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16. Abstract

This report presents a catalog of available speed control methods for work zones. Information contained in the report comes from three sources: a literature review, a telephone survey of SDHPT District personnel, and field studies of radar transmitters at work zones. The objective of the catalog is to present a synthesis of research concerning the effectiveness of each speed control method, document the perceived effectiveness and usage within the state of Texas, and identify any major site-specific factors which have been shown to influence the effectiveness of one or more methods.

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CATALOG OF WORK ZONE SPEED CONTROL METHODS

by

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

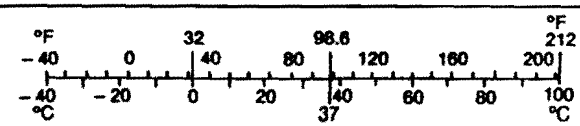
Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectores (10 000 m²)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

SUMMARY

This report presents a catalog of available speed control methods for work zones. Information contained in the report comes from three sources: a literature review, a telephone survey of SDHPT District personnel, and field studies of radar transmitters at work zones. The objective of the catalog is to present a synthesis of research concerning the effectiveness of each speed control method, document the perceived effectiveness and usage within the state of Texas, and identify any major site-specific factors which have been shown to influence the effectiveness of a particular method.

Law enforcement and flagging appear to be the most effective work zone speed control methods available. One of three types of enforcement are typically used at work zones: circulating patrols, stationary patrols, and a police traffic controller (where the officer leaves his vehicle and stands next to traffic at the work zone). The circulating patrol method is most commonly used in Texas, especially at rural and suburban long-term construction projects. Stationary patrols and police traffic controllers are used less frequently. The circulating patrol method does appear to be less effective in reducing vehicle speeds at the work zone, however, than either the stationary patrols or police traffic controller methods. Flaggers are also commonly used for speed control in work zones, and have been shown in some instances to be nearly as effective in reducing speeds as law enforcement.

Regulatory and advisory speed limit signing is used quite extensively at work zones in Texas. Selection of a reduced speed limit is typically based on such factors as work zone design speed, speed limits used at similar work zones in the past, and upon the perceived need for slower speeds for certain types of work zones (such as when workers are out standing next to traffic). Research, however, indicates that reduced speed limits have very little effect upon speeds. This lack of effect is acknowledged by most SDHPT personnel. Nevertheless, it is commonly felt that reduced speed limits should be posted to indicate to motorist that hazardous conditions may be present and that slower speeds may be necessary.

Several other methods to reduce speeds (changeable message signs, rumble strips, transverse paint stripes, reduced lane widths, and radar transmissions,) have also been tried at work zones. Overall, these methods have been shown to have a smaller effect upon speeds than either enforcement or flagging. Use of these methods in Texas appears to be limited to special situations.

IMPLEMENTATION STATEMENT

This report provides an overview of the different methods available for work zone speed control, their effectiveness, and site-specific conditions which may influence their effectiveness. The report should be useful to those developing work zone traffic control plans as well as to Department maintenance personnel when selecting appropriate work zone speed control methods in the future.

DISCLAIMER

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Nationwide, emphasis continues to shift from the construction of new highway facilities to the repair of existing ones. This same trend is found in Texas, as more and more roadways near the end of their service life and require increasing numbers of temporary repairs and eventual rehabilitation and reconstruction. These repairs generally must be made while also maintaining traffic flow through the work zone. Proper traffic control at work zone locations is essential to the successful completion of these activities.

During the 1970's and early 1980's, the traffic and worker safety problem in work zones became a high priority concern. Considerable money, time, and talent has been expended researching and documenting deficiencies in work zone traffic control (1,2,3), and then developing and testing improved traffic control techniques and strategies (as summarized in 4 and 5). This has resulted in work zone traffic control guidelines and practices that are safer and more efficient than ever before. However, accident rates within work zones still tend to be higher than for normal highway sections; therefore, so efforts must continue to improve safety and operations in work zones.

One of the more difficult and emotionally-charged issues yet to be resolved concerns the need for, and use of, speed control at work zones. Two basic schools of thought exist as to the use of work zone speed control (6):

1. Work zone speeds should be similar to normal roadway speeds in order to minimize speed differentials and thus accident potential.

2. Work zone speeds should be reduced, since work zones typically contain many hazardous elements and are therefore inherently more dangerous.

Support for each of these approaches can be found in the literature. Accident studies (7,8) have presented evidence citing excessive speed as a contributing factor in a large number of work zone accidents. Likewise, specific case studies of work zones have indicated a need for reduced speeds (and improved speed control) in some instances (1). This approach has wide support, as surveys of state and local highway agencies indicate that most jurisdictions generally invoke reduced speed limits in work zones (9,10). Consequently, it is apparent that reducing vehicle speeds at some work zone locations will improve safety.

On the other hand, research and experience have shown that it is extremely difficult to reduce vehicle speeds in work zones below their normal levels. Drivers will not reduce their speed at a work zone unless they perceive a need to do so (11). Consequently, the Manual of Uniform Traffic Control Devices (12), the Traffic Control Devices Handbook

(13), and various work zone speed control implementation guidelines (14,15) indicate that the work zone should be designed with the intent of maintaining normal travel speeds. In fact, some theoretical research (using simulation) of the potential effects of speed control suggests that increased compliance with speed limit reductions may produce undesirable effects upon traffic operations in some situations (16). While this work is far from conclusive, it does suggest that attempts to control speeds may not always be beneficial. Any attempts to control traffic must be followed by an evaluation to determine if it is having the desired effect on vehicle speed and operations.

Actual practice speed control lies somewhere between these two extremes. Whereas it is desirable to design every work zone to operate at normal operating speeds, certain conditions and combinations of conditions at a given location can make this impossible. Conversely, although certain conditions make it necessary to attempt to reduce speeds in some work zones, reduced speeds are not a necessary or even desirable goal at all locations. Therefore, the critical tasks for the engineer charged with planning work zone traffic control are to (1) determine whether conditions exist which necessitate speed control in a work zone, (2) determine how much speed reduction is needed for those conditions, and (3) identify which of the available techniques for speed control should be used (if any). Following implementation of the speed control strategy, the situation should be monitored to determine if safety has been improved and/or if other techniques should be employed.

At the present time, there is very little current guidance available to the engineer regarding any of those tasks. There exists a need for a process by which engineers can evaluate the characteristics of a work zone, determine if and how much of a speed reduction is needed, and then (in conjunction with sound engineering judgement) select an appropriate speed control strategy that matches the needs of that particular work zone.

Previous work zone speed control research has focused primarily on the ability of various methods to reduce speeds from their "normal" level at a work zone to some lower level. These studies have provided an indication of the relative effectiveness of the methods under different conditions. However, one notices considerable variation from study to study (and from site to site within a study) in the absolute effects of the methods upon speeds. This variability is not unexpected. Driver decisions regarding speeds are made at the control and guidance levels of the driving task, in response to stimuli about the driving environment received from the various senses (17). Drivers must sift through the vast amounts of information presented to them, identify those factors in the environment that have relevance to the driving task, make decisions based on those factors, and take appropriate actions to implement those decisions. Over time, the importance of these factors may change, depending on the information needs of the driver at that time. Also, the importance of a factor to a driver may differ from location to location, depending on what other factors are present. Consequently, the effect of introducing a single factor (i.e., a speed control technique) into an environment is likely to depend on the other factors present which affect driving speeds. The result will be varying effects from location to location.

As an initial step towards a comprehensive speed control selection process, this report presents a catalog of the devices and strategies available for work zone speed control. The focus of the report is to assess the effectiveness of the speed control methods available and to examine how this effectiveness is influenced by site-specific conditions present at a work zone. The material contained in this report comes from three main sources: (1) published literature on work zone speed control and related topics, (2) a telephone interview of selected Texas State Department of Highways and Public Transportation (SDHPT) personnel involved with selecting and implementing work zone speed control measures, and (3) field studies of the effects of radar transmissions without a visible law enforcement presence at work zones. The results of the telephone interview are included as Appendix A. Appendix B documents the field studies of radar transmissions at work zones.

2. CATALOG OF SPEED CONTROL METHODS

This chapter presents a synthesis of research and experience with speed control methods in work zones. The chapter is subdivided by the various speed control methods that are available. A number of devices normally present at a work zone, including work zone advance warning signs, channelizing devices, and arrow panels (4), have been shown to have an effect on traffic speeds. One study demonstrated that characteristics of the work zone itself, such as the type, intensity, and location of work activity within the work zone all affect traffic speeds to some degree (18). However, the focus of this synthesis is on those devices and techniques that are actually implemented for the purpose of speed control.

Nine speed control methods discussed in this synthesis are:

1. Regulatory and Advisory Speed Limit Signing,
2. Changeable Message Signing,
3. Transverse Striping,
4. Rumble Strip Applications,
5. Lane Width Reductions,
6. Flagging,
7. Enforcement,
8. Unmanned Radar Transmitters, and
9. Utilization of a Traffic Queue (congestion).

Two other methods identified through the literature were the Iowa weave section and the use of a pace car to lead alternating, two-way traffic through a one-lane work zone. One study indicated that the Iowa weave did reduce speeds under the conditions that were tested (19). However, this method requires considerable effort to set-up and maintain. The pace car provides strong control over vehicle speeds, but has limited applicability. Consequently, these two methods are not discussed further in this report.

Regulatory and Advisory Speed Limit Signing

Application and Usage

Regulatory and advisory speed limit reductions are by far the most common method of speed control in work zones. A national survey of work zone speed limit usage recently conducted found that 33 of the 47 states responding (70%) used reduced regulatory speed limits in work zones at least occasionally (9). A survey of engineers in seven SDHPT Districts found that all used reduced regulatory speed limits on long-term construction projects. Advisory speed limits are also commonly used in Texas, typically for short-term maintenance projects. In addition, advisory limits are also often used in conjunction with reduced regulatory limits in some Districts. A construction project may be speed zoned 10 to 15 mph lower than the normal speed limit of the roadway for the duration of the project, with an even lower advisory speed limit posted when workers are out next to traffic during the day.

Effectiveness

Although it is quite common to reduce speed limits in work zones, it is generally felt that reduced limits have little effect on traffic speeds. Early studies (20) found that neither advisory or regulatory signing had any effect on vehicle speeds in work zones on urban or rural freeways or on urban arterial streets. Speeds were also found to be unaffected by reduced speed limits in a later study of work zone speed control methods (6). These results mimic other studies of speed limit reductions at non-work zone locations (21).

However, other evidence suggests that speed limits can affect work zone speeds in some instances. Work zone studies in Australia (22) found that lower speed limits reduced mean speeds by 4 to 5 mph. However, it was noted that 80 to 95 percent of traffic still exceeded the reduced speed limit posted. In the U.S., a recent study in Minnesota (23) showed that the introduction of a 40 mph speed limit at a work zone lane closure on a rural interstate section reduced 85th-percentile speeds by about 10 mph when compared to speeds at the work zone without the posted speed limit. Another article reported that speeds at an interstate work zone in Minnesota were reduced 15 mph after posting a lower regulatory speed limit (24). Minnesota has adopted legislation allowing posting and enforcement of reduced regulatory speed limits at work zones without a traffic and engineering investigation and without prior highway commission approval (24). In addition, an extensive public information campaign has been ongoing to encourage motorist caution and slower speeds in work zones. Additional research will be needed to determine whether this type of emphasis on slower speeds and motorist caution will have only a temporary, novelty effect on vehicle speeds or result in long-term changes in driver speed choice behavior at work zones.

Limitations

In Texas, reduced work zone regulatory speed limits at a location are allowed only after approval by the Highway Commission (25). Consequently, such limits generally cannot be used for short-term maintenance activities. In comparison, advisory speed limits may be posted at a work zone without prior commission approval. However, it has been noted that it may be easier to obtain speeding convictions for regulatory speed limits than for advisory speed limits (11). Nevertheless, advisory speed limits are enforceable, and law enforcement agencies and the courts may need to be made aware of this fact.

Changeable Message Signs (CMSs)

Application and Usage

Changeable message signs (CMSs) can provide drivers with real-time information about conditions, and can be particularly useful at highway construction and maintenance work zones where unexpected traffic or detour situations exist. The decision to use CMSs at work zones are based on a number of factors including availability, reliability of equipment (especially under extreme environmental conditions), and installation/maintenance costs. New technology has been developed (such as the flip-disk CMS) to improve upon some of these issues; however, additional research is needed to determine their effectiveness.

