.0	90.1	-6.6	-18.5	**-11.9**
		Truck	109.6	99.9	87.2	-9.7	-22.4	**-12.7**
	Reverse Curve	Car	108.5	98.5	84.0	-10.1	-24.6	**-14.5**
		Truck	109.6	90.3	79.8	-19.3	-29.8	**-11.4**
Site 4[a]	Road Work – Traffic Fines Double	Car	108.5	102.8	100.3	-5.8	-8.4	-2.6
		Truck	109.6	97.4	84.7	-12.2	-24.9	**-12.7**
	Road Work Ahead	Car	108.5	96.9	93.0	-11.7	-15.6	-3.9
		Truck	109.6	95.0	79.8	-14.6	-29.8	**-15.1**
	Reverse Curve	Car	108.5	89.5	85.8	-19.2	-22.9	-3.7
		Truck	109.6	79.7	74.8	-29.9	-34.8	-4.8
	Activity Area	Car	108.5	43.8	41.5	-64.9	-67.1	-2.3
		Truck	109.6	47.0	31.1	-62.6	-78.5	**-15.9**

[a] No data were obtained in the work zone at Site 3 and upstream at site 4 due to counter failure.
[b] Speeds shown in bold and shaded have a statistically significant difference.
[c] To convert speeds to mph, multiply by 0.62.

TABLE 3 Percent of Vehicles Exceeding Speed Limit

Site	Location	Vehicle Type	Percent Speeding					
			Free Flow (A)	Normal Traffic Control (B)	Treatment (C)	Δ (B-A)	Δ (C-A)	Δ [b] (C-B)
Site 1	Upstream	Car	24.7%	25.5%	45.5%	+0.8%	+20.8%	**+20.0%**
		Truck	23.8%	40.0%	21.1%	+16.2%	-2.7%	**-18.9%**
	Road Work – Traffic Fines Double	Car	24.7%	22.5%	26.4%	-2.2%	+1.7%	+3.9%
		Truck	23.8%	23.1%	14.4%	-0.7%	-9.4%	**-8.7%**
	Road Work Ahead	Car	24.7%	25.3%	18.1%	+0.6%	-6.6%	**-7.2%**
		Truck	23.8%	40.0%	6.0%	+16.2%	-17.8%	**-34.0%**
	Left Lane Closed Ahead	Car	24.7%	10.5%	6.7%	-14.2%	-18.0%	**-3.8%**
		Truck	23.8%	6.7%	1.3%	-17.1%	-22.5%	**-5.4%**
	Activity Area	Car	24.7%	5.7%	1.0%	-19.0%	-23.7%	**-4.7%**
		Truck	23.8%	0.0%	0.4%	-23.8%	-23.4%	+0.4%
Site 2	Upstream	Car	24.7%	34.2%	45.6%	+9.5%	+20.9	+11.4%
		Truck	23.8%	29.6%	20.0%	+5.8%	-3.8%	-9.6%
	Road Work – Traffic Fines Double	Car	24.7%	29.0%	29.6%	+4.3%	+4.9%	+0.6%
		Truck	23.8%	11.9%	21.7%	-11.9%	-2.1%	+9.8%
	Road Work Ahead	Car	24.7%	19.0%	24.3%	-5.7%	-0.4%	-0.7%
		Truck	23.8%	19.0%	14.3%	-4.8%	-9.5%	-4.7%
	Left Lane Closed Ahead	Car	24.7%	7.5%	5.7%	-17.2%	-19.0%	-1.8%
		Truck	23.8%	4.3%	6.5%	-19.5%	-17.3%	+2.2%
	Activity Area	Car	24.7%	3.2%	2.9%	-21.5%	-21.8%	-0.3%
		Truck	23.8%	0.0%	0.0%	-23.8%	-23.8%	0.0%
Site 3[a]	Upstream	Car	23.2%	40.0%	36.5%	+16.8%	+13.3%	-3.5%
		Truck	18.9%	25.0%	27.8%	+6.1%	+8.9%	+2.8%
	Road Work – Traffic Fines Double	Car	23.2%	25.0%	7.0%	+1.8%	-16.2%	**-18.0%**
		Truck	18.9%	20.0%	4.0%	+1.1%	-14.9%	**-16.0%**
	Road Work Ahead	Car	23.2%	16.1%	0.0%	-7.1%	-23.2%	**-16.1%**
		Truck	18.9%	0.0%	0.0%	-18.9%	-18.9%	0.0%
	Reverse Curve	Car	23.2%	20.0%	0.0%	-3.2%	-23.2%	**-20.0%**
		Truck	18.9%	0.0%	0.0%	-18.9%	-18.9%	0.0%
Site 4[a]	Road Work – Traffic Fines Double	Car	23.2%	18.2%	11.5%	-5.0%	-11.7%	-6.7%
		Truck	18.9%	15.8%	0.0%	-3.1%	-18.9%	-15.8%
	Road Work Ahead	Car	23.2%	18.0%	11.8%	-5.2%	-11.4%	-6.2%
		Truck	18.9%	0.0%	0.0%	-18.9%	-18.9%	0.0%
	Reverse Curve	Car	23.2%	1.5%	7.3%	-21.7%	-15.9%	**+5.8%**
		Truck	18.9%	0.0%	0.0%	-18.9%	-18.9%	0.0%
	Activity Area	Car	23.2%	0.0%	0.0%	-23.2%	-23.2%	0.0%
		Truck	18.9%	0.0%	0.0%	-18.9%	-18.9%	0.0%

