Speed Control Through Freeway Work Zones: Techniques Evaluation

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In this paper, the implementation and evaluation of four techniques for improving the effectiveness of speed zoning in construction areas on multilane freeways are presented. The techniques are (a) the flagging procedure of the *Manual On Uniform Traffic Control Devices* (MUTCD), (b) the use of the MUTCD flagging procedure plus having the flagger point at a nearby speed limit sign with the free hand after motioning motorists to slow, (c) a marked police car with cruiser lights and radar active, and (d) a uniformed police officer to control traffic. Each of the techniques was applied continuously on a six-lane freeway for a period of 10 to 15 days. The results of the analysis indicate that all four techniques can provide significant reduction in traffic speed through highway construction zones. The flagging methods were effective in construction areas where one lane remained open to traffic. The law enforcement methods demonstrated a stronger speed reduction capability, particularly when the lane closures result in two or more lanes open. The construction projects used for the collection of field data collection required speed reduction from the regulatory 55 mph to an advisory 45 mph. Although the law enforcement techniques were determined to be effective, their implementation requires a high degree of administrative coordination and cooperation involving police departments, highway officials, and construction contractors.

Use of excessive speed for existing conditions reduces the effectiveness of corrective navigational maneuvers made by motorists as they travel through highway construction zones. The safety of motorists and work crews in construction zones remains an unresolved issue, in spite of numerous techniques for speed control. Traffic accidents in construction sites are a continuing problem. Several studies have concluded that highway construction zones have a propensity for increasing accidents. In a 1965 California accident study (*1*) of 10 randomly selected construction projects, a 21.4 percent increase in the accident rate was observed, with a 132 percent increase in the fatality component. In a study of 207 highway resurfacing projects on two-lane highways, Graham et al. (*2*) reported a 61 percent increase in total accidents, 67 percent increase in injuries, and 68 percent increase in fatalities during construction. The Virginia Highway Research Council (*3*) reported a 119 percent increase in accident frequency in construction zones on I-495 in northern Virginia. The National Safety Council surveys (*4*) show that over 500 people working on the roadway are reported killed by traffic accidents each year.

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There is no doubt that highway construction and maintenance zones increase the potential for traffic accidents. Attention must be focused on innovative traffic control measures that are more responsive to drivers in highway construction zones. This paper examines the long-term effectiveness of two flagging and two law enforcement techniques in reducing speeds in freeway construction zones. These techniques were previously determined to have reasonable promise for reducing speeds during 1–2-hr applications (*5*). The four treatments were

MUTCD Flagging. This is the flagging procedure described in the 1978 edition of the *Manual on Uniform Traffic Control Devices* (MUTCD) (*6*). The flagger, equipped with a red flag and orange vest, performs the "alert and slow" signal detailed in Part IV of the MUTCD.

Innovative Flagging. This flagging technique combines the MUTCD procedure with having the flagger use the other hand (without the flag) to motion traffic to slow and then to point at a nearby speed limit sign (Figure 1).

Stationary Police Cruiser with Lights and Radar on. This technique requires a marked patrol car with cruiser lights and radar in operation to be stationed at the site.

Uniformed Police Traffic Controller. A uniformed officer standing on the side of the road near a speed limit sign manually motions the traffic to slow down.

Two applications of each of the above techniques were studied on a six-lane Interstate freeway in Delaware.

BACKGROUND

The safety of motorists and workers in highway construction zones has been the subject of many research studies (*7–12*). The results of these studies, as well as others, have contributed to major improvements in the way traffic is controlled to improve safety in highway construction zones. The 1978 version of the *Manual on Uniform Traffic Control Devices* (*6*) and its periodical revisions represent the results of years of experimentation and are the national engineering standard for highway traffic control, including traffic control in maintenance and construction zones. In spite of great progress in reducing the accident rates in construction zones, safety remains a continuing issue, primarily because of the tragic nature of accidents in construction zones. The fundamental hypothesis of this research is that further reduction in the rate, frequency, and severity of accidents in construction zones could be obtained

FIGURE 1 "Innovative" MUTCD flagging.

through the use of improved techniques for causing drivers to reduce speeds.

Traffic accidents in highway work zones are caused by a combination of factors, including driver error, inadequate visibility, poor road surface condition, construction obstructions, inadequate traffic control and information, and improper management of material, equipment, and personnel in construction zones. Liberty Mutual Insurance Company (*13*) noted that more than one half of the accidents in the vicinity of road closures are caused by driver error and negligence. Unsafe operating speeds for existing conditions is a frequent driver error. In the review of work zone accidents on rural highways in Ohio, Nemeth (*14*) concluded that in comparison to other causative factors, excessive speed is 5.5 times more frequently cited as the reason for traffic accidents in highway construction areas. Humphries (*15*) studied 103 work zones located in several states and concluded that both unsafe operating speed and inadequate speed control can be blamed for many traffic accidents in highway construction zones. Richards and Faulkner (*16*) studied accidents in Texas and observed that speed violation contributed to 27 percent of work zone accidents, compared to 15 percent for non-work zone accidents. More effective ways are needed to cause motorists to reduce speed in highway construction zones where slower operating speeds are required. The standard practice of using signs to control speeding in work zones is not working. Drivers are generally not responsive to purely advisory and regulatory speed signing in construction zones.

Graham et al. (*2*) conducted experiments to evaluate several speed reduction techniques for highway work zones in the Kansas City metropolitan area. The researchers observed speed, erratic maneuvers, and conflicts at three sites: an urban freeway, a rural freeway, and an urban street. Data collection was limited to 2 to 3.5 hr per technique. The study did not address the long-term speed reduction potential of each technique.