Portable changeable messages signs have been used at work zones to display a reduced advisory speed and/or a statement to reduce speed or proceed with caution. While these signs perform a function similar to advisory speed limit signing, the increased conspicuity of the sign, and the flashing messages of the bulb-matrix-type signs, makes them potentially more effective in reducing work zone speeds. None of the SDHPT Districts surveyed mentioned the use of CMSs to reduce speeds at work zones. In general, it appears that if the District personnel determine that active speed control is necessary, other speed control methods which are more effective are selected.

Effectiveness

Testing of these devices has been limited primarily to high-speed rural freeways and highways, although one test has been performed on an urban arterial. Table 2-1 summarizes the results of these tests. Studies of freeway lane closures in California, Colorado, and Georgia (26) showed that CMS reduced mean speeds approximately 7 mph in California, and 2 to 3 mph in Georgia. No reduction was reported in Colorado; however it was noted that mean speeds at the Colorado site were already low (47 mph), and that there was little room for a significant reduction in speeds below that point. Different CMS treatments (one line, two line, or three line messages) produced no significant differences in speed reducing capabilities.

A later study of CMS use in Texas found 3 to 5 mph reductions in mean speeds at rural freeway work zones, a 0 to 2 mph reduction at an urban freeway work zone (depending on the location of the CMS), and a 3 mph reduction at a work zone on an urban arterial (6). An evaluation of CMSs at rural freeway lane closures in Kentucky suggested a 3 mph or smaller decrease in mean speeds due to CMSs. In that study,

TABLE 2-1. EFFECT OF CHANGEABLE MESSAGE SIGNS (CMS) ON WORK ZONE SPEEDS

Study	Reduction in Mean Speeds			
	Rural Freeway	Urban Freeway	Urban Arterial	Rural Two-Lane Highway
Hanscom (26)*	0 - 7 mph	---	---	---
Richards et al. (6)	3 - 5 mph	0 - 2 mph	3 mph	---
Pigman and Agent (27)	0 - 3 mph	---	---	---

* Numbers underlined in parentheses (_) are reference numbers

sight distance restrictions were cited as a possible reason for the lack of better CMS performance at some of the sites (27).

Limitations

As the research indicates, CMSs provide modest speed reductions in some cases. No research exists as to their effects on two-lane, two-way highways, and data regarding their effect on urban freeways and arterials is limited. Also, it has been noted that CMS effectiveness may diminish over time as drivers become accustomed to the presence of the sign (27). Finally, concern exists as to whether or not the advisory speed presented by a CMS can be enforced as an advisory speed limit. It may be necessary to post advisory speed limit plates at the work zone (W 13-1) (12) in addition to the CMS if enforcement is desired.

Transverse Striping

Application and Usage

Another potential method of work zone speed control is to place stripes at decreasing spacings across the travel lanes in advance of a work zone. When approached in a vehicle, this technique presents a visual illusion that the vehicle is accelerating, with an anticipated result that drivers will slow down. Limited testing of transverse striping in a few non-work-zone situations has shown them to have some speed-reducing effect (28,29). In Texas, transverse striping does not appear to be used to any significant degree; none of the SDHPT Districts surveyed indicated that they had used transverse striping to reduce work zone speeds.

Effectiveness

Testing of transverse striping at work zones has found them to be generally ineffective in reducing vehicle speeds. An early study in which such striping was used in conjunction with advisory and regulatory speed zoning found that striping had little or no effect on mean speeds (20). A similar result was demonstrated during in-vehicle laboratory studies on a test track (6).

Limitations

At best, transverse striping has limited potential as a work zone speed control method. The method requires significant implementation time and effort, making it applicable only for long-term work zones. One would expect any effect the striping patterns would have to diminish over time as local drivers traveling repeatedly through the work zone become accustomed to the patterns. In addition, the highway agency must then continue to maintain the stripes or face additional liability. Testing of the method is limited: therefore, one cannot say for certain that it would never reduce speeds through a particular work zone. However, it is doubtful that transverse striping would be a consistently effective work zone speed control technique for most situations.

Rumble Strips

Application and Usage

Rumble strips are another means available for work zone speed control. In addition to speed control, rumble strips have also been tried as a means of encouraging earlier merging of traffic at lane closures. Based on the survey of SDHPT District personnel, rumble strips are not used to any significant degree for work zone speed control in Texas. None of those surveyed mentioned that rumble strips were used in their District to reduce speeds at work zones.

Effectiveness

Tests of rumble strips in non-work-zone situations suggest that they may be able to reduce vehicle speeds considerably under certain conditions (21). Research to date on rumble strips at work zones has provided conflicting evidence concerning their effect on vehicle speeds. In-vehicle laboratory studies conducted on a test track found rumble strips to have no effect on vehicle speeds (6). Data collected where rumble strips were installed on a two-lane highway in advance of a work zone showed them to reduce mean speeds about 2 mph (6).

In a more recent study, rumble strips were used in advance of a lane closure on a section of rural four-lane interstate (27). The strips were placed in the closed lane 1.5, 1.0, 0.6, 0.3, and 0.1 miles in advance of the lane closure. The primary purpose of the strips was to encourage earlier merging of closed lane traffic into the open lane. However, some decrease in mean speed was noted. Unfortunately, because of the analysis methodology used, it was not possible to determine the actual incremental effect that rumble strips may have had on speeds.

Finally, a recent synthesis of rumble strip usage in work zones has documented claims made by a rumble strip manufacturer, based upon a test in New Mexico. According to this test, the rumble strips resulted in an additional 8 mph reduction in mean speeds compared to mean speeds when rumble strips were not used (30). Unfortunately, details about the work zone conditions where this test occurred were not provided.

Limitations

Rumble strips require substantial time and effort to install and remove, and so their use is generally limited to long-term construction projects or major maintenance operations. The recent synthesis (30) recommends that rumble strips be used only for unusual situations. Also, the effectiveness of rumble strips for speed control will likely decrease over time at work zones where there is considerable repeat traffic (local drivers).

Because of the limited research and experience to date with rumble strips at work zones, additional research on this technique is warranted in several areas. For example, what effect rumble strips may have upon speed differentials between vehicles approaching the work zone needs to be studied. In addition, additional research is needed to determine how rumble strips affect small vehicle and motorcycle safety and operations, particularly under adverse weather and pavement conditions. Such information will answer many unresolved design and legal issues currently surrounding the use of rumble strips at work zones.

Lane Width Reductions

Application and Usage

Reducing the width of travel lanes is another technique that has been shown to reduce vehicle speeds within work zones in some situations. Major freeway reconstruction projects typically implement reduced lane widths in order to create work spaces for the contractor, separating the travel lanes from the work area by portable concrete barriers. A technique labeled as an "effective lane width reduction" has also been tested at a limited number of work zones. Here, portable channelizing devices (cones, barrels, tubes) are placed inside existing lane lines to simulate narrower lane widths.

Narrow lanes are commonly used during long-term urban freeway construction projects in Texas (where right-of-way is limited), but effective lane width reductions during short-term operations are not. Only one of seven Districts surveyed indicated that they reduced lane widths via channelizing devices on occasion in order to lower speeds.

Effectiveness

Table 2-2 summarizes the existing database regarding the effect of reduced lane widths on traffic speeds. An early use of narrow lanes (i.e., 10-ft widths) during a freeway rehabilitation project in Houston reduced mean speeds 3 to 8 mph (31). However, the number of lanes available for traffic during the project was also reduced (from 5 to 3 lanes). It is possible that the increased lane volumes through the narrowed section may

TABLE 2-2. EFFECT OF NARROW LANES ON WORK ZONE SPEEDS

Study	Reduction in Mean Speeds			
	Rural Freeway	Urban Freeway	Urban Arterial	Rural Two-Lane Highway
Richards et al. (31)*	---	3 - 8 mph[a]	---	---
Kuo and Mounce (32)	---	(-2) - 3 mph[b]	---	---
Richards et al. (6)	2 - 5 mph[c] 2 mph[d]	0 mph[c] 0 mph[d]	4 mph[c] 2 mph[d]	4 - 8 mph[c] 4 - 7 mph[d]

* Numbers underlined in parentheses (_) are reference numbers

Negative numbers in parentheses (-) indicate speeds were higher when narrow lanes were present

[a] 3 10-ft lanes with portable concrete barriers on both sides of road

[b] 3 10-ft lanes with portable concrete barriers on one or both sides of road

[c] 11.5-ft lanes with traffic cones (effective lane width reduction)

have also caused slower speeds. In comparison, an evaluation of traffic flow during the reconstruction of I-10 (Katy Freeway) in Houston found speeds slightly affected by narrowed lanes during construction (32).

Traffic cones were used as the channelizing devices in a series of field studies to evaluate effective lane width reductions (6). Lanes narrowed to 11.5-ft lowered mean speeds 2 to 8 mph at rural freeway and two-lane highway work zones. At an urban arterial work zone, the mean speed was reduced 2 to 4 mph. However, at an urban freeway site, the narrow lanes had no effect on speeds. As part of this same research, the cones were placed 12.5 ft apart, wider than a normal travel lane but with the illusion of a somewhat restricted section (since cones were placed on both sides of the travel lane). In this situation, mean speeds were reduced 2 mph at rural freeway work zones, 4 to 7 mph at work zones on two-lane highways, 2 mph at an urban arterial street work zone, and 0 mph at an urban freeway work zone.

Limitations

The effective lane width reduction method requires considerable set-up and removal time. Also, keeping the channelizing devices (particularly cones) upright within the work zone may also be a problem (6). However, for situations where channelizing devices are necessary for traffic control anyway and work zone capacity is not a major concern, reducing the effective lane widths appears to provide moderate speed reductions.

Flagging

Application and Usage

According to the Texas MUTCD (33), one of the uses of flaggers at work zones is to help reduce speeds through the work zone. Flagging is a commonly used work zone speed control technique in Texas. Five of seven Districts surveyed stated that they use flaggers to reduce work zone speeds on occasion. In general, the field supervisor in charge decides whether or not to use flaggers. This decision is typically based upon the supervisor's perception of work zone conditions and prevailing traffic speeds.

The Texas MUTCD defines the standard motion to be used by a flagger when alerting and slowing traffic through a work zone. The flagger faces traffic and slowly waves the flag between the 6 o'clock and 9 o'clock hand positions, never raising the flag above horizontal. A driver survey, however, indicated that this procedure was not readily understood as indicating a need for reduced speeds (34). An innovative flagging technique has also been developed and tested which attempts to convey the need for reducing speeds more clearly. This technique requires the flagger to stand next to a reduced speed limit sign, make eye contact with the approaching motorist, and point to the speed limit sign.

Effectiveness

Studies and experience have shown that flaggers are effective in reducing vehicle speeds through a work zone. In fact, some research suggests that the use of flaggers, under certain conditions, can reduce speeds nearly as much as the presence of enforcement. This finding is important as flaggers are generally more available to highway agencies than police officers used as traffic controllers. In addition, flaggers will not have to leave their post periodically to chase and apprehend speeders as enforcement personnel may do from time to time.

Table 2-3 summarizes the results of two work zone speed control studies assessing the effectiveness of flaggers. In the first study (6), the innovative flagging technique generated reductions in mean speeds of 7 to 13 mph at two rural freeway work zones, 13 mph at an urban arterial work zone, 10 to 16 mph at two rural two-lane highway work zones, and a 4 to 5 mph reduction at an urban freeway work zone. At the same sites, the MUTCD flagging treatments also reduced mean speeds significantly, but never as much as the innovative flagging technique. In fact, the innovative flagging technique generally resulted in additional 1 to 6 mph reductions in mean speeds over the MUTCD flagging technique.

A later study found the innovative and MUTCD flagging techniques less effective at reducing speeds at a rural freeway work zone. In this research, mean speeds were lowered from 0 to 7 mph (35). Data were collected immediately after beginning the use of either flagging technique, and again two weeks after the technique had been in daily use. No consistent decline over time was reported in the effectiveness of either technique.