[a] Due to equipment malfunction, no data were obtained inside the work zone at site 3 and upstream of the work zone at site 4.
[b] Cells shown in bold and shaded exhibit a statistically significant difference.

FIGURE 1 Speed display

FIGURE 2 Rumble strip installation

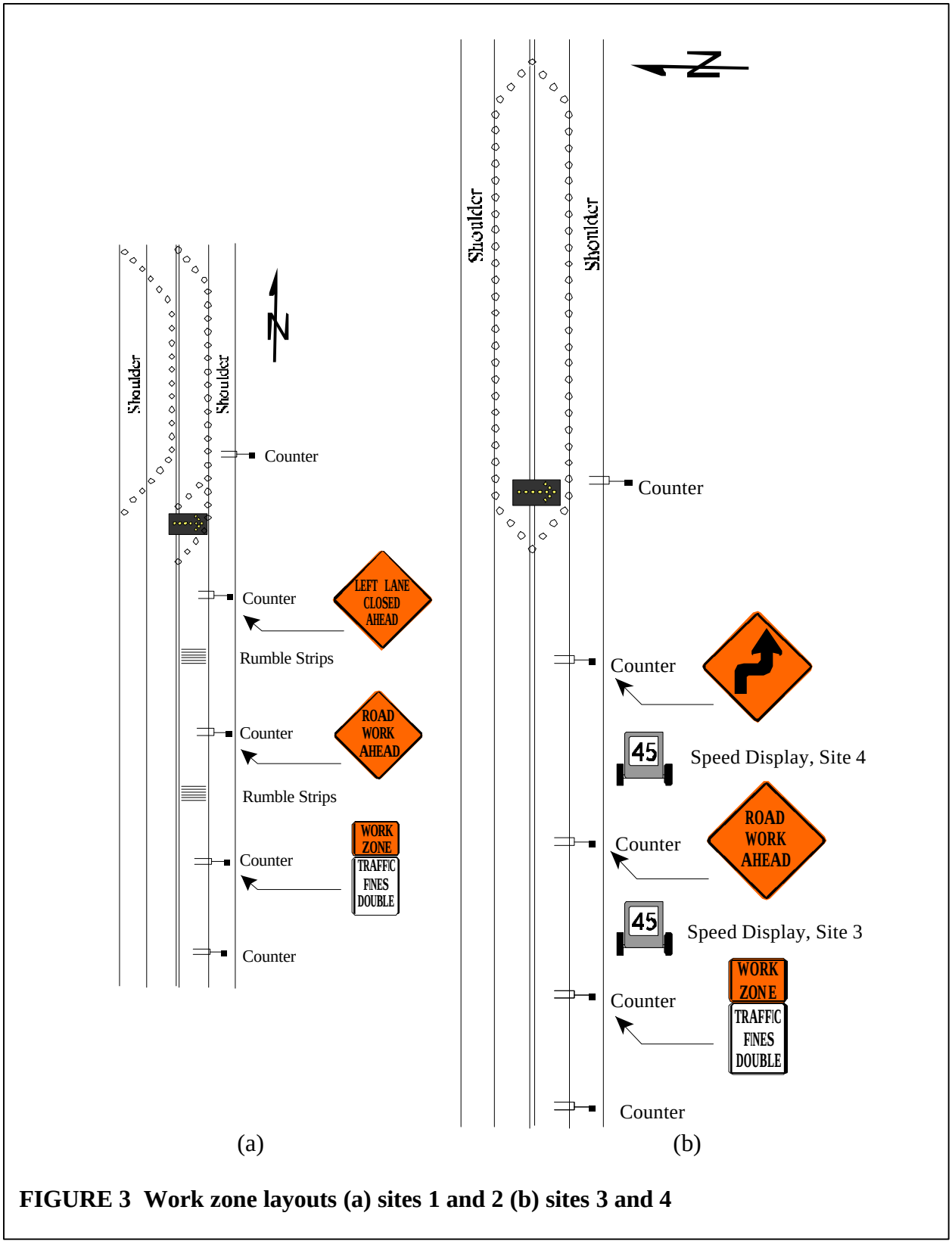
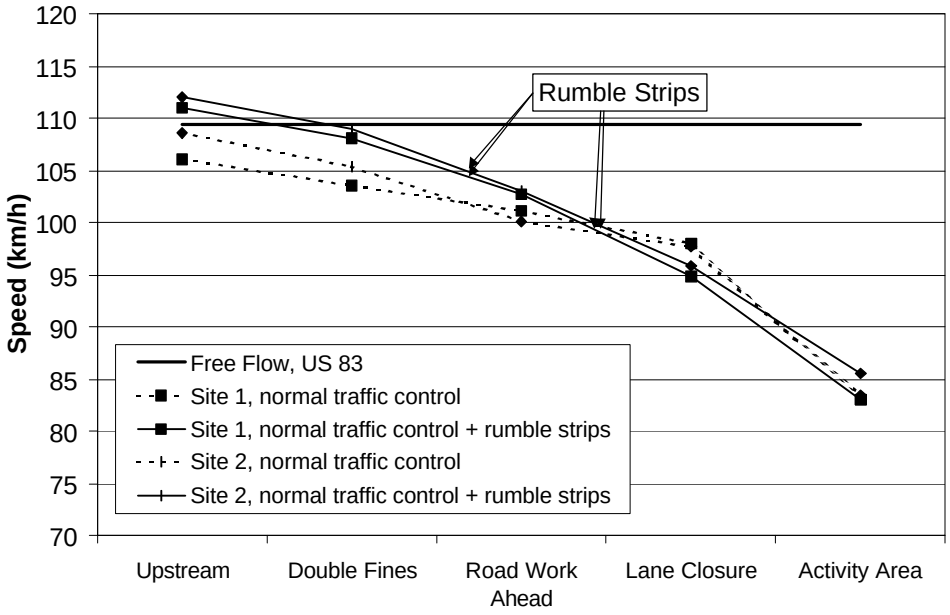
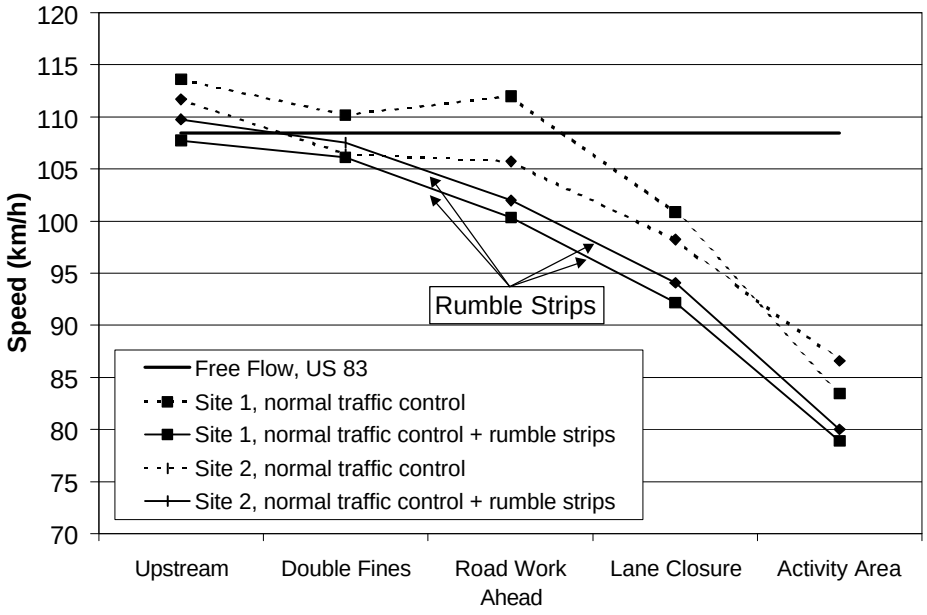