Richards et al. (*5*) studied the short-term effectiveness of a number of work zone speed reduction methods. The flagging technique described in the MUTCD (*6*), an innovative flagging modification of the MUTCD method, police controller, and police car with activated radar on site were among the techniques studied. The study examined the short-term speed-reduction response of motorists to each technique. Observations for each treatment were made over 1 to 2 hr. In comparison to the standard MUTCD flagging method, the innovative flagging treatment resulted in larger speed reduction at five of the six study sites. On the urban freeway site, the innovative flagging treatment reduced speeds by 4 mph (7 percent) and the MUTCD flagging reduced speed by 3 mph (5 percent). These reductions, from a traffic operational standpoint, are not significant. Richards et al. state that the police controller technique was not evaluated at any of the freeway sites because of the reluctance of the police to stand at the roadside. The stationary patrol car reduced speeds by 4 to 12 mph (6 to 22 percent). This method was determined to be most successful on urban arterials and apparently less so on urban freeways. These four reduction techniques were determined to have modest promise on the basis of short-term observations of 1 to 2-hr durations. The unanswered question is whether the potential demonstrated for the short-term application of the four techniques can be reached during long-term application on freeways. Construction activities that last more than 2 weeks are common occurrences on freeways. Thus, the experiments initiated by Richards et al. need to be expanded to cover long-term conditions.

IMPLEMENTATION

Study Sites

Eight study sites were selected on Interstate 495 in the suburbs of Wilmington, Delaware. I-495 is a six-lane divided freeway, with three lanes in each direction. The construction activity was performed in two phases for each bridge. The left and center lanes were closed in phase 1, and the right lane was closed in phase 2. Figure 2 shows the typical two-lane closure used on all sites. The typical one-lane closure is depicted in Figure 3. Figures 2 and 3 also provide information on the location of treatment stations in relation to the sensors at speed

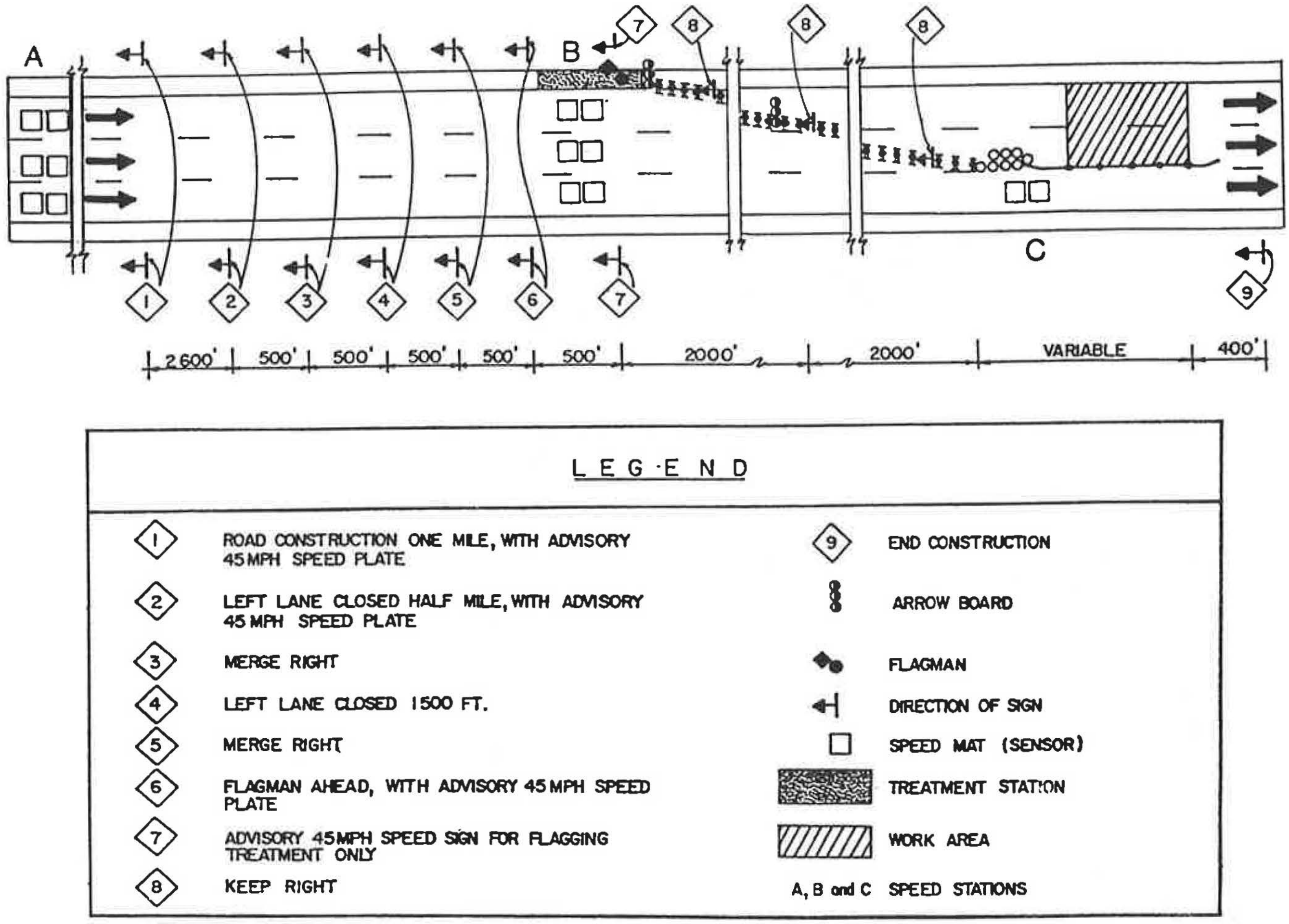

FIGURE 2 Schematic of typical left and center lane closure.

stations A, B, and C. Station A was placed about 5,000 ft upstream of Station B. The regulatory speed limit at Station A was 55 mph. An advisory speed of 45 mph was posted throughout the construction area. All study sites had the same geometrical, topographical, and traffic operating conditions. The distance between B and C was either 2,500 or 4,500 ft, depending on the number of lanes closed. Table 1 provides a listing of the treatments and the spatial separation between speed stations. Traffic control devices in the construction area were not visible from Station A.

Application of Treatments

Each of the four treatments was applied during the two-lane closure phase and then during the one-lane closure phase on the same bridge. No treatment was repeated on any other bridges. For example, the MUTCD flagging was applied only to bridge 802 during phase 1 and phase 2 construction for that bridge (see Table 1 for treatments and lane closures applied to other bridges). The treatment applied to each lane-closure situation remained in place for 10 to 15 days, depending on the schedule of the construction contractor.