The effect of these techniques appears to depend on the number of lanes that are open to traffic within the work zone. Table 2-4 presents the results of the two studies categorized by the number of freeway lanes open to traffic. In this table, results from both urban and rural freeways are included. In general, reductions in mean speeds were greater when more lanes were closed to traffic. This would be expected, as drivers have less room in which to maneuver as lane volumes are increased.

Limitations

Flagging is a physically taxing job, and it is recommended that flagging personnel be rotated every 1.5 to 2 hours to maintain a high level of alertness. Also, flagging is labor intensive, and therefore is applicable primarily for work zones of short duration.

TABLE 2-3. EFFECT OF FLAGGERS ON WORK ZONE SPEEDS

Study	Flagging Technique	Reduction in Mean Speeds			
		Rural Freeway	Urban Freeway	Urban Arterial	Rural Two-Lane Highway
Richards et al. (6)	MUTCD Innovative	4 - 7 mph 7 - 13 mph	3 mph 4 - 5 mph	11 mph 13 mph	8 - 12 mph 10 - 16 mph
Noel et al. (35)	MUTCD Innovative	(-3) - 5 mph (-2) - 4 mph	--- ---	--- ---	--- ---

* Numbers underlined in parentheses (_) are reference numbers

Negative numbers in parentheses (-) indicate speeds were higher or had increased

Innovative flagging technique--flagger stands next to speed limit sign, makes eye contact with motorist, and points to speed limit sign

TABLE 2-4. FLAGGING EFFECTIVENESS VERSUS NUMBER OF LANES OPEN TO TRAFFIC

Study	Flagging Technique	Reduction in Mean Speeds	
		Two Lanes Open Through Work Zone	One Lane Open Through Work Zone
Richards et al. (6)*	MUTCD Innovative	3 - 4 mph 5 - 7 mph	7 mph 13 mph
Noel et al. (35)	MUTCD Innovative	(-3) - 1 mph (-2) - 2 mph	4 - 5 mph 3 - 4 mph

* Numbers underlined in parentheses (_) are reference numbers

Negative numbers in parentheses (-) indicate speeds were higher when treatment was implemented

Innovative flagging technique--flagger stands next to speed limit sign, makes eye contact with motorist, and points to speed limit sign

Data presented in previous research indicated that flagging costs averaged approximately $20.00/hr (in 1983 dollars) (6). It is important that flaggers by used as a speed control technique only when necessary. Although flagging can reduce the speeds of motorists approaching and traveling through a work zone (and intuitively improve motorist and worker safety), the flagger is placed at risk out near oncoming, high-speed traffic. The trade-offs that exist between motorist and flagger safety, when used for speed control, have not been determined at this time.

Law Enforcement

Application and Usage

The use of law enforcement at work zones has consistently been shown to be one of the most effective speed control techniques available. The high visibility of the enforcement symbol (uniformed officer, police vehicle with flashing lights) and the threat of apprehension and penalty serve as a strong speed-reducing technique at work zones, as demonstrated in several studies (6),(25),(35). Furthermore, law enforcement and highway officials perceive significant safety benefits at work zones where enforcement is used to control speeds (36),(37).

The magnitude by which speeds are slowed has been shown to vary according to the method of enforcement. Basically, three enforcement methods have been used:

1. Moving or Circulating Patrols,
2. Stationary Patrols, and
3. Police Traffic Controller.

During moving patrols, the law enforcement officer continuously drives back and forth in the area of the work zone. During stationary patrols, the officer is parked immediately up stream of the work zone, in a conspicuous location next to the side of the road. The final enforcement method is the police traffic controller. A uniformed officer stands next to the side of the road immediately up stream of the work zone, as a flagger would do.

In Texas, circulating or stationary patrols are commonly used at long-term construction and maintenance sites. In some Districts, the Department has contacted the local Department of Public Safety (DPS) office to notify them that work will be going on at a particular location and ask them to patrol that location. In other instances, DPS officers on regular patrol increase their enforcement levels after finding that a work zone is present at a location. In contrast, police traffic controllers are used occasionally by two urban Districts.

Effectiveness

Table 2-5 presents the results of several studies of the effect of law enforcement at work zones. In general, moving patrols have been found to have the least effect on speeds. At a series of studies at rural freeway work zones, circulating enforcement reduced mean speeds 3 mph (20). A study of circulating patrols at a work zone on a two-lane highway found mean speeds were also reduced approximately 2 to 3 mph (6).

Stationary patrols have been shown to be quite effective at reducing speeds under normal roadway conditions (21) as well as at work zones (6). A study of stationary enforcement at a series of work zones in Texas found that mean speeds were lowered 5 to 9 mph on rural freeways and two-lane highways, and 12 mph on an urban arterial (6). Also, during the study, the effectiveness of the stationary patrol increased slightly when the patrol unit had its lights flashing and/or its radar activated. A later study, using a stationary patrol unit with radar activated, reduced mean speeds 4 to 5 mph immediately after enforcement was begun at a rural freeway work zone (35). Measurements taken after approximately 2 weeks of constant enforcement showed speeds were reduced even more (6 to 8 mph). A third study of stationary enforcement (and radar) at a rural freeway lane closure reduced 85th-percentile speeds by 13 mph (23). If the patrol vehicle left the scene to issue a citation, however, speeds soon increased to a level similar to those observed when no enforcement was used.

A police traffic controller standing next to traffic at the work zone has also been shown to reduce vehicle speeds. In one study, this technique lowered mean speeds 9 to 13 mph at rural two-lane highways and at an urban arterial work zone (6). In another study, mean speeds at a rural freeway work zone were reduced 3 to 4 mph (35). Experience with the use of police traffic controllers has been quite positive; one article contends that the use of police traffic controllers during freeway lane closures in Houston has helped improve worker and motorist safety dramatically (36).

As with flaggers, the effectiveness of law enforcement as a speed control technique appears to depend on the number of traffic lanes that remain open through the work zone. As Table 2-6 indicates, speed reductions due to enforcement were, in general, greater when there are fewer lanes open to traffic. Speed limits at these study sites were posted at 40 to 45 mph. It is not known what effects enforcement would have had if reduced speed limits had not been posted. Research conducted at non-work zone locations suggests a relationship between enforcement effectiveness at a location, mean speeds, and the posted speed limit (21),(38).

Limitations

One of the most prohibitive aspects of the use of enforcement for work zone speed control is its high cost. Data presented in previous research found off-duty enforcement costs to range from $10.00 to $25.00 per hour (in 1983 dollars) (67). Also, the labor

TABLE 2-5. EFFECT OF LAW ENFORCEMENT ON WORK ZONE SPEEDS

		Reduction in Mean Speeds			
Study	Enforcement Technique	Rural Freeway	Urban Freeway	Urban Arterial	Rural Two-Lane Highway
Graham et al. (20)*	Circulating	3 mph	---	---	---
	Stationary	---	---	---	---
	Controller	---		---	----
Richards et al. (6)	Circulating	---	---	---	2 - 3 mph
	Stationary	5 - 9 mph	3 - 6 mph[(a)]	12 mph	7 mph
	Controller	---	---	13 mph	9 - 14 mph
Noel et al. (35)	Circulating	---	---	---	---
	Stationary	(-1) - 5 mph	---	---	---
	Controller	2 - 7 mph	---	---	---
Jackels et al. (23)	Circulating	---	---	---	---
	Stationary	13 mph[(b)]	---	---	---
	Controller	---	---	---	---

* Numbers underlined in parentheses (_) are reference numbers
Negative numbers in parentheses (-) indicate speeds were higher when treatment implemented

(a) 4 and 6 mph average speed reductions were achieved with flashing lights and radar on, respectively
(b) reduction in 85th percentile speed (average speeds were not provided in literature)

Circulating Enforcement travelling periodically through work zone
Stationary Enforcement stopped next to roadway at work zone
Controller Officer out of vehicle standing next to work zone

TABLE 2-6. ENFORCEMENT EFFECTIVENESS VERSUS NUMBER OF LANES OPEN TO TRAFFIC (FREEWAY WORK ZONES)

Study	Enforcement Technique	Reduction in Mean Speeds	
		Two Lanes Open Through Work Zone	One Lane Open Through Work Zone
Richards et al. (6)*	Circulating	---	---
	Stationary	3 - 5 mph	9 mph
	Controller	---	---
Noel et al. (35)	Circulating	---	---
	Stationary	(-1) - 4 mph	4 - 5 mph
	Controller	2 - 4 mph	5 - 7 mph

* Numbers underlined in parentheses (_) are reference numbers
Negative numbers in parentheses (-) indicate speeds were higher when treatment was implemented

Circulating Enforcement travelling periodically through work zone
Stationary Enforcement parked at work zone
Controller Officer out of vehicle standing next to work zone

resources of most law enforcement agencies are limited, and must be allocated among a number of different activities (in addition to work zone traffic control) to preserve public safety. In certain jurisdictions, it is difficult to obtain uniformed officers for work zone traffic control purposes. However, when they can be obtained, the presence of law enforcement personnel can be counted upon to provide a strong speed-reducing effect.

Radar Transmitters

Application and Usage

Although law enforcement has proven to be an effective speed-reducing method at work zones, it is costly to implement and sometimes difficult to schedule. Recently, attention has turned to the possible use of radar signals at work zones as a speed control technique. Radar has been shown to have an additional speed-reducing effect when used to supplement stationary law enforcement. In one study, the mean speed of traffic when stationary enforcement and radar were present was 3 mph lower than when enforcement was present but the radar was not operating (6). A similar small incremental speed reduction due to radar was documented during studies of enforcement on normal highway sections (21).

More recently, there has been some research of the effects of a low watt output radar signal emitted without the presence of visible law enforcement. A Texas study (39) found mean speeds were slightly reduced (generally less than 2 mph) in the presence of radar. The effect of radar was shown to be greater for trucks than for cars, and greater for high-speed vehicles than for the entire speed sample as a whole. Meanwhile, the standard deviation of speeds decreased slightly in the presence of radar. A study of radar signals at two hazardous interstate highway locations in Kentucky (40) found that mean speeds (by lane) decreased 1 to 2 mph at one site, but decreased less than 0.5 mph at the second site. The use of radar at these sites also reduced the number of vehicles exceeding 65 mph and 80 mph, as well as the speed variance.

Effectiveness

Appendix B documents the study of radar signals (emitted by intrusion detection devices) at work zones in Texas as part of this research effort. The studies were conducted primarily on suburban and rural interstate and multilane state highways. Two basic types of work zones were considered; those involving a lane closure, and those where no closure was present. Work zone speed limits posted at the sites ranged from none (normal roadway speed limits) to a work zone limit 15 mph below the normal speed limit. Table 2-7 summarizes the characteristics of each study site.

TABLE 2-7. SUMMARY OF STUDY SITE CHARACTERISTICS

Site	Location	Road Type	No. of lanes	Work Type	Normal Speed Limit	Work Zone Speed Limit	1987 ADT	Approximate Hourly Volume Observed/Lane
1	SH6 Bypass SB, College Station	Suburban Divided Highway	2	Detour w/ Lane Closure	55	40 (R)	14,300	200
2	SH6 NB south of College Station	Rural Divided Highway	2	Detour w/ Lane Closure	55	40 (R)	12,600	200
3	IH-10 EB east of San Antonio	Suburban Interstate	2	Temporary Lane Closure	55	none posted	22,000	300
4	IH-10 WB east of San Antonio	Suburban Interstate	2	Temporary Lane Closure	55	none posted	22,000	250
5	IH-35 SB north of Austin	Suburban Interstate	2	Work Adjacent to Roadway	65	55 (R)	51,000	650
6	IH-35 NB north of Austin	Suburban Interstate	2	Work Adjacent to Roadway	65	55 (R)	67,000	800
7	IH-45 SB north of Houston	Suburban Interstate	3	Work Adjacent to Roadway	55	none posted	163,000	1400
8	IH-45 NB north of Houston	Suburban Interstate	3	Work Adjacent to Roadway	55	none posted	163,000	1250

SB = Southbound EB = Eastbound
NB = Northbound WB = Westbound

(R) = Regulatory Speed Limits

Overall, results from this study indicate that radar reduced mean speeds within the work zone approximately 0 to 2 mph, depending on the site (Figure 2-1). To gain additional understanding of the effects of radar, the changes in speeds between an upstream control station and the data collection station within the work zone were also examined. Based on this analysis, the effect of radar was found to be slightly greater for trucks than for cars, as seen graphically in Figure 2-2. Also, the effect of radar was greater for vehicles approaching the work zone in excess of 65 mph than for the study sample as a whole. This is illustrated in Figure 2-3. All of these findings correlate well with the results of the previous studies of radar described previously.