FIGURE 3 Work zone layouts (a) sites 1 and 2 (b) sites 3 and 4

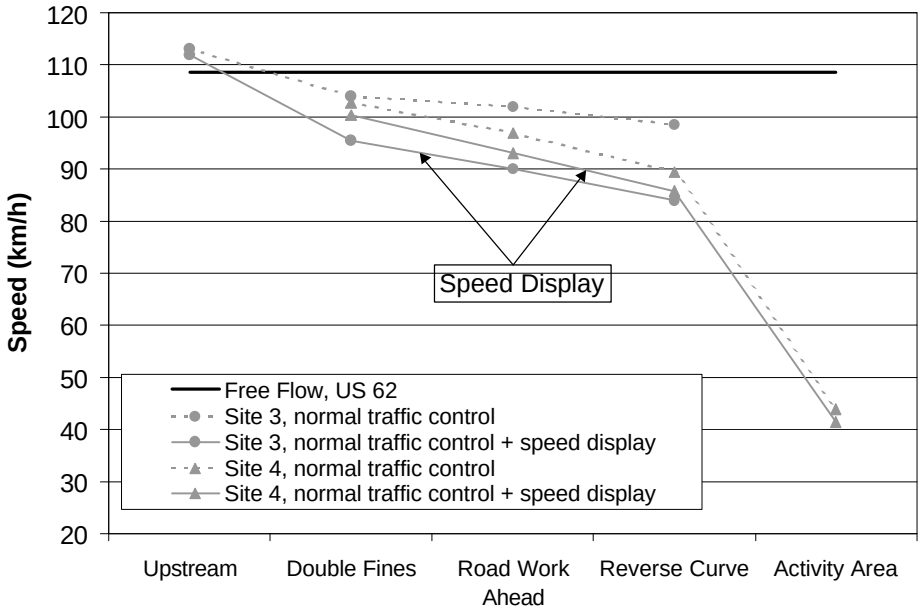


(a)