The data collection periods were on weekdays only, lasted for approximately 3 hr, involved good weather and dry pavement, and were carefully selected to avoid night conditions and peak traffic periods. VC 1900 traffic analyzers with loop detectors were used to obtain speed, volume, and vehicle classification. Two portable electromagnetic loop detectors mounted on rubber mats (see Figure 4) were placed in each through lane. One VC 1900 traffic analyzer was used at each speed station. Use of the analyzer aided concealment of the experiment and removed the need for the field team to remain on site while data were being automatically collected.

Data Collection Procedure

For each treatment, speed observations were made at the three speed stations (A, B, and C) before test procedures were implemented, within the first three days of implementation, and about 10 to 15 days after implementation. The exact duration of the 10 to 15–day exposure period depended on construction progress. No treatment received less than a 10-day exposure. For each treatment and speed station, at least 100 speed observations per lane were made, except for speed stations that preceded the tapered one- or two-lane closure. Occasionally, the fast lanes were less frequently used than the other two lanes, and this factor resulted in less than 100 speed observations for some time periods.

All the lanes that were open to traffic at the three speed stations were equipped with sensors to detect speed and classify vehicles in two categories (cars and trucks.) The VC 1900 traffic analyzer was programmed to detect the speed and

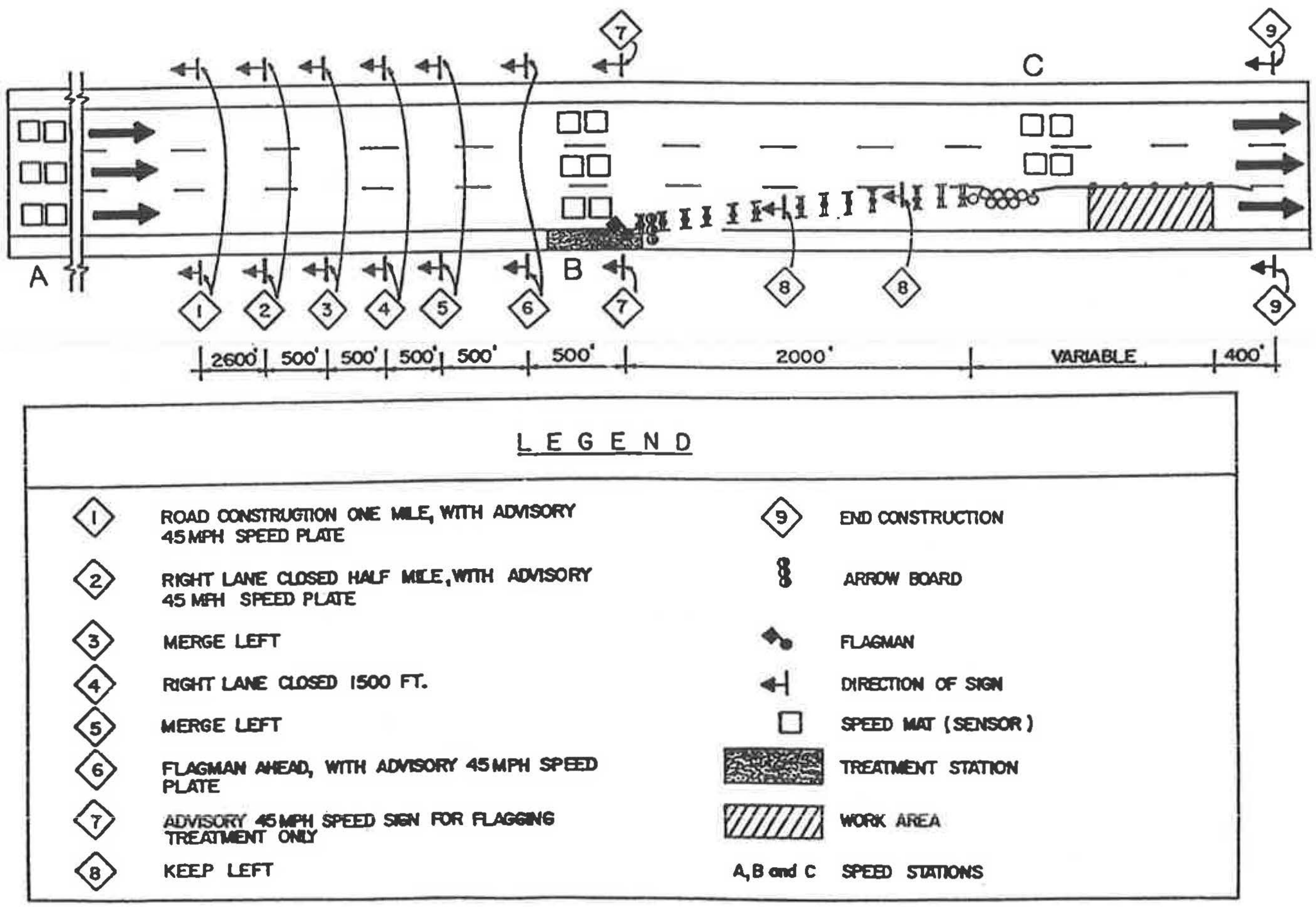

FIGURE 3 Schematic of typical right lane closure.

TABLE 1 LANE CLOSURES AND DISTANCES BETWEEN STATIONS

Treatment Type	Site No.	Freeway	Unidirectional Lanes	Lanes Closed	Distance Between Stations (ft) A–B	B–C
MUTCD	802	I-495S	3	Center, left	5,000	4,500
MUTCD	802	I-495S	3	Right	5,000	2,500
Police Car & Radar	805	I-495N	3	Center, left	5,000	4,500
Police Car & Radar	805	I-495N	3	Right	5,000	2,500
Police Controller	813	I-495N	3	Center, left	5,000	4,500
Police Controller	813	I-495N	3	Right	5,000	2,500
Innovative Flagging	826A	I-495N	3	Center, left	5,000	4,500
Innovative Flagging	826A	I-495N	3	Right	5,000	2,500

NOTE: MUTCD is the flagging procedure in the *Manual of Uniform Traffic Control Devices* (*6*). All sites located in Wilmington, Delaware.

type of vehicles separated by a selected headway of 4 sec. A Husky Hunter portable microcomputer was used to program the traffic analyzers placed at each speed station. Vehicle data were electronically stored in the memory of the traffic analyzer and were retrieved periodically with a Kaypro 2000 portable microcomputer, which is compatible with the IBM Personal Computer. Once the equipment at all speed stations was programmed for data collection, the field team left the stations and took on a supervisory role, periodically observing the equipment.