Figure 2-4 presents a comparison of the standard deviation of speeds with and without radar present. Although the previous studies found speed variability to decrease in the presence of radar, the data collected at the work zone study sites do not show such a trend. In fact, speed variability actually increased at some of the sites. Such an effect is undesirable, given the correlation between the variability in speeds and accident frequency suggested by some studies (21).

The presence of radar also appears to have a significant effect upon vehicle conflicts at the study sites. Severe braking actions and last-second lane-changing increased at essentially every site when the radar was operating. Figure 2-5 illustrates the total vehicle conflict rate at each site with and without the radar transmitting. The increases were proportionally the greatest at sites 1 and 2, although sites 4 and 6 also experienced increases.

Although it is not possible to determine conclusively why the change in vehicle conflicts varied so dramatically from site to site, some insight into one possible factor can be seen when the change in the conflict rate is plotted against the difference between the mean speed and the posted speed limit at each site. This relationship is shown in Figure 2-6. Clearly, one sees a trend towards larger increases in vehicle conflicts at sites where mean speeds are considerably higher than the posted speed limit. Such a relationship seems intuitively correct, as drivers at those sites would have to decelerate more severely in order to comply with the speed limit (and thereby avoid a possible ticket). While the actual relationship between accidents and vehicle conflicts at work zones is not known, this data suggests a potential safety problem with the use of radar at sites where the posted speed limit is considerably lower than the normal speed of traffic.

Limitations

The radar transmissions used in this research were emitted from a prototype self-contained intrusion detector developed for a previous TTI study (39). As such, these devices are not commercially available. Since only a couple of studies of these types of devices have been performed to date, additional research and demonstration of their use

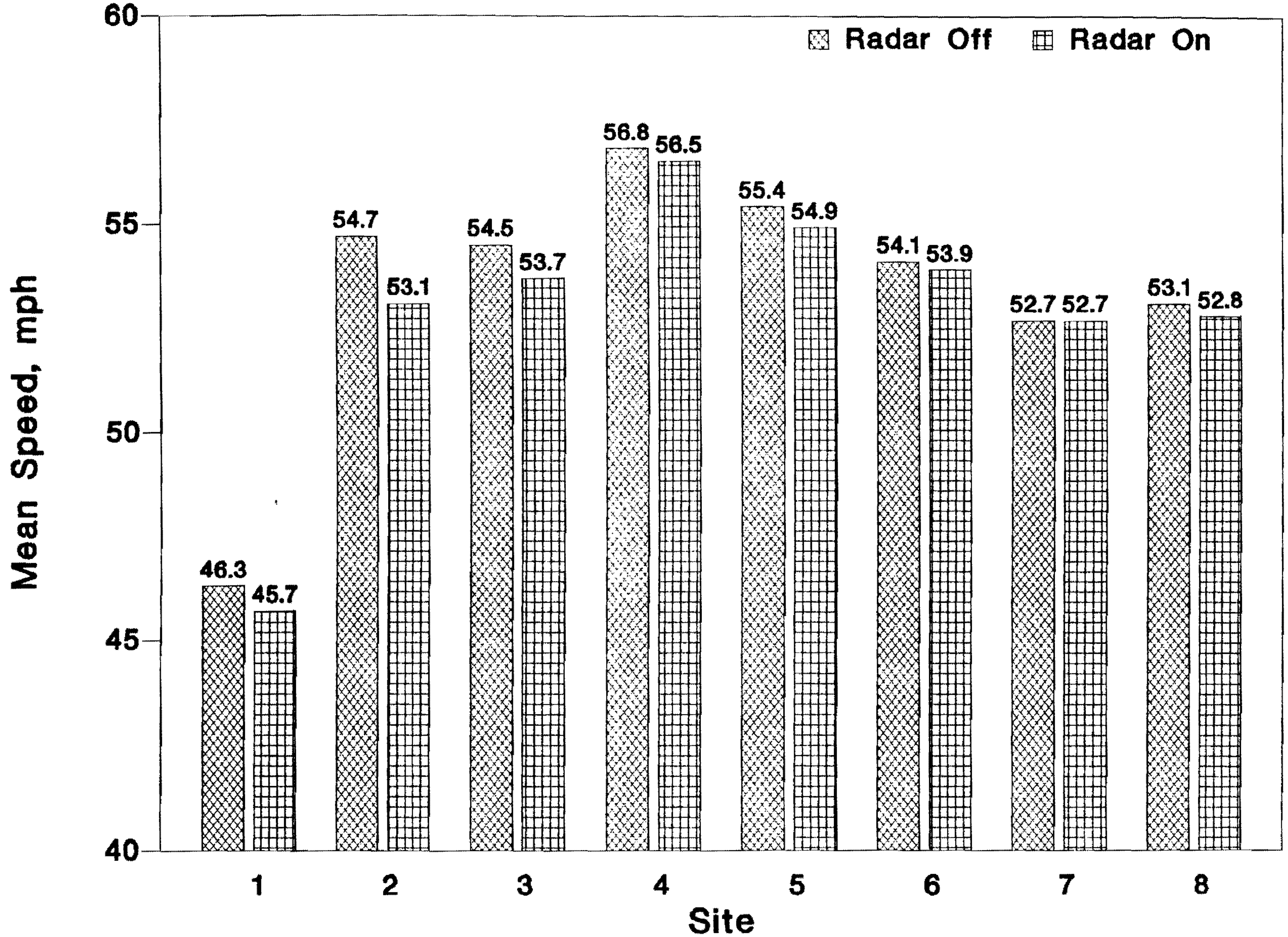


Figure 2-1. Effect of Radar Transmissions on Mean Speeds within Work Zones

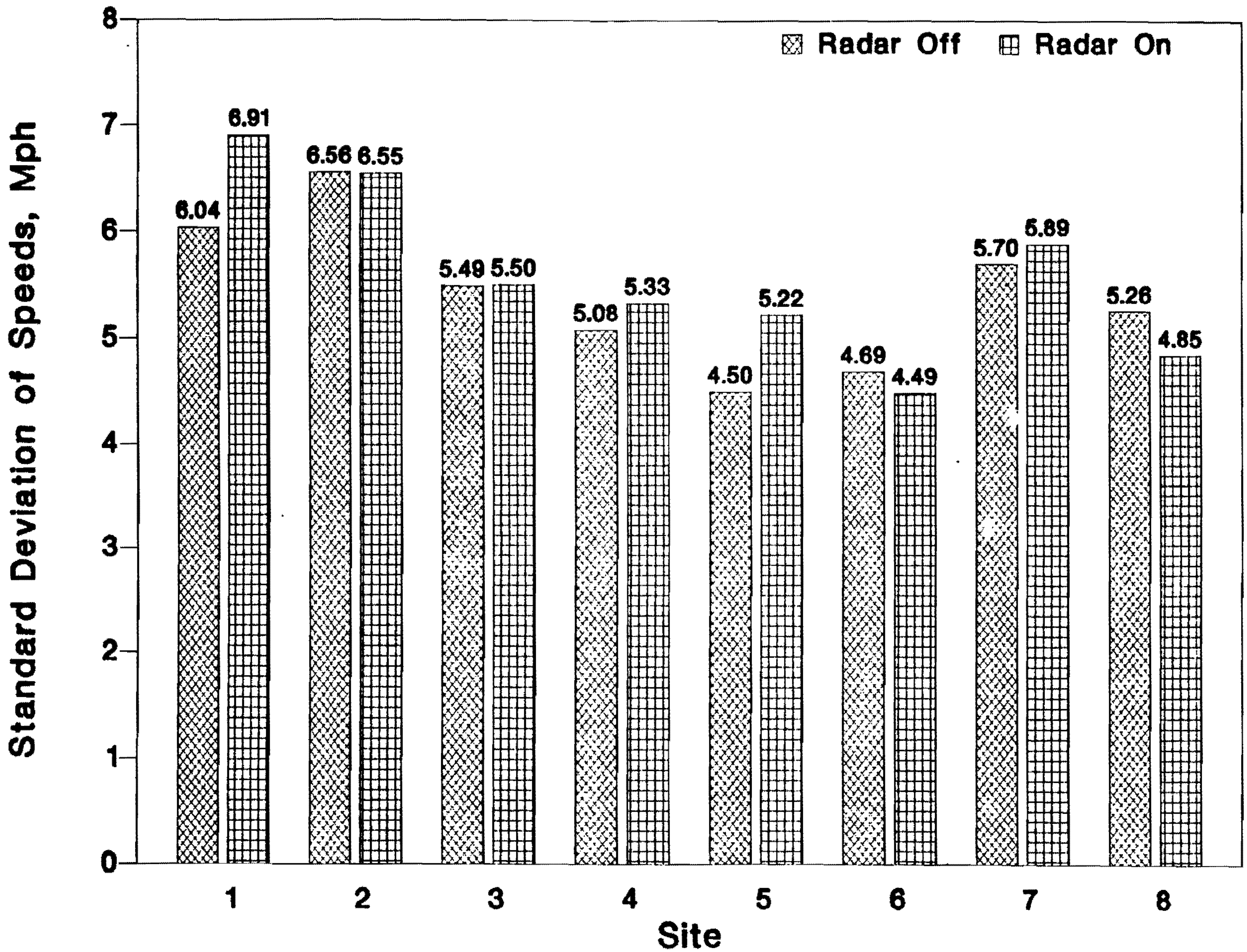


Figure 2-2. Effect of Radar Transmissions on Standard Deviations of Speeds within Work Zones