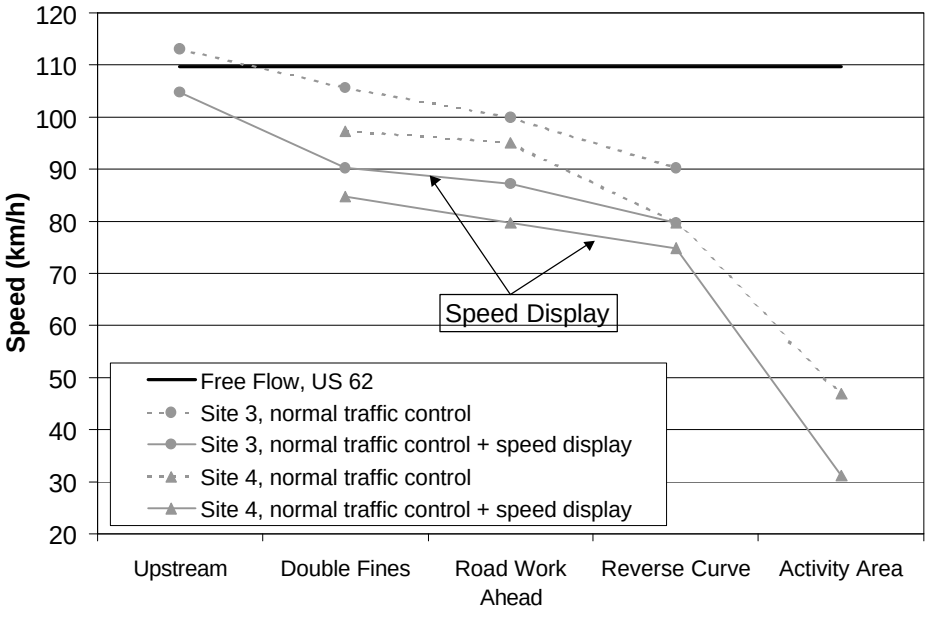


(b)

FIGURE 4 Average speeds at sites 1 and 2 for (a) cars (b) trucks

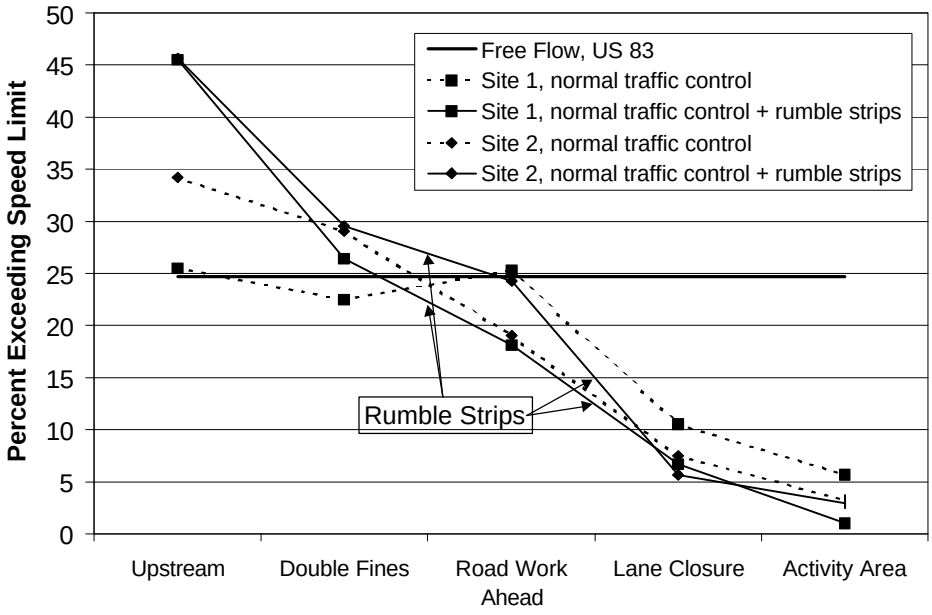


(a)

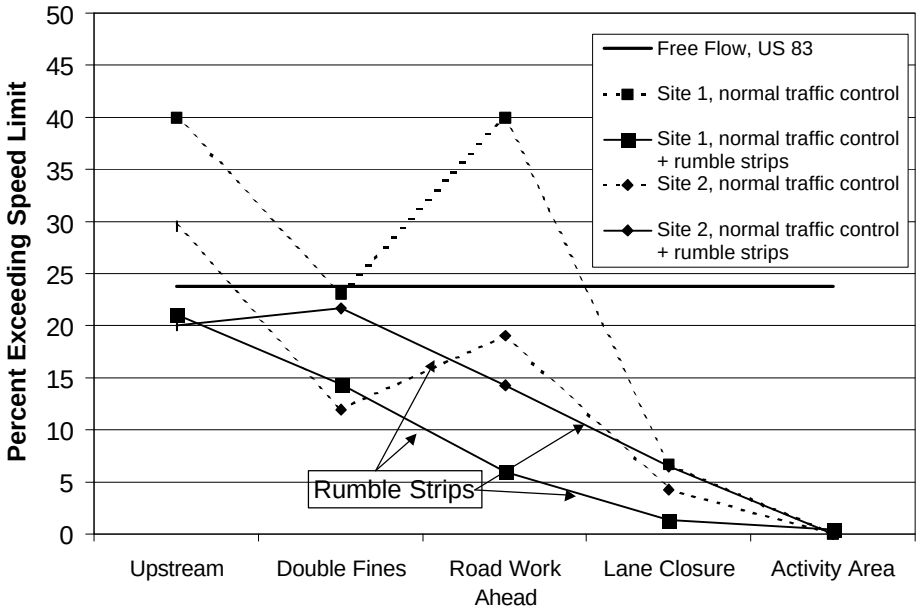


(b)

FIGURE 5 Average speeds at sites 3 and 4 for (a) cars (b) trucks.