Data Reduction

The means and standard deviations of speed for each treatment are presented in Table 2. Although the long-term speed reduction capability of some treatments is already indicated by the tabulation of unadjusted data (for example, the police car and radar treatment shows a consistent decrease in speed from base to long-term periods), consideration must be given the speed changes due to differences in driver population across the periods.

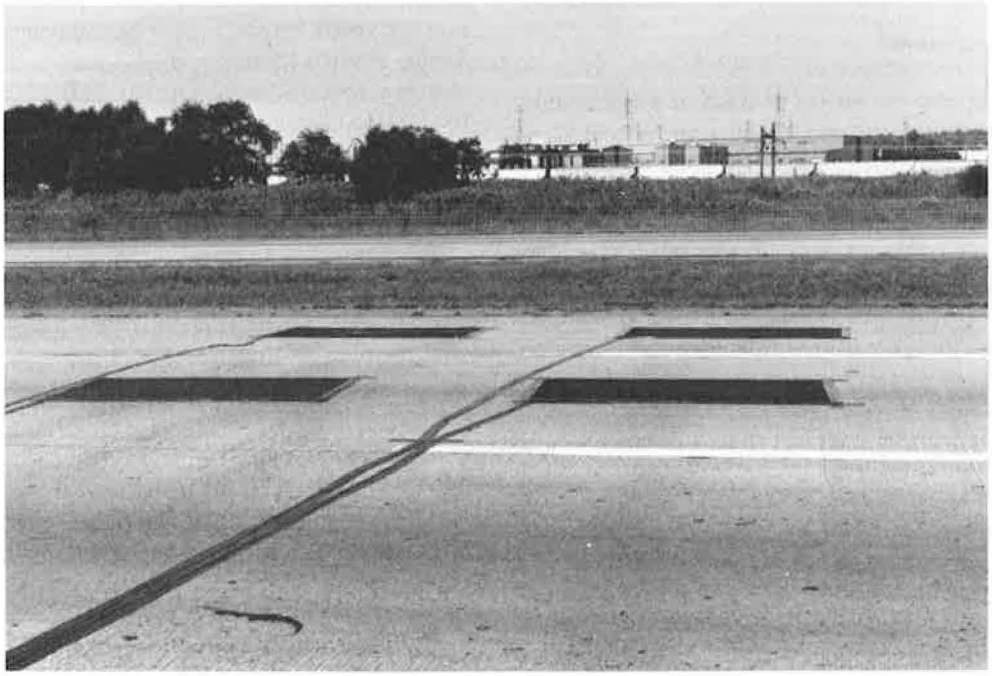

FIGURE 4 Mat-mounted electromagnetic loop detectors.

TABLE 2 MEANS AND STANDARD DEVIATION OF SPEEDS OF ALL VEHICLES

Treatment	Lanes Closed	STATION A						STATION B						STATION C					
		Base		Short-Term		Long-Term		Base		Short-Term		Long-Term		Base		Short-Term		Long-Term	
		$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
MUTCD Flag	CL & LL	60.8	5.7	57.7	6.5	58.4	8.3	57.3	7.8	60.9	7.2	58.2	7.1	60.4	6.1	52.6	6.6	54.2	7.7
MUTCD Flag	RL	62.2	7.1	58.3	7.8	59.0	8.0	53.8	6.0	55.1	6.0	60.0	5.8	60.5	7.1	59.2	7.1	58.1	4.9
INN. Flag	CL & LL	55.6	6.8	57.9	7.1	59.0	7.9	61.8	7.7	57.7	7.8	58.5	7.1	60.8	7.2	59.5	7.8	61.2	7.0
INN. Flag	RL	58.8	5.7	56.0	5.5	57.2	5.5	57.5	6.5	56.1	6.6	55.6	6.6	63.8	6.3	59.3	6.2	63.6	6.2
Police Car and Radar	CL & LL	55.6	5.4	56.3	6.5	58.3	5.9	56.6	5.6	60.9	7.0	53.9	5.6	63.6	6.2	60.3	7.6	59.9	6.1
Police Car and Radar	RL	59.0	8.2	57.9	6.0	57.6	5.7	60.2	6.6	56.7	5.6	59.3	6.0	66.7	5.5	61.6	5.2	56.9	8.1
Police Controller	CL & LL	56.7	6.8	57.7	6.5	58.4	6.6	58.9	7.0	53.6	6.6	53.8	6.4	62.0	7.6	57.7	7.4	60.4	6.7
Police Controller	RL	54.9	7.0	57.8	7.1	57.2	6.9	55.5	6.9	53.3	6.8	55.5	6.2	59.9	8.0	59.3	7.1	58.9	6.6

*located in active construction area $\overline{X}$ = means speed (mph) S = standard deviation

Statistical Method

All statistical analyses were done on an AT&T microcomputer using the Statistical Analysis System for Personal Computers (PC-SAS). The experimental design provided statistical controls for site differences and driver populations within sites by incorporating speed data from a base station (Station A) and a base period across all stations. A one-way analysis of variance procedure was used to compare mean driver speeds among the treatments. The driver speeds were adjusted for potential differences in the driving population before the analysis by subtracting the mean driver speeds at the base station (Station A). This adjustment assumes that the driver speeds at Station A adequately reflect the speeds of the population of drivers and that this population of drivers has the same variability at all stations. This assumption of equal variability was statistically tested and found to be valid at the .05 level of significance. The mean driver speeds among the stations were ranked and compared using the Scheffé method of multiple comparison (*17*). The individual levels of significance for these multiple comparison tests were adjusted so that the overall conclusions drawn are reliable at the .05 level of significance.