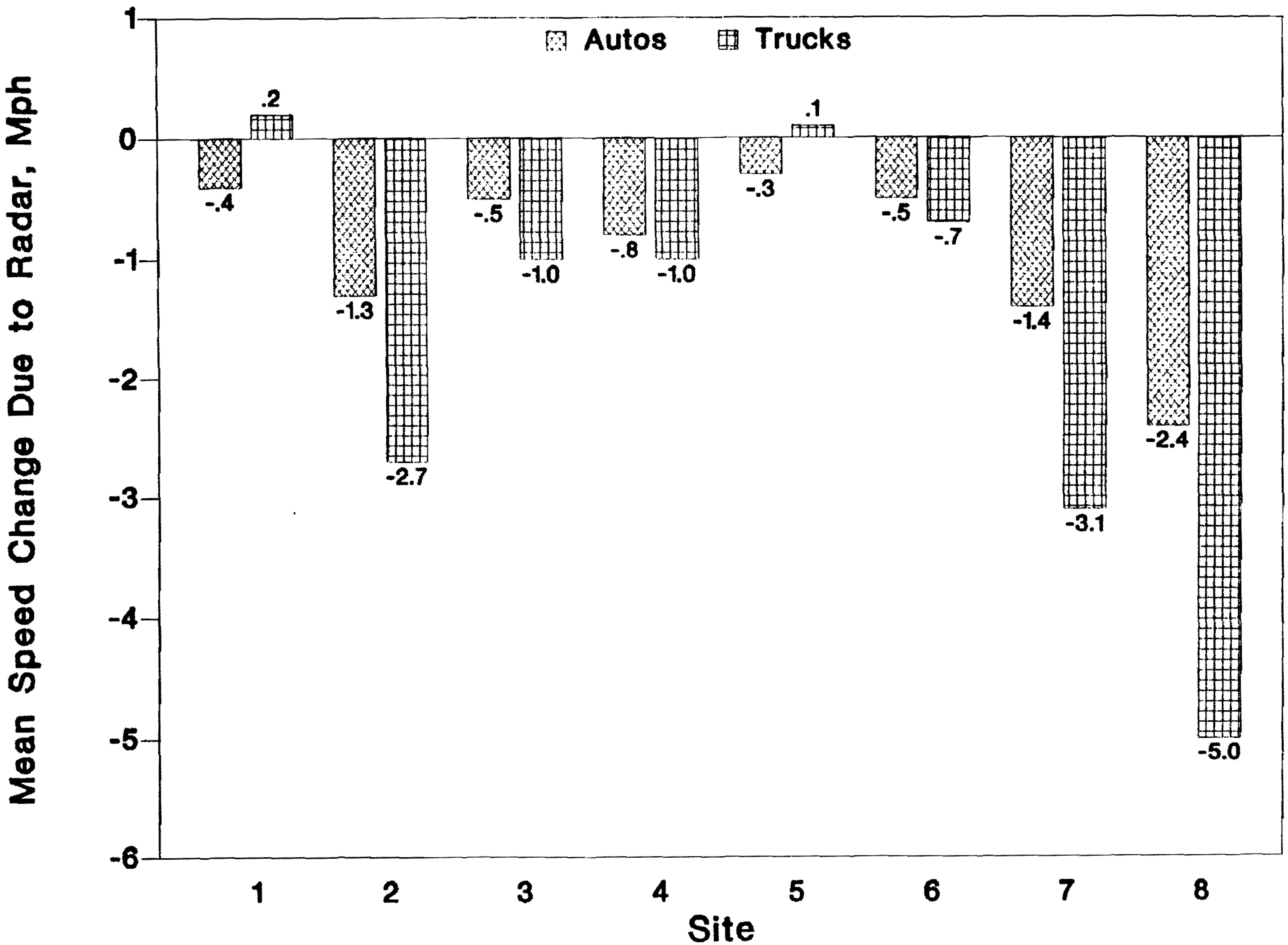


Figure 2-3. Effect of Radar Transmissions by Vehicle Type

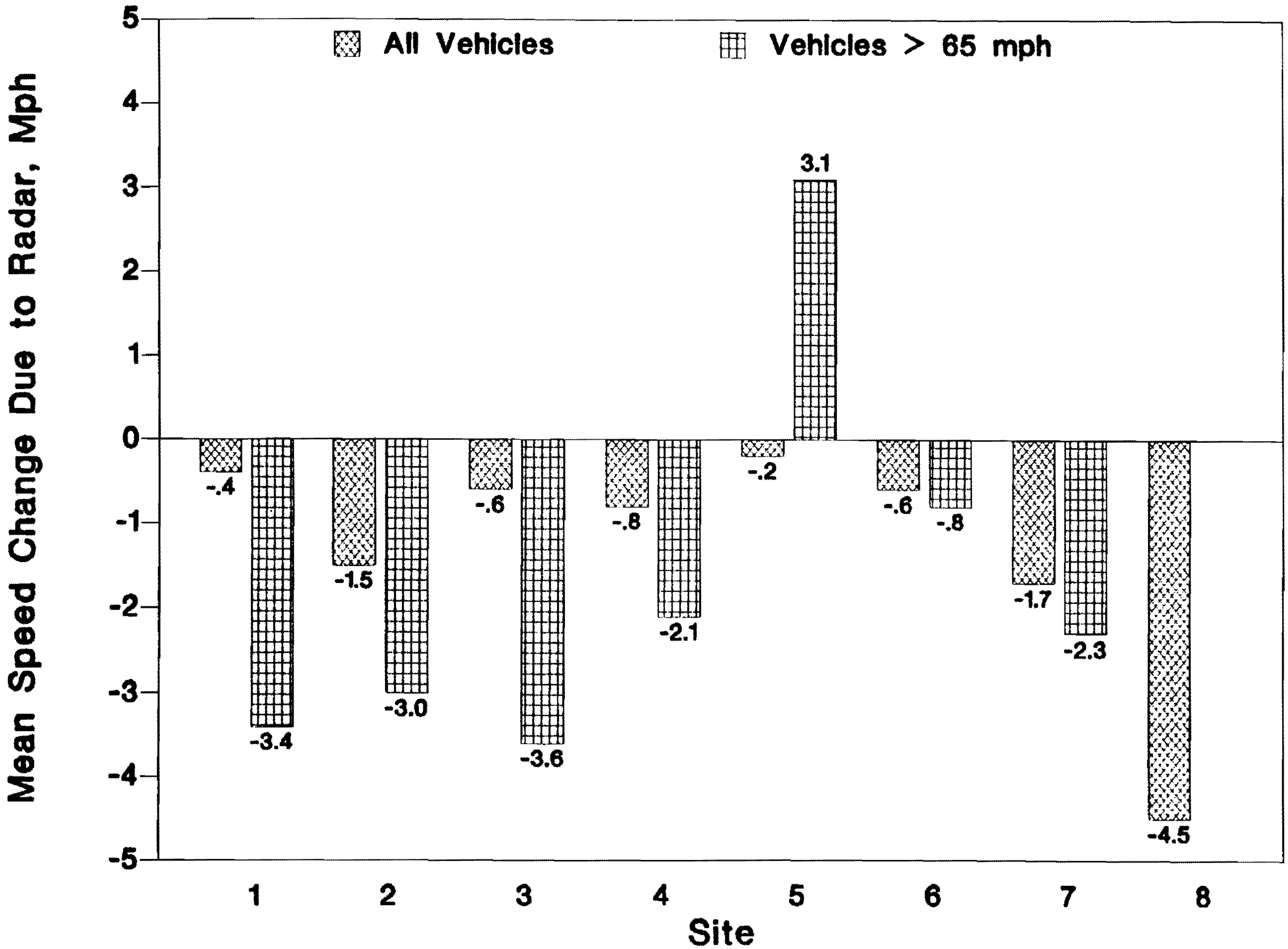


Figure 2-4. Effect of Radar Transmissions upon High-Speed Drivers

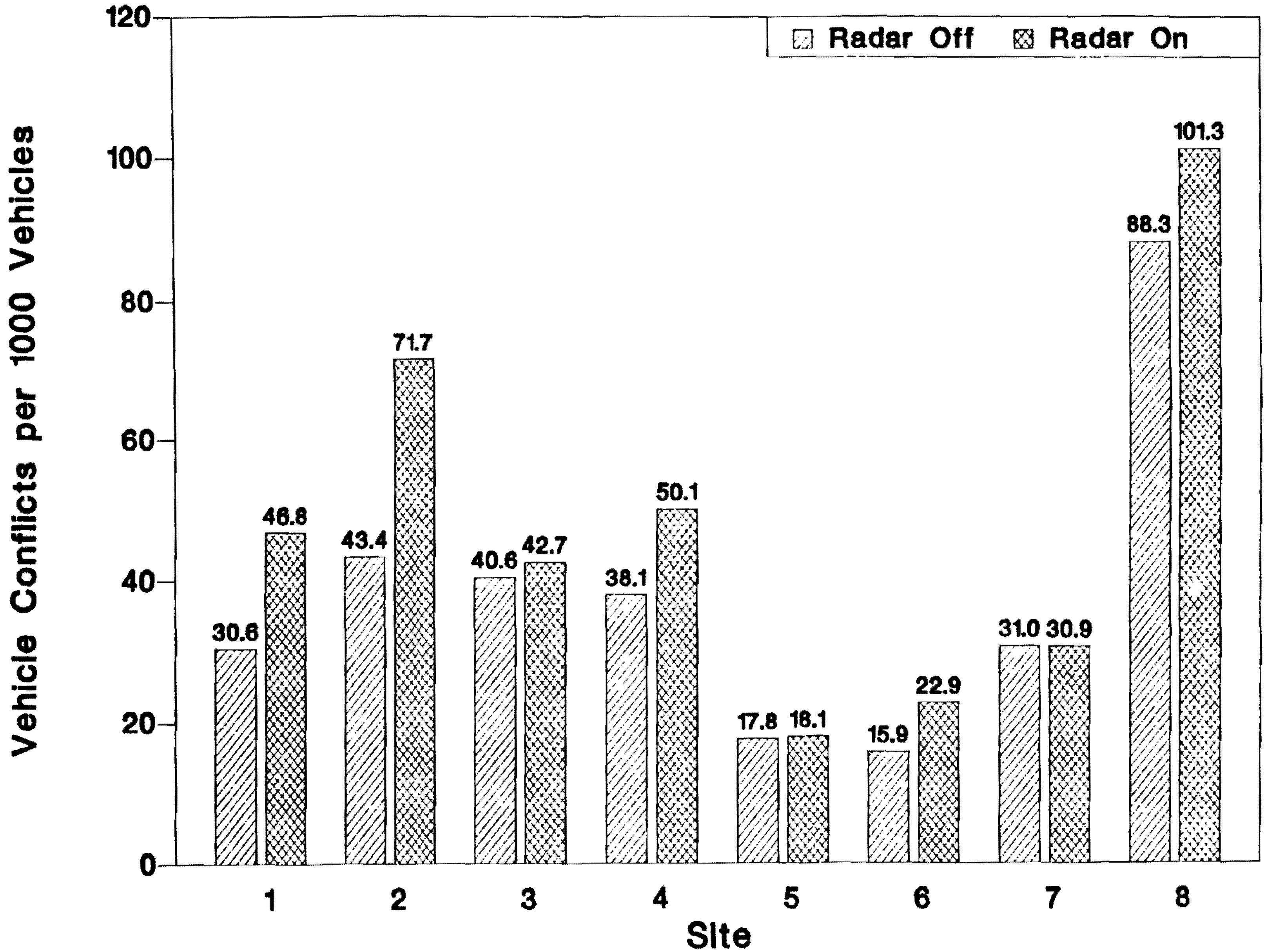


Figure 2-5. Effect of Radar Transmissions Upon Vehicle Conflict Rates at Work Zones

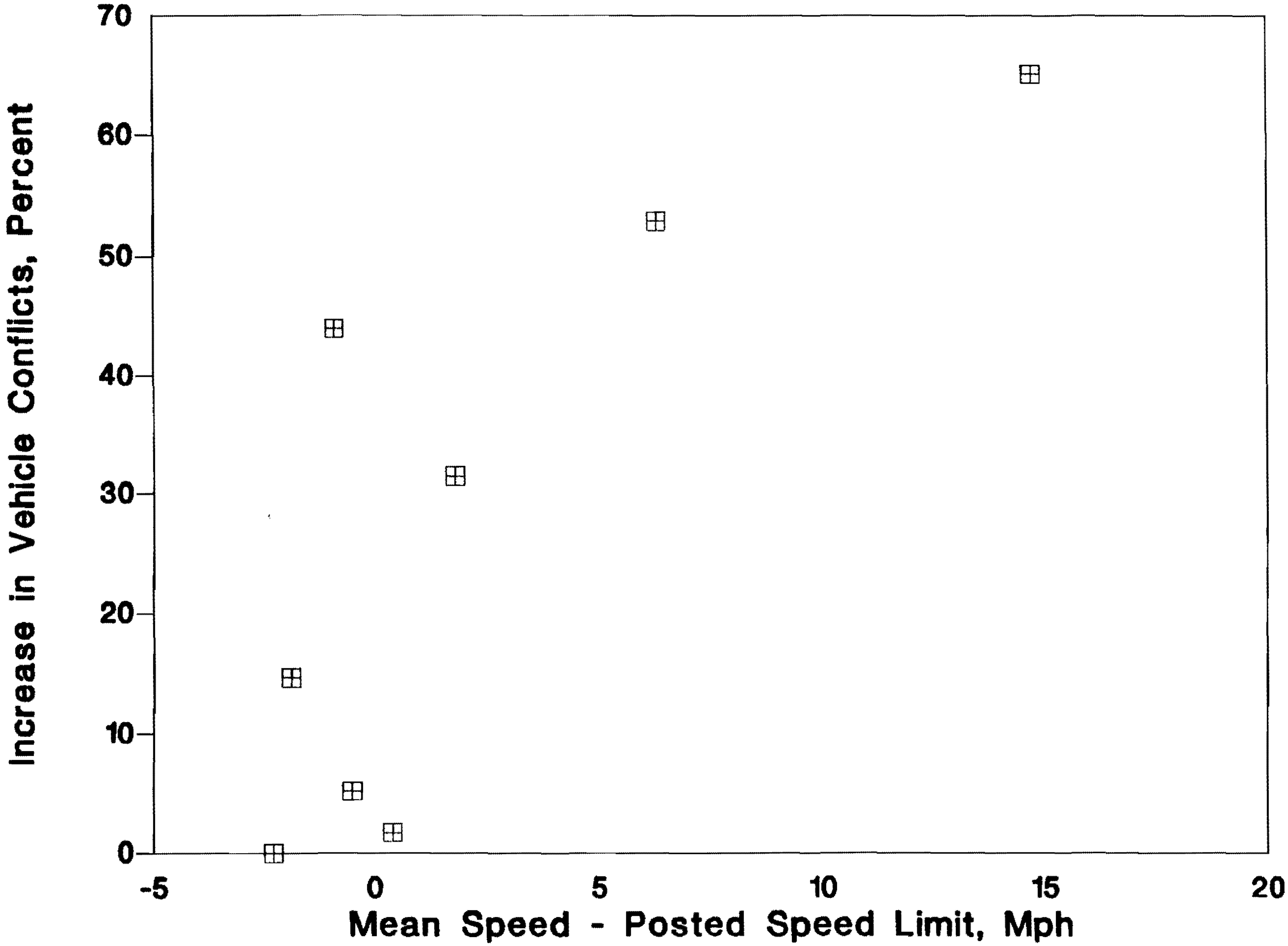


Figure 2-6. Change in Vehicle Conflict Rates versus Difference Between Mean Speed and Posted Speed Limit

at work zones will be necessary before a conclusion as to their applicability and effectiveness at work zones can be made.