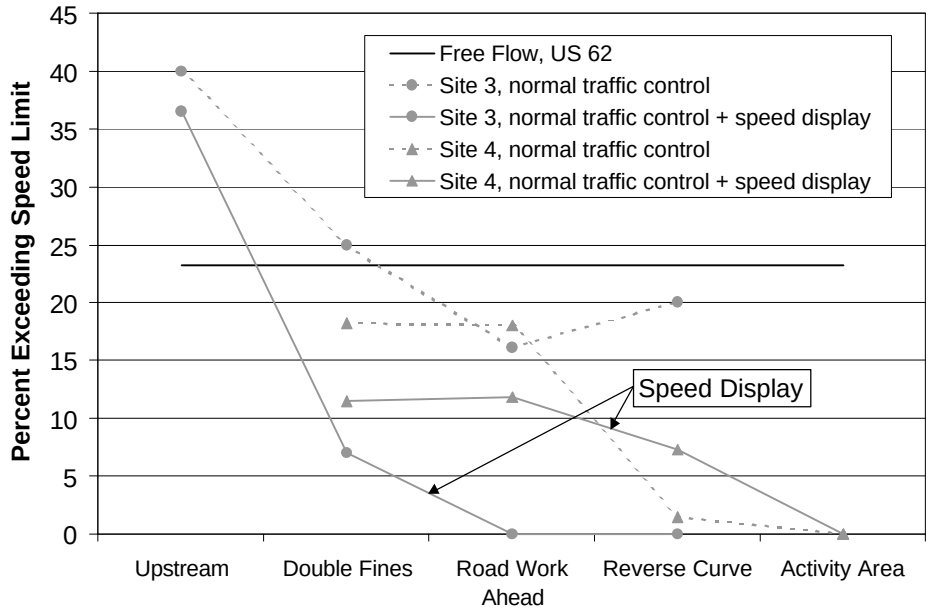


(a)

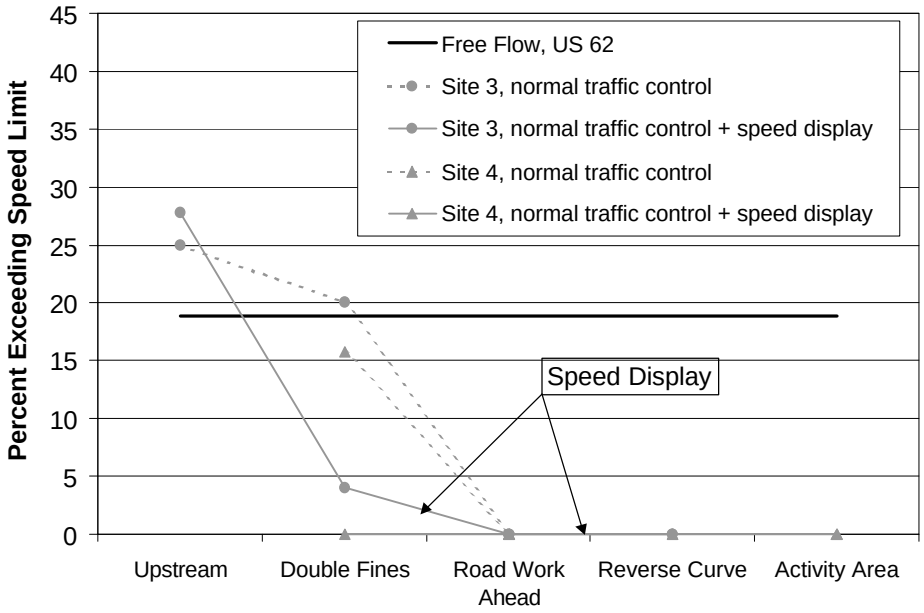


(b)

FIGURE 6 Percent of vehicles speeding at sites 1 and 2 for (a) cars (b) trucks.