EVALUATION OF SPEED CONTROL TREATMENTS

Measure of Effectiveness

This analysis compared the effects of the four speed control treatments (Police Radar, Police Controller, Innovative Flagging, MUTCD Flagging) during the base (reference condition without any treatment) and short-term (within a few days after implementation of the treatment) time periods and during the base and long-term (10 to 15 days of continuous exposure) periods. The effect of the treatment was evaluated on the basis of the estimated expected speed change at Station C, adjusted for the actual speed change at the upstream base station, Station A. When the effect of the treatments at the point of application was assessed, Station B was used in place of Station C. However, the most dramatic treatment effect was anticipated at Station C.

The unadjusted speed change at Station C due to a speed control treatment was estimated by subtracting the average speed at Station C during the short-term period from the average speed during the base time period. This average speed change at Station C was then adjusted for differences in speeds that might be anticipated under no speed control treatment conditions (i.e., differences due to changes in the driver populations between the base and early periods). The net speed change was estimated by subtracting the average speed at Station A during the base time period. Because traffic at the upstream Station A was not influenced by the speed control treatment implemented near Station B, changes in average speed at Station A (between the base and short-term periods) could be assumed to be the result of differences in driver populations. Thus average speed differences at Station C were adjusted accordingly. The same procedure was used in estimating the net speed change at Station B.

Table 3 summarizes the estimated average (net) speed changes at stations A and C and the expected net average speed changes at Station C after adjusting for Station A speed differences. For example, for the MUTCD Flagging one-lane closure for all vehicles (cars and trucks), the difference in average speed between the base and long-term periods at Station A was −3.9 mph and −1.3 mph at Station C, for a net change at Station C of +2.6 mph [(−1.3) − (−3.9)]. Note that for the MUTCD Flagging speed control treatment to be effective, the average speed at Station C should have decreased by more than 3.9 mph. However, there was actually a net increase in speed at Station C.

A two-way analysis of variance model was applied to the base and long-term data of Station C for all treatments, adjusted for Station A speeds for each respective treatment period. The factors in the analysis of variance were site, treatment period (base or short-term), and site by treatment interaction. The interaction hypothesis in these two-way analysis of variance tables was equivalent to testing equality among the speed changes in columns labeled "net change" in Table 3. The adjusted (net change) estimates were tested using a modified interaction test.

If a significant overall difference in net speed change was found, the next step was to determine which treatments were different. This was done by using the Scheffé test for multiple comparisons at the overall level of significance of .05 for three contrasts.

The results of these statistical tests are summarized in Table 4. These results were interpreted separately for one- and two-lane closure conditions.

Short-Term Exposure at Station C

One-Lane Closure

Statistically, the Police Radar and Police Controller treatments were equally effective, with net average speed changes of −4.0 and −3.5 mph. Both were significantly more effective in reducing speeds than the Innovative Flagging and the MUTCD Flagging treatments, with net average speed changes of −1.7 and +2.6 mph, respectively, during the field studies. However,

TABLE 3 AVERAGE SPEED CHANGES (MPH), BASE VERSUS SHORT-TERM PERIODS

	One-Lane Closure			Two-Lane Closure		
	Station A	Station C	Net Change Station C	Station A	Station C	Net Change Station C
All Vehicles						
MUTCD	-3.9	-1.3*	+2.6*	-3.1	-7.8*	-4.7*
Police with Radar	-1.1	-5.1*	-4.0	+0.7	-3.3*	-4.0*
Police Controller	+2.9	-0.6*	-3.5*	+1.0	-4.3*	-5.3*
Innovative Flagging	-2.8	-4.5*	-1.7*	+2.3	-1.3*	-3.6*
Cars						
MUTCD	-3.5	-0.7	+2.8	-2.7	-7.1	-4.4
Police with Radar	-1.3	-5.0	-3.7	+0.5	-3.0	-3.5
Police Controller	+2.3	0.0	-2.3	+0.7	-3.9	-4.6
Innovative Flagging	-2.1	-4.5	-2.4	+2.6	-1.3	-3.9
Trucks						
MUTCD	-6.8	-3.0	+3.8	-2.1	-9.3	-7.2
Police with Radar	-2.0	-5.1	-3.1	+1.7	-4.2	-5.9
Police Controller	+3.8	-0.6	-4.4	-0.1	-4.9	-4.8
Innovative Flagging	-1.4	-4.8	-3.4	+1.4	-1.5	-2.9

M.P.H = Miles per hour

TABLE 4 RANKING WITHIN ONE- OR TWO-LANE CLOSURES AT STATION C: SHORT-TERM TREATMENT EFFECT

One-Lane Closure			Two-Lane Closure		
Rank	Treatment	mph	Rank	Treatment	mph
All Vehicles					
1	Police Controller	−4.0	1	Police Controller	−5.3
2	Police Controller	−3.5	2	MUTCD Flagging	−4.7
3	Innovative Flagging	−1.7	3	Police Radar	−4.0
4	MUTCD Flagging	+2.6	4	Innovative Flagging	−3.6
Cars					
1	Police Radar	−3.7	1	Police Controller	−4.6
2	Innovative Flagging	−2.4	2	MUTCD Flagging	−4.4
3.	Police Controller	−2.3	3	Innovative Flagging	−3.9
4	MUTCD Flagging	+2.8	4	Police Radar	−3.5
Trucks					
1	Police Controller	−4.4	1	MUTCD Flagging	−7.2
2	Innovative Flagging	−3.4	2	Police Radar	−5.9
3	Police Radar	−3.1	3	Police Controller	−4.8
4	MUTCD Flagging	+3.8	4	Innovative Flagging	−2.9

because the differences in speed reductions for the Police Radar and the Police Controller were at most 2.3 mph greater [(−4.0) − (−1.7)] than the Innovative Flagging, from a practical standpoint, it cannot be said that the Police Radar and Police Controller treatments were better than the Innovative Flagging.