Utilization of a Traffic Queue

Application and Usage

A final method of controlling speeds at work zones to be discussed in this report is the managed use of traffic congestion resulting from work zone capacity reductions. Traffic flow theory (41) as well as empirical evidence show that traffic speeds on a section of roadway are related to the volume-to-capacity (v/c) ratio on that section. Specifically, speeds decrease as the v/c ratio increases. However, this relationship is not linear. In fact, recent evidence indicates that speeds are relatively unaffected by volume until the v/c ratio begins to approach capacity (42,43). A work zone that reduces the available capacity of the roadway (via lane closures, narrow lanes, etc.) would be expected to result in lower speeds through the work zone if volumes approach or exceed the reduced capacity of the work zone.

Work zone lane closures on high-volume urban freeways typically experience reduced traffic speeds within the work zone because demand volumes exceed the work zone capacity. Excess demand queues upstream of the work zone, with traffic in the queue operating at stop-and-go (congested) conditions. This congestion upstream of the work zone can be thought of as a means of speed control. As such, it is quite effective, as essentially every approaching vehicle comes to a stop, and proceeds to crawl through the queue until reaching the beginning of the work zone. However, consideration must be given to the fact that this approach can create large speed differentials between vehicles (approaching vehicles versus queued vehicles) at the beginning of the queue. Also, the queues themselves can become exceedingly long (possibly extending beyond the advance warning signing) if the work zone capacity is substantially below traffic demands.

This technique can be quite useful in situations where the shoulder is used as a temporary lane around the work zone. By dynamically managing the information provided to drivers about the use of the shoulder for travel (through changeable message signs or other means), the queue can be kept to desired lengths. In more congested situations, additional information suggesting diversion to other routes may also be necessary. In all cases, it is imperative that experienced work zone personnel be able to communicate with each other in order to properly monitor and manage the queue, route diversion, speed differentials upstream of the work zone, and speeds through the work zone. The traffic control devices used must be properly maintained to keep them working and legible throughout the duration of the work zone.

Effectiveness

Thirty miles per hour is typically used as the average speed of traffic through a bottleneck section when demands equal capacity (41). Data collected as part of past work zone research (44) suggests that the speed/volume-to-capacity ratio relationship for a given roadway section is not altered when a work zone was introduced at that location. Others have questioned this hypothesis, however, based on data they have collected (18). Nevertheless, it is widely accepted that speeds at a work zone will be dramatically lower if traffic conditions are congested as compared to uncongested conditions.

Limitations

Obviously, the use of a traffic queue as a speed control method will not be widely applicable to all work zone situations and roadway conditions. Instead, it is a result of necessary roadway capacity restrictions within a work zone. In some cases, the project supervisor in charge may have leeway to select among different levels of capacity restrictions (lane closures). In these situations, the ability to effectively control work zone speeds by creating traffic congestion is a factor which should be considered.

3. SUMMARY

This report documents the results of the first year's research efforts on HPR study 1161 to quantify the use and effectiveness of various work zone speed control methods. Data collected during a survey of selected SDHPT personnel, a literature review, and field studies of radar transmissions at work zones have been synthesized into the catalog of methods presented in chapter 2.

The results of the synthesis indicate that law enforcement and flagging are generally the most effective speed control methods used in Texas. With respect to law enforcement techniques, the survey found that circulating patrols were the most common type of enforcement used, even though research has shown them to have less of an effect upon mean speeds at work zones than either stationary patrols or a police traffic controller. Flaggers are also commonly used to reduce speeds at work zones, undoubtedly due in large part to the fact that they are readily available and can adapt to a wide variety of situations.

Studies on the effectiveness of flaggers and enforcement at work zones have indicated that effectiveness increases as the number of lanes available for traffic is reduced. When fewer lanes are open, drivers have less maneuverability and opportunity to pass individual vehicles who are traveling at reduced speeds in response to flagging or enforcement. As a result, more vehicles may actually be affected. Also, it is possible that a significant factor influencing treatment effectiveness is the difference between the average speed of traffic and the posted speed limit.

Reduced regulatory and advisory work zone speed limits are also commonly used. Reduced regulatory speed limits are usually requested for long-term construction projects, while lower advisory speed limits are commonly used during short-term maintenance work zones. In some instances, a reduced regulatory speed limit may be posted at a construction site 24 hours a day, and an even lower advisory speed limit posted when workers are actually doing work. However, even though work zone speed limits are used extensively, research has repeatedly shown that they do not affect work zone speeds to any significant degree. Common opinion indicates that reduced speed limits are important to convey a sense of urgency about possibly dangerous conditions present at the work zone. Since traffic speeds will likely not be reduced because of lower work zone speed limits, it is important to remember that the speed used when selecting traffic control devices, taper lengths, and making sight distance calculations must be based on prevailing traffic speeds and not on the posted speed limit.

Several other techniques (CMSs, transverse striping, rumble strips, reduced lane widths, and unmanned radar transmissions) have been tested to determine the possible speed-reducing effects they may have at work zones. Interest in these techniques exists because they do not require a constant supply of manpower, unlike enforcement or flagging techniques. However, studies indicate that, in general, these techniques have a smaller effect upon speeds than either enforcement or flagging. In addition, some methods (such as transverse striping) would be expected to decrease in effectiveness over time as repeat drivers become accustomed to their presence.

It should be noted that research to date on the various speed control methods has focused on the effectiveness of the techniques at reducing traffic speeds (typically measured by the mean speed or 85th percentile speed) at a work zone. However, it may be that the overall effects of the methods are not always the most important considerations. In many work zone situations there is little need to reduce the overall traffic speeds, as proper traffic control principles and worker safety practices result in a very safe work zone. Undoubtedly, though, there will be the occasional driver operating his vehicle at unsafe speeds or in an otherwise unsafe manner who may be positively influenced by the presence of some speed control method. This kind of effect, while difficult to detect in the overall speed distribution, would nevertheless improve the safety of that work zone. It appears that continued study of some or all of the available methods is warranted to determine their effect on other measures of traffic operations and safety. As an example, the study of unmanned radar transmitters found them to have only a small effect on mean speeds. However, when the data were stratified and categorized, a larger speed-reducing effect was detected among the small proportion of vehicles exceeding 65 mph, those high-speed drivers who are often a safety concern to highway officials, work zone personnel, and even the general driving public.

Along these same lines, little research has been performed to identify and quantify what adverse effects some or all of these speed control techniques may have upon work zone safety. Again as an example, the study of unmanned radar, although indicating a potential safety benefit by substantially reducing the speed of high-speed drivers, also caused an increase in the overall vehicle conflict rates at some sites. Additional research should be performed with the other speed control techniques, especially flagging and enforcement strategies, to determine what effects these methods have upon traffic safety measures other than speed. With this information, highway officials would then have a more realistic perspective of the benefits and problems associated with the use of the available work zone speed control methods.

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APPENDIX A: SURVEY OF SDHPT PERSONNEL

INTRODUCTION

In fulfillment of Task 1.2 of Study 1161, a telephone survey was conducted. Selected SDHPT personnel in seven Districts (Paris (1), Ft. Worth (2), Amarillo (4), Abilene (8), Houston (12), Austin (14), and Corpus Christi (16)) were interviewed. The Districts were selected to reflect a range of traffic conditions, road types, topography, and District size and administration. Personnel contacted at the Districts included Construction, Maintenance, Traffic, and Resident engineers. The purpose of the interviews was to gather the opinions and perceptions of SDHPT personnel regarding work zone speed control methods, and to determine how these personnel select where, when, and what type of speed control methods to use at work zones. The telephone conversations followed an open-ended survey format to allow those being interviewed to freely express their opinions and perceptions. A total of 13 people were interviewed.

AREAS OF INTEREST

The survey concentrated on four major topic areas as described below:

1. What types of work zones do you believe require speed control and why? This question was asked in order to try and determine the work zone characteristics that field personnel believe make speed control necessary. No attempt was made to limit responses to active (i.e., flagging, enforcement) or passive (i.e., speed zoning, perceptual treatments) speed control methods. Instead, the interviewer attempted to determine what method would be used for the various work zone types (if different methods were used) and what reasons there might be for using one method instead of another.

2. What speed control methods have you used at your work zones, and how effective have they been? This question had two purposes. The first of these was to establish the frequency that the different methods were being used across the state. The second purpose was to determine how field personnel perceived the effectiveness of these methods. It was assumed that those methods not perceived to be effective would not be implemented by field personnel unless forced to do so. The interviewer listed the available techniques during the interview to prompt the respondent.

3. What guidelines or rules-of-thumb do you follow to select and implement speed control methods at your work zones? This question was somewhat related to question #1. The purpose was to help identify what work zone and site-specific characteristics were considered when deciding on work zone speed control.

4. What problems exist with current work zone speed control methods and what measures could be taken to reduce or eliminate these problems? The last question asked of the interviewees was to describe what problems they believed to exist with current work zone speed control methods, and to discuss what (if anything) could be done to improve the effectiveness of speed control or to eliminate or reduce the problems they had identified. This question provided an open forum to the respondents, and provided information concerning field personnel perceptions and complaints of work zone speed control and/or general work zone traffic control.

SURVEY RESULTS

Work zones that need speed control

Three of the respondents indicated that they felt all work zones needed some type of speed control. They believed it was important to reduce speeds so that drivers would have additional time to react to any unusual circumstances they might encounter. Another reason given for speed control in all work zones was that it was another means of getting the driver's attention at a work zone.

Several specific roadway and work zone characteristics were mentioned by the remaining respondents as conditions requiring work zone speed control. These were:

1. Work zones where traffic was traveling on base or loose material (higher speeds kick up rocks into trailing vehicles and into the work area where it hits the workers).

2. Work zones where the work activity is going on immediately next to the travel lane(s).

3. Work zones on rural interstates, where normal traffic speeds are the highest.

4. Work zones where traffic must be detoured into another lane or onto a different path. This would include lane closures, crossovers, and detours onto temporary pavements.

5. Work zones where pavement drop-offs exist. It was felt that the driver needed additional reaction time, and the potential severity of an accident was felt to be reason to pursue lower speeds.

6. Roadways where sight distance restrictions exist, either due to topography (hills, curves) or the general location (within the forest where trees and curves limit visibility).

7. Long duration work zones. It was felt that short-term work zones did not require speed control since they were in place only for a short time.

8. Work zones that require narrow (less than 9 ft) lanes. It was specified that speed zoning was necessary in this situation to warn of the tight conditions present.

Speed Control Methods Used

Those interviewed identified several speed control methods being used in the Districts surveyed. The most common method was reduced speed zoning, either regulatory or advisory. All of the Districts surveyed indicated that they used regulatory speed zoning on occasion. In general, regulatory zoning was used in the long-term construction zones, and was approved through a Highway Commission Minute Order. One District indicated that it also used regulatory zoning on some short-term maintenance operations (it is not known whether Commission Minute Orders are obtained for these operations).