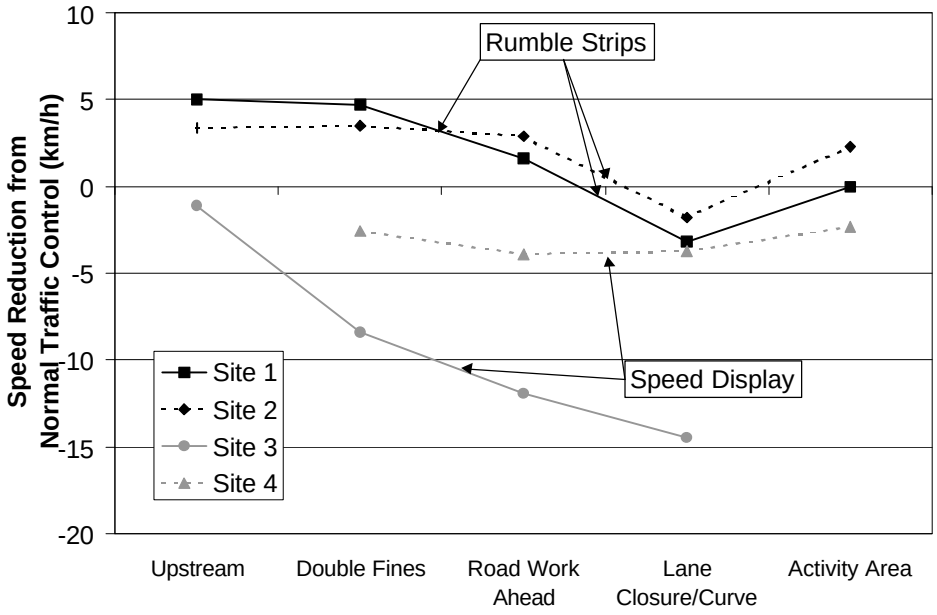


(a)

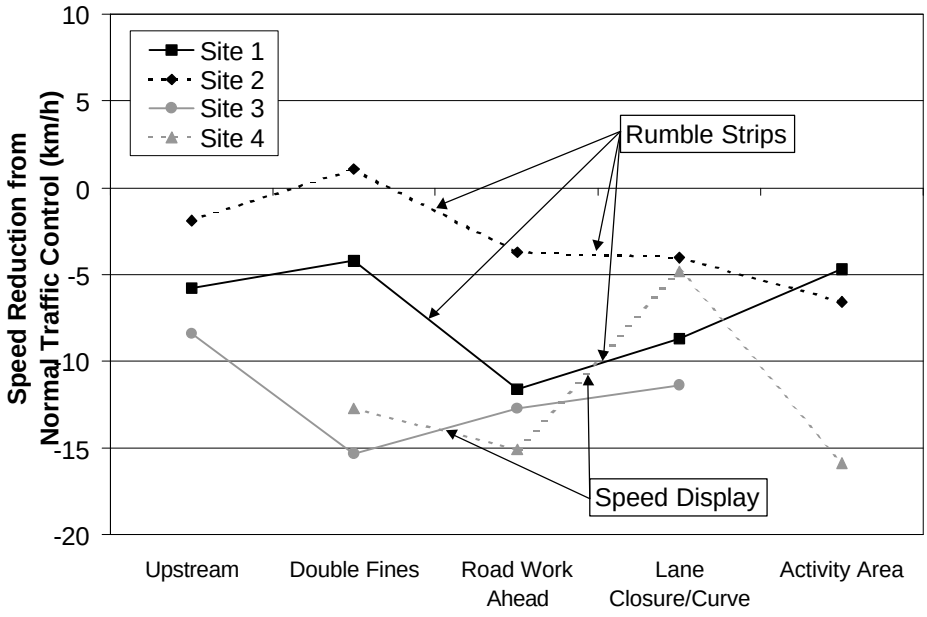


(b)

FIGURE 7 Percent of vehicles speeding at sites 3 and 4 for (a) cars (b) trucks.



(a)



(b)

FIGURE 8 Speed reductions from normal work zone traffic control for (a) cars (b) trucks.