The net average speed increase of 2.6 mph for the MUTCD Flagging was significantly different from any of the other treatment effects. It should be noted that the site at which the MUTCD Flagging was studied was the first site for data collection and analysis.

Analysis of cars only indicated that the Police Radar treatment, with an average speed change of −3.7 mph, was better at a statistically significant level than the other treatments. The Innovative Flagging treatment was found to be as effective as the Police Controller treatment in reducing average speeds. There was no statistically significant difference in average speed reductions between the Innovative Flagging and Police Controller treatments (−2.4 versus −2.3 mph). From a practical standpoint, there was no difference between the Police Radar, Police Controller and Innovative Flagging treatments.

The net average speed of cars during the MUTCD Flagging treatment increased by 2.8 mph. The results of the analysis of truck-only data were similar to those for cars only. The Police Controller, Innovative Flagging, and Police Controller resulted in statistically significant reductions in net average truck speeds of 4.4, 3.4, and 3.1 mph. The MUTCD Flagging resulted in a net increase of 3.8 mph in average truck speed.

Two-Lane Closure

For the two-lane closure condition, the net average vehicle speeds for all four speed control treatments were both statistically and practically lower than the speeds during the base conditions. The average speeds were reduced by a net of 5.3, 4.7, 4.0, and 3.6 mph for the Police Controller, MUTCD Flagging, Police Radar, and Innovative Flagging treatments. There were no statistically significant differences among the four treatments for all vehicles, cars only, or trucks only.

The results of the data for the two-lane closure are somewhat surprising in comparison to the one-lane closure. For example, it is difficult to understand why the MUTCD Flagging treatment would be effective for two-lane closures and not effective for one-lane closures. One proposed theory is that an experimental artifact may have biased the results at Station C during the two-lane closures. For example, it is possible that drivers were forced to reduce speeds to merge into one open lane during the two-lane closures. Thus the speed reductions may have been tempered by things other than the speed control treatments, in spite of efforts to collect data in free-flowing traffic.

Short-Term Exposure at Station B

Station B was analyzed with the same procedures that were used at Station C. Both short-term and long-term speed control treatment effects were evaluated, with adjustments for differences in Station A speeds. Tables 5 and 6 summarize the speed changes at stations A and B, the net adjusted speed change, and the ranking and results of statistical tests of significance of these net changes.

One-Lane Closure

For the one-lane closure for all vehicles (cars and trucks), all treatments showed a statistically significant change in net speeds. The Police Controller and the Police Radar treatments both significantly reduced net speeds (−5.1 and −2.4 mph). The Police Controller treatment resulted in a significantly lower net speed than the Police Radar treatment. The MUTCD Flagging and the Innovative Flagging treatments resulted in increases in net speed (+0.2 and +1.4 mph). The changes in speed that resulted from the Police Radar, MUTCD Flagging, and Innovative Flagging treatments were not considered to be of practical significance (i.e., there were essentially no changes in net speeds with these treatments).

For cars and trucks as one group, the Police Controller treatment was effective in reducing speeds. The Police Radar

TABLE 5 AVERAGE SPEED CHANGES (MPH), BASE VERSUS EARLY PERIODS

	One-Lane Closure			Two-Lane Closure		
	Station A	Station B	Net Change Station B	Station A	Station B	Net Change Station B
All Vehicles						
MUTCD	-3.9	-3.7	+0.2	-3.1	+3.6	+6.7
Police with Radar	-1.1	-3.5	-2.4	+0.7	+4.3	+3.6
Police Controller	+2.9	-2.2	-5.1	+1.0	-5.3	-6.3
Innovative Flagging	-2.8	-1.4	+1.4	+2.3	-4.1	-6.4
Cars						
MUTCD	-3.5	-3.6	-0.1	-2.7	+3.2	+5.9
Police with Radar	-1.3	-3.9	-2.6	+0.5	+4.2	+3.7
Police Controller	+2.3	-2.0	-4.3	+0.7	-5.6	-6.3
Innovative Flagging	-2.1	-2.1	0.0	+2.6	-4.1	-6.7
Trucks						
MUTCD	-6.8	-2.7	+4.1	-2.1	+4.3	+6.4
Police with Radar	-2.0	-1.9	+0.1	+1.7	+5.2	+3.5
Police Controller	+3.8	-3.1	-6.9	-0.1	-5.6	-5.5
Innovative Flagging	-1.4	+1.9	+3.3	+1.4	-3.2	-4.6

M.P.H = Miles per hour

TABLE 6 RANKING WITHIN ONE- OR TWO-LANE CLOSURES AT STATION B: SHORT-TERM TREATMENT EFFECT

One-Lane Closure			Two-Lane Closure		
Rank	Treatment	mph	Rank	Treatment	mph
All Vehicles					
1	Police Controller	−5.1	1	Innovative Flagging	−6.4
2	Police Radar	−2.4	2	Police Controller	−6.3
3	MUTCD Flagging	+0.2	3	Police Radar	+3.6
4	Innovative Flagging	+1.4	4	MUTCD Flagging	+7.8
Cars					
1	Police Controller	−4.3	1	Innovative Flagging	−6.7
2	Police Radar	−2.6	2	Police Controller	−6.3
3.	MUTCD Flagging	−0.1	3	Police Radar	+3.7
4	Innovative Flagging	0.0	4	MUTCD Flagging	+5.9
Trucks					
1	Police Controller	−6.9	1	Police Controller	−5.5
2	Police Radar	+0.1	2	Innovative Flagging	−4.6
3	Innovative Flagging	+3.3	3	Police Radar	+3.5
4	MUTCD Flagging	+4.1	4	MUTCD Flagging	+6.4

treatment was effective in reducing car speeds but resulted in no effect for trucks. The Innovative Flagging and the MUTCD Flagging treatments were found to be equal in effect. No net speed change was found for cars, and speed increases were found for trucks.

Two-Lane Closure

For the two-lane closure, the Innovative Flagging and the Police Controller resulted in very significant net reductions in speed (−6.4 and −6.3 mph). The MUTCD Flagging and the Police Radar resulted in significant increases in net speeds (+6.7 and +3.6 mph). The increase in speed using the MUTCD Flagging treatment was significantly higher than the increase with the Police Radar treatment.