Advisory speed zones were also used quite commonly. Respondents in five of the seven Districts surveyed mentioned that they used advisory speed zoning, primarily for short-term maintenance operations. In some instances, regulatory and advisory speed zoning was used together. The regulatory speed zone would be established by a Commission Minute Order for a long-term project at 40 to 45 mph. Then, during special work conditions such as temporary lane closures, advisory speed zones of 25 to 35 mph would be posted in the immediate work area.

Another speed control method that was quite common was increased law enforcement patrolling and ticketing in the vicinity of the work zone (mentioned by 4 of the 7 Districts). A few of the respondents stated that they contacted the enforcement agency and actually asked for the increased patrolling, while others indicated that the enforcement personnel increased their efforts without being asked (possibly due to the posting of a regulatory speed zone, although this was never mentioned specifically). Respondents from the two urban Districts surveyed (Ft. Worth and Houston) stated that they had used officers out of their vehicles next to the work zone for traffic control purposes.

Flagging was a common method of speed control, mentioned by five of the seven Districts surveyed. In general, the decision of whether or not to use flaggers for speed control was based on the field supervisor perceptions of work zone conditions and prevailing traffic speeds.

Other methods mentioned by those interviewed included lane width reductions (by one respondent who felt that this technique was more effective than flaggers), placing red flags on speed limit and advance warning signs (two respondents in two Districts), the general traffic control set-up of cones with an arrow panel (one respondent), and a pilot vehicle through alternating one-lane sections (one respondent).

Guidelines for Selecting Work Zone Speed Control

When asked for specific guidelines or rules-of-thumb used when selecting work zone speed control, the majority of the respondents provided regarding speed zoning guidelines used in their jurisdiction.

Regulatory Speed Zones:

In general, regulatory speed zones were established at 40, 45, or 50 mph at long-term construction projects. Guidelines for using these speed zones varied as followed:

1. Zones set 10 to 15 mph below normal speed limits,
2. Zones set 10 to 15 mph below work zone design speed,
3. Zones set to 40 mph if project on roadway with ADTs > 750 vpd,
4. Zones set 40 to 45 mph in construction zones regardless.

In general, these guidelines are not mutually exclusive. For example, a work zone with a design speed of 50 or 55 mph might be used at a project on a road with ADTs exceeding 750 vpd, and a speed limit of 40 or 45 mph be posted. In this case, the zone would satisfy all 4 criteria identified. However, the survey does show how reasons for using reduced speed zoning vary from District to District.

Advisory Speed Zones:

Since advisory speed zones do not require a Commission Minute Order, the respondents had more control over their use and provided more specific implementation criteria for them. These criteria included:

1. Using 35 mph zones in active work areas
2. Using 25 to 30 mph for work zones requiring detours (the actual speed value would be determined at the pre-construction conference immediately prior to the start of the project)
3. Using 35 mph for most situations, but 25 mph for alternating one-lane sections, and 45 mph when work is confined to the shoulder of a roadway

In addition to these specific guidelines some of the respondents indicated that they based the speed zone on "an engineering analysis of conditions (traffic, roadway, work zone)." Another respondent stated that the project inspector looks for "trouble spots" and will adjust the speed zone if he feels it necessary. One resident engineer stated that the basic criteria above was followed, but if there was a lot of traffic on the road, the engineer may decide to reduce the speeds further to increase safety.

With respect to flaggers, no specific criteria were provided. It was generally felt that the person in charge would determine if speeds were too high for conditions, and in this case might use a flagger. A similar criteria was specified for those Districts who sometimes use law enforcement for traffic control.

Current Problems with Speed Control

The respondents had several general comments concerning speed control and work zone traffic in general. There was consensus that speed limit signs were not very effective in reducing speeds, but were felt to be necessary nonetheless to bring the work zone to the attention of the driver. One respondent did indicate that projects where unrealistically low limits are posted or where zones are posted for an entire project length when only one section is under construction reduces the credibility of the limits. Another fairly common perception was that drivers do not have respect for the workers out next to traffic, and that someone must try and educate the public to be courteous to workers and slow down. One respondent went so far as to state that drivers do not understand any of the signing used in construction and maintenance zones, and do not know what the proper response to the signs should be. A final comment made by one respondent was that their biggest problem was with trucks who ignore speed zoning in construction areas.

SUMMARY

The results of the telephone survey of seven SDHPT Districts indicate that the primary form of speed control used in work zones is speed zoning. In general, regulatory speed limits are established for long-term construction projects, since there exists time to obtain a Highway Commission Minute Order to establish the zones. For short-term projects, the Districts must rely on advisory speed zoning.

With respect to the specific speed zones used in construction and maintenance work zones, regulatory speed zones are typically established at 40 to 50 mph. However, considerable variation exists as to the reasons these limits are used. Advisory speed limits for short-term projects also vary, from as low as 25 mph up to 45 mph on some projects. In some cases, no advisory speed limits are used for short-term projects.

In certain Districts, law enforcement (patrolling) is increased through of work zones. Some Districts request increased patrolling, while other Districts rely on the enforcement agencies to decide when and if to increase patrolling. Only the Ft. Worth and Houston

Districts reportedly use police officers outside of their vehicles for traffic control during work zones.

Flaggers are also used to actively control speeds in certain work zones in most Districts. The decision of whether to use flaggers for speed control generally rests with the engineer in charge of the project, who provides flaggers when he believes speeds need to be reduced.

The primary speed control problem perceived by Department personnel is that drivers travel too fast for conditions and do not heed work zone warning and speed control signs. Consequently, the personnel interviewed believe it is necessary to reduce the speed limit in order to indicate that the work zone is more hazardous and that extra caution is necessary. However, it is generally conceded that the reduced speed limits will have little effect on traffic speeds.

APPENDIX B: STUDY OF RADAR TRANSMISSIONS AT WORK ZONES

INTRODUCTION

Despite impressive improvements in work zone traffic control procedures during the past two decades, work zone safety continues to be a topic of major concern to highway agencies. One of the more difficult issues that has not yet been fully resolved is that of speed control within work zones. While it is generally recommended that work zones be designed so as not to require drivers to reduce their speeds, the unusual and dynamic characteristics of work zones sometimes necessitate slower travel. When the need for reduced speeds is readily perceived by drivers, they can usually be counted upon to adjust their speeds appropriately, and reduced regulatory or advisory speed limits are usually sufficient. However, if the need for slower speeds is not readily apparent, drivers cannot be expected to reduce their speeds without some active form of speed control.

Research throughout the decade has focused on various techniques available to highway agencies for controlling speeds in work zones (6,14,15,16,22,23). Overall, it is apparent that the presence of law enforcement is one of the most effective work zone speed control methods available. Reductions in mean speeds of up to 13 mph have been found in some instances (6). This result is not surprising; other research has shown enforcement to be effective in reducing speeds when used for special situations such as school zones as well as on normal highway sections (21).

Unfortunately, law enforcement in most jurisdictions is a costly speed control measure. Perhaps more importantly, enforcement resources are limited, and must be distributed among a number of activities (in addition to traffic control) to preserve public safety. As a result, highway agencies continue to search for methods of work zone speed control that are less costly and easier to implement than law enforcement.

Recently, attention has turned to the possible use of radar transmissions to reduce speeds. Past research indicates that radar has an additional speed-reducing effect when used in conjunction with law enforcement. More recently, a limited amount of research has been performed evaluating the effect of radar without law enforcement personnel present (39,40). These studies, conducted on normal sections of highway, suggest that mean speeds can be reduced slightly when radar signals are emitted. These studies also found radar to affect high-speed vehicles more significantly. Radar transmissions have the potential for reducing speeds at work zones as well. However, the overall effect that radar signals have upon safety at work zones must first be determined. Radar, unlike other forms of work zone speed control, does not present a speed-reducing stimulus to each driver approaching a work zone. Rather, only those vehicles using a radar detector will receive any type of signal. There exists the possibility of conflicts developing between vehicles with detectors (who may decelerate suddenly when a radar signal is received) and vehicles without detectors. This report documents the result of a study conducted to evaluate these and other possible effects of radar transmissions at work zones.

STUDY DESCRIPTION

Objectives

The objectives of this study were twofold:

1. Determine the effect of unmanned radar upon vehicle speeds approaching and passing through work zones.

2. Determine what effects unmanned radar may have upon vehicle maneuvers and interactions between vehicles as they approach the work zone.

These objectives were accomplished through an extensive data collection effort at a total of eight work zone locations in Texas.

Study Approach

Prototype radar transmitters, constructed for use in a previous study of unmanned radar by TTI (39), were employed during this study. Figure B-1 shows the transmitter, a small, self-contained box which was mounted to a sign, barrel, or railing at the beginning of the work zone. The unit was turned on and off by means of a small switch located on the top of the box. When operating, the unit emitted a standard traffic radar signal approximately 1500 to 2000 ft upstream, depending on geometric and environmental conditions. A receiver in the unit was connected to an output signal jack, which could be used to operate a light or other intrusion detection system (although this detection capability was not used in this study).

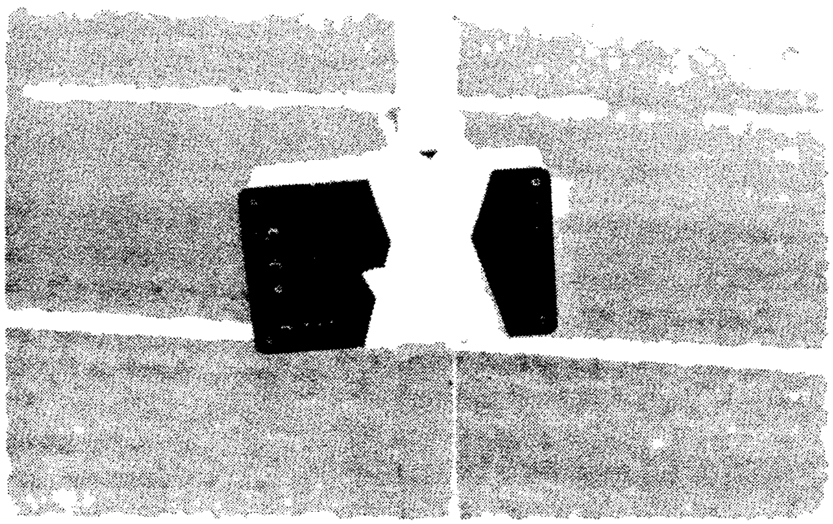

Figure B-1. Radar transmitter used in study

A radar on/ radar off analysis was used at each study site. Data were collected for a 30 to 45 minute period without transmitting the radar signal. The radar was then turned on, and data were collected for another 30 to 45 minutes. This cycle was repeated throughout the day. The use of multiple time periods counterbalanced any effects differences in traffic volumes at a given site may have had upon speeds. Data collected while the radar was turned on were then compared to data collected with the radar off to determine what effect the presence of a radar signal had upon traffic.

Study Site Selection

Vehicle speeds in work zones are affected by a multitude of factors. These factors include the typical geometric, traffic, and environmental elements that affect speeds on normal roadway sections (21), as well as the unique and dynamic features of a work zone itself (18). It is likely that the effectiveness of speed control methods is influenced by these or other factors as well. Principal factors considered in the study design and site selection included the following:

1. Roadway type (interstate, multilane highway),

2. Traffic volumes (low, moderate, high),

3. Work zone lane closure present (yes, no), and

4. Work zone speed limit (none, 10 mph below normal, more than 10 mph below).

The studies were limited to interstate or multilane highways in order to insure that a suitable vehicle sample size could be obtained. Also, it was felt that radar detector usage would be highest on these types of roadways. Since the response to a radar signal at a location would likely be directly related to the percentage of vehicles with radar detectors, focusing the study on these types of roadways would provide an indication of the maximum effects to be expected from radar. Testing over a range of traffic volumes was desired in order to see if undesirable vehicle conflicts increased at higher volume levels due to the radar signal. It was desirable to examine the influence of work lane closures upon the effectiveness of radar transmitters. A lane closure reduces the capacity of the roadway dramatically, while a work zone without a lane closure may have little or no effect on capacity. Finally, since the premise of a radar signal is the simulation of the presence of enforcement, one would expect the effect of radar to depend on the normal and work zone speed limits posted, and whether actual speeds are dramatically higher than the posted limit.