Long-Term Exposure at Station B

Results of the speed changes at Stations A and B, the net speed changes (adjusted speeds), and the ranking and results of statistical tests of significance are summarized in Tables 7 and 8.

One-Lane Closure

For the one-lane closure for all vehicles, only the Police Controller resulted in a statistically significant reduction in net speed. However, the −2.3 mph speed change was not of practical significance. The Innovative Flagging and the Police Radar treatments had no effect on net speeds. The MUTCD Flagging resulted in a statistically and practically significant increase in net speeds: the change was +4.4 mph. For cars,

TABLE 7 AVERAGE SPEED CHANGES (MPH), BASE VERSUS LONG-TERM PERIODS

	One-Lane Closure			Two-Lane Closure		
	Station A	Station B	Net Change Station B	Station A	Station B	Net Change Station B
All Vehicles						
MUTCD	-3.2	+1.2	+4.4	-2.4	+0.9	+3.3
Police with Radar	-1.4	-0.9	+0.5	+2.7	-2.7	-5.4
Police Controller	+2.3	0.0	-2.3	+1.7	-5.1	-6.8
Innovative Flagging	-1.6	-1.9	-0.3	+3.4	-3.3	-6.7
Cars						
MUTCD	-2.2	+1.1	+3.3	-3.4	+0.6	+4.0
Police with Radar	-1.5	-1.2	+0.3	+2.0	-3.0	-5.0
Police Controller	+1.7	+0.6	-1.1	+0.9	-5.1	-6.0
Innovative Flagging	-1.4	-2.7	-1.3	+3.2	-3.3	-6.5
Trucks						
MUTCD	-6.8	+2.7	+9.5	+2.4	+1.6	-0.8
Police with Radar	-1.8	+0.3	+2.1	+1.0	-0.5	-1.5
Police Controller	+3.9	-3.1	-7.0	+3.9	-5.4	-9.3
Innovative Flagging	-0.4	+1.4	+1.8	+1.4	-2.9	-4.3

M.P.H = Miles per hour

TABLE 8 RANKING WITHIN ONE- OR TWO-LANE CLOSURES AT STATION B: LONG-TERM TREATMENT EFFECT

One-Lane Closure			Two-Lane Closure		
Rank	Treatment	mph	Rank	Treatment	mph
All Vehicles					
1	Police Controller	−2.3	1	Police Controller	−6.8
2	Innovative Flagging	−0.3	2	Innovative Flagging	−6.7
3	Police Radar	+0.5	3	Police Radar	−5.4
4	MUTCD Flagging	+4.4	4	MUTCD Flagging	+3.3
Cars					
1	Innovative Flagging	−1.3	1	Innovative Flagging	−6.5
2	Police Controller	−1.1	2	Police Controller	−6.0
3.	Police Radar	+0.3	3	Police Radar	−5.0
4	MUTCD Flagging	+3.3	4	MUTCD Flagging	+4.0
Trucks					
1	Police Controller	−7.0	1	Police Controller	−9.3
2	Innovative Flagging	+1.8	2	Innovative Flagging	−4.3
3	Police Radar	+2.9	3	Police Radar	−1.5
4	MUTCD Flagging	+9.5	4	MUTCD Flagging	−0.8

none of the treatments resulted in any practical changes in net speed. However, for trucks, the Police Controller resulted in a −7.0 mph change in speed, whereas the MUTCD Flagging treatment resulted in a +9.5 mph change in speed.

Two-Lane Closure

For the two-lane closure, all treatments except the MUTCD Flagging treatment reduced net speeds significantly. The Police Controller, Innovative Flagging, and Police Radar resulted in net speed changes of −6.8, −6.7, and −5.4 mph. The MUTCD Flagging resulted in a 3.3 mph increase in speed. The results with respect to decreases and increases in net speeds were repeated when the car data alone were analyzed. However, for trucks only, the Police Radar and the MUTCD Flagging treatments resulted in no significant change in net speeds.

Long-Term Exposure at Station C

The speed changes at stations A and C between the base and long-term treatment periods and the net speed change for Station C adjusted for Station A speeds are listed in Table 9. Rankings of the speed control treatments and the results of statistical tests of significance among these treatments are presented in Table 10. If there was a long-term speed control treatment effect, the results of this analysis should agree with those of the short-term treatment effect at Station C.

One-Lane Closure

For the long-term period sample with all vehicles (cars and trucks) and one-lane closure, the rankings of the treatments agree with the short-term treatment analysis. However, the data indicated that the Police Radar treatment improved with time.

TABLE 9 RANKING WITHIN ONE- OR TWO-LANE CLOSURES AT STATION C: LONG-TERM TREATMENT EFFECT

One-Lane Closure			Two-Lane Closure		
Rank	Treatment	mph	Rank	Treatment	mph
All Vehicles					
1	Police Radar	−8.4	1	Police Radar	−6.4
2	Police Controller	−3.3	2	MUTCD Flagging	−3.8
3	MUTCD Flagging	+0.8	3	Police Controller	−3.3
4	Innovative Flagging	+1.4	4	Innovative Flagging	−3.0
Cars					
1	Police Radar	−8.7	1	Police Radar	−5.8
2	Police Controller	−2.4	2	Police Controller	−3.5
3.	MUTCD Flagging	−0.4	3	Innovative Flagging	−3.2
4	Innovative Flagging	+1.2	4	MUTCD Flagging	−2.3
Trucks					
1	Police Controller	−6.4	1	MUTCD Flagging	−10.6
2	Innovative Flagging	−4.9	2	Police Radar	−4.1
3	Police Radar	+0.1	3	Police Controller	−1.5
4	MUTCD Flagging	+6.2	4	Innovative Flagging	−0.8

TABLE 10 AVERAGE SPEED CHANGES (MPH), BASE VERSUS LATE PERIODS

	One-Lane Closure			Two-Lane Closure		
	Station A	Station C	Net Change Station C	Station A	Station C	Net Change Station C
All Vehicles						
MUTCD	-3.2	-2.4	+0.8	-2.4	-6.2	-3.8
Police with Radar	-1.4	-9.8	-8.4	+2.7	-3.7	-6.4
Police Controller	+2.3	-1.0	-3.3	+1.7	-1.6	-3.3
Innovative Flagging	-1.6	-0.2	+1.4	+3.4	+0.4	-3.0
Cars						
MUTCD	-2.2	-2.6	-0.4	-3.4	-5.7	-2.3
Police with Radar	-1.5	-10.2	-8.7	+2.0	-3.8	-5.8
Police Controller	+1.7	-0.7	-2.4	+0.9	-2.6	-3.5
Innovative Flagging	-1.4	-0.2	+1.2	+3.2	0.0	-3.2
Trucks						
MUTCD	-6.8	-0.6	+6.2	+2.4	-8.2	-10.6
Police with Radar	-1.8	-8.2	-6.4	+1.0	-3.1	-4.1
Police Controller	+3.9	-1.0	-4.9	+3.9	+2.4	-1.5
Innovative Flagging	-0.4	-0.3	+0.1	+1.4	+0.6	-0.8

M.P.H = Miles per hour

The net change in average speed with the Police Radar treatment was −8.4 mph. This reduction is also better at a statistically significant level than the Police Controller treatment, which caused a net speed change of −3.3 mph during the long-term period. Neither Innovative Flagging nor MUTCD Flagging were significant in reducing speeds, and although there were speed increases for both of these treatments, the increases were neither statistically nor practically significant. It should be noted that the net speed increase for the MUTCD Flagging during the short-term period was statistically significant.

For cars only, all treatments were significantly different from each other. For trucks only, the net speed changes for all treatments were significant but equal.

Two-Lane Closure

For the two-lane closure, all speed control treatments resulted in a net average speed reduction during the long-term period. However, the Police Radar treatment reduced net speeds by an even greater amount than in the short-term treatment period. When vehicle types were separated, however, this improvement was not statistically significant for cars. For trucks the new speed change for the MUTCD Flagging became significantly higher than it was during the short-term period. The sample sizes for trucks in this analysis were extremely low for some treatments, however, and the variability was higher (as evidenced in the results of statistical equality between the Police Radar and Innovative Flagging treatments, despite a 3.3-mph difference).

SUMMARY OF RESULTS

The basic theory is that the speed reduction treatments applied at Station B, where all the freeway lanes are opened to traffic, will result in reduced speed at Station C, located in the area of active construction. Lane closure refers to the reduction of the number of lanes opened to traffic at Station C only. A summary of results is presented next.

Station C with One-Lane Closure

The results indicate that the Police Radar and the Police Controller were effective in reducing vehicle speeds in both the short term (about 3 days) and the long term (more than 10 days) after the speed control treatments were implemented on the freeway work sites studied. The Innovative Flagging speed control treatment elicited a speed decrease of less than 2 mph in the short term. From a practical sense, however, it cannot be said that the Police Radar and Police Controller treatments were better than Innovative Flagging. In the long term, the Innovative Flagging did not result in speed reductions at Station C. The MUTCD Flagging treatment actually resulted in a small increase in speed in both the short and long term.

Station C with Two-Lane Closure

Significant reductions in speeds were experienced in both short term and long term for all four speed control treatments when two of the three freeway lanes were closed. The amount of speed reduction was the same statistically for each treatment. The exception was the Police Radar treatment, which resulted in a greater long-term speed reduction.

Station B with One-Lane Closure at C

The Police Controller was the only speed control treatment that resulted in a significant (both statistically and practically) short-term speed reduction at Station B. The Police Controller also resulted in a long-term speed reduction; however, the reduction was only 2.3 mph, which was not considered to be of practical significance. There was essentially no long-term speed reduction for the Police Radar or the Innovative Flagging treatments. In the long term, the MUTCD Flagging treatment resulted in an increase in speed.

Station B with Two-Lane Closure at C

Significant long-term speed reductions were found at Station B when the Police Controller, Police Radar, or Innovative Flagging treatments were used. There was a significant long-term speed increase during the MUTCD Flagging operations.

CONCLUSIONS

The results of this research indicate that the long-term (more than two weeks) application of all the tested speed control treatments can derive significant reduction in traffic speed through the work area in highway construction zones. However, the effectiveness of the treatments appears to depend on the number of lanes that remain open to traffic in the work area. The flagging techniques are effective in reducing speed in the work area of multilane freeways where one lane is open to traffic. It should be noted, however, that the entire data collection effort was conducted under ideal traffic conditions, with level of service A. It stands to reason that at lower levels of service (higher lane volume) the flagging methods could have increased effectiveness during one-lane closures.

The law enforcement methods demonstrated strong long-term speed reduction capability. This finding, however, must be evaluated with due consideration given to the normal level of law enforcement activity on the freeways. In this research, all the study sites were located on facilities where there was already an exceptionally high level of police patrol. Thus most motorists were already aware of the high probability of being ticketed and saw compliance with speed control as the convenient option. Jurisdictions in which the police force does not have a reputation for enforcing the speed limit may not obtain significant reductions in speed via law enforcement methods. Consistent enforcement of speed limits will facilitate the effectiveness of speed control techniques that use law enforcement.

RECOMMENDATION

When this research began, the study team contacted highway officials in several states, seeking their cooperation in implementing the data collection on construction sites. Every contacted state official said that speeding through highway construction zones was a serious continuing problem, and most were skeptical about any solution. This skepticism appears to be rooted in the scarcity of resources for effective implementation of speed control methods and the inability to establish an integrated administrative mechanism that would enable the speed reduction methods of this research to be included in construction specifications as part of the traffic control plan. The engineer responsible for developing the traffic control plan should select a safe operating speed for the work zone and determine the need for specific speed reduction measures. Because the effectiveness of using police officers for speed control was noteworthy in this study, state and local highway agencies are encouraged to make special contractual provisions for implementation of law enforcement treatments into the traffic control plans. These provisions should include procedures for obtaining off-duty police personnel for the work sites, compensation, lists of contact people, applicable union requirements, scheduling, dress, and equipment.

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