Unfortunately, it was not physically or financially possible to evaluate the radar transmitter at enough sites to fill a complete factorial design. Likewise, the limited number and location of potential study sites precluded the use of an incomplete factorial design. Therefore, sites were selected and categorized according to the above factors, and the data collection effort designed to maximize the statistical strength of an individual evaluation.

Table B-1 presents a summary of the characteristics of the study sites. Sites 1 and 2, located on a section of four-lane divided highway with low traffic volumes, involved a long-term work zone lane closure (using barrels) and detour onto adjacent frontage roads. A reduced work zone speed limit of 40 mph was posted at these sites. Sites 3 and 4 were located on a section of suburban four-lane interstate with moderate traffic volumes. The work zones at these sites involved the temporary closing of one traffic lane (using cones); however, no reduced work zone speed limits (below the normal 55 mph speed limit) were posted. Sites 5 through 8 were work zones also located on suburban sections of four- and six-lane interstate highway. No long- or short-term lane closures were present at these sites, however. In addition, sites 5 and 6 were posted with a reduced speed limit of 55 mph (down from the normal 65 mph limit). The speed limits at sites 7 and 8 (55 mph) were not reduced in the study section.

Data Collection and Reduction

Researchers collected two types of data at each study site. Figure B-2 illustrates the basic data collection layout at each study site. Vehicle speeds, measured by traffic radar detuned so as to be undetectable by radar detectors, were collected at three stations upstream and within the work zone. The first station, situated approximately 3000 ft upstream of the work zone and determined to be beyond the influence of the work zone or the radar signal, was used as a control. The second station was located about 750 to 1250 ft upstream of the beginning of the work zone. The radar transmitter, always installed at the beginning of the work zone, had a range of approximately 1500 ft. Therefore, speeds measured at station 2 represented conditions immediately after those vehicles with radar detectors were first able to receive a signal. The quality and capabilities of radar detectors vary from model to model, so there was most likely some variation in the exact location individual drivers first received the signal. The third station was positioned within the work zone immediately beyond the radar transmitter location.

At each station, data collection personnel recorded the speed of vehicles, along with a description of the vehicle onto a cassette recorder. This allowed vehicles to be "tracked" through the study section so that changes in speed from station 1 to stations 2 and 3 could be examined. This approach provided a stronger statistical design for evaluation.

Over 20,000 speed observations were collected at the eight study sites. The breakdown of sample sizes by site, data collection station, and vehicle type are shown in Table B-2. The number of vehicles which could be tracked from station 1 to 2 and

TABLE B-1. SUMMARY OF STUDY SITE CHARACTERISTICS

Site	Location	Road Type	No. of lanes	Work Type	Normal Speed Limit	Work Zone Speed Limit	1987 ADT	Approximate Hourly Volume Observed/Lane
1	SH6 Bypass SB, College Station	Suburban Divided Highway	2	Detour w/ Lane Closure	55	40 (R)	14,300	200
2	SH6 NB south of College Station	Rural Divided Highway	2	Detour w/ Lane Closure	55	40 (R)	12,600	200
3	IH-10 EB east of San Antonio	Suburban Interstate	2	Temporary Lane Closure	55	none posted	22,000	300
4	IH-10 WB east of San Antonio	Suburban Interstate	2	Temporary Lane Closure	55	none posted	22,000	250
5	IH-35 SB north of Austin	Suburban Interstate	2	Work Adjacent to Roadway	65	55 (R)	51,000	650
6	IH-35 NB north of Austin	Suburban Interstate	2	Work Adjacent to Roadway	65	55 (R)	67,000	800
7	IH-45 SB north of Houston	Suburban Interstate	3	Work Adjacent to Roadway	55	none posted	163,000	1400
8	IH-45 NB north of Houston	Suburban Interstate	3	Work Adjacent to Roadway	55	none posted	163,000	1250

SB = Southbound NB = Northbound EB = Eastbound WB = Westbound
(R) = Regulatory Speed Limits

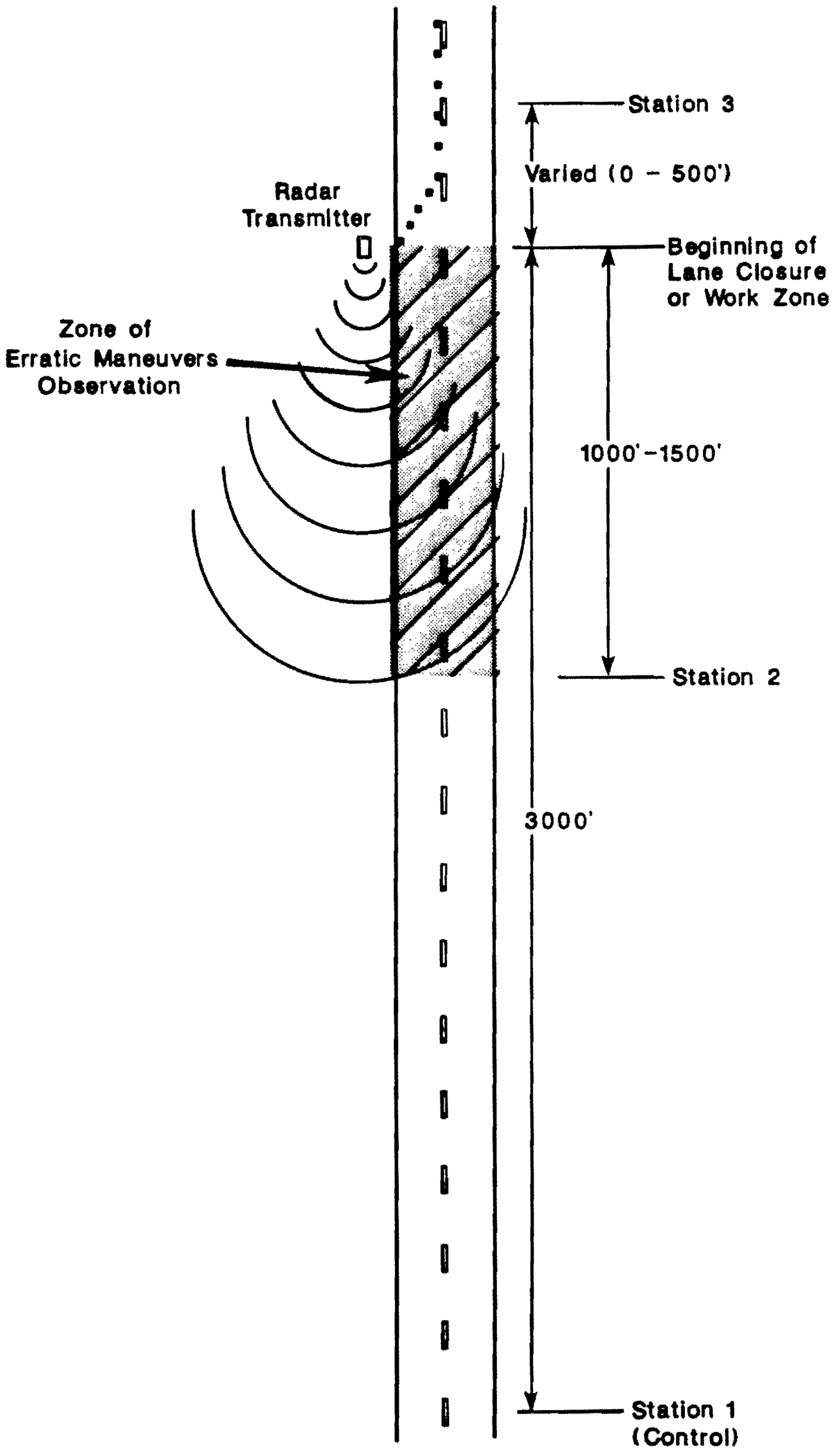

Figure B-2. Illustration of Data Collection Locations

TABLE B-2. VEHICLE SPEED SAMPLE SIZES COLLECTED

Site	Veh. Type	Station 1		Station 2		Station 3		Traced St. 1 - St. 2		Traced St. 1 - St. 3	
		Off	On	Off	On	Off	On	Off	On	Off	On
1	All	352	356	330	325	186	203	330	325	186	203
	Autos	313	322	292	295	162	179	292	295	162	179
	Trucks	39	34	38	30	24	24	38	30	20	24
2	All	502	734	443	681	395	543	443	679	395	541
	Autos	412	584	359	539	316	426	359	537	316	424
	Trucks	90	150	84	142	79	117	84	142	79	117
3	All	333	489	309	458	339	484	264	412	279	424
	Autos	298	446	274	413	304	438	232	373	246	385
	Trucks	35	43	35	45	35	46	32	39	33	39
4	All	603	484	560	427	295	356	559	416	294	355
	Autos	492	394	458	354	242	274	457	353	241	273
	Trucks	111	90	102	73	53	82	102	73	53	82
5	All	1035	484	778	499	726	514	456	186	461	160
	Autos	844	318	633	400	572	418	348	137	341	118
	Trucks	191	66	145	99	154	96	108	49	120	42
6	All	779	1320	273	942	483	493	203	572	341	351
	Autos	653	1128	214	805	388	381	152	453	271	264
	Trucks	126	192	59	137	95	112	51	119	70	87
7	All	478	244	828	467	723	409	226	107	162	79
	Autos	411	194	707	384	673	371	186	72	136	65
	Trucks	67	50	121	83	70	38	40	35	22	14
8	All	267	280	252	344	184	194	14	40	7	23
	Autos	233	234	219	274	177	173	6	11	3	14
	Trucks	34	46	33	70	7	21	8	29	4	9

from station 1 to 3 are also shown in the table. Consolidated over all sites, approximately 60% of the vehicles recorded at station 1 were tracked to station 2, and 49% of vehicles at station 1 could be tracked to station 3. On a site-by-site basis, these percentages were much greater for sites 1 through 4, where traffic volumes were lower.

The second type of data collected at each site were vehicle conflicts occurring within the 1500 to 1000 ft approach to the work zone. Traffic volumes were collected simultaneously in order to develop vehicle conflict rates for comparison purposes. Conflicts occurred in isolation (i.e. a single vehicle braking severely) and also because of vehicle interactions (i.e. vehicles behind a hard-braking vehicle were forced to swerve out of the lane or to also brake severely), and an attempt was made by the observer at each site to document the type of conflicts which occurred. Vehicle conflicts were categorized into four main types: (1) severe braking, identified by a dramatic nosedive or skidding by the vehicle, (2) abrupt last-second lane-changing, (3) accelerating into the work zone at high speeds to get around one or more vehicles before the lane closure or to exit at a downstream ramp, and (4) other vehicle conflicts (stopping on road, run-off-the-road, etc.).

RESULTS

Effect of Radar on Vehicle Speeds

Tables B-3 and B-4 present a comparison of the mean speed, standard deviation, and percent of traffic exceeding 65 mph at stations 2 and 3 with and without a radar signal transmitted. These statistics are shown for the entire vehicle sample and separately for each vehicle type (automobiles and large trucks). In general, the effect of radar varied from site to site. In Table B-3, mean speeds at station 2 were unchanged or decreased slightly at six of the eight sites, (from 0 to 2.8 mph). Only a few of these reductions were statistically significant, however (based on a comparison of means test). At sites 4 and 7, mean speeds with the radar on were actually higher than those with the radar off. At sites 3 and 4, the work activity within the work zone moved throughout the day, which may have influenced driver behavior to some degree. At site 7, traffic volumes were quite heavy, and the congestion occasionally caused some slowdowns, possibly affecting the speed measurements taken.

Table B-3 also illustrates the effect of radar upon the standard deviation of speeds at station 2. Approximately one-half of the sites experienced increases, while the remaining sites displayed slight decreases in the standard deviation of speeds. Again, very few of these changes were statistically significant (using an F test of the equality of the variances). No consistent pattern emerged when the proportions of traffic exceeding 65 mph were compared. Likewise, no clear trend was evident with respect to automobile or truck speeds.

TABLE B-3. EFFECT OF RADAR UPON SPEEDS AT STATION 2

Site	Veh. Type	Mean Speeds, mph Off	Mean Speeds, mph On	Mean Speeds, mph Change	Standard Deviations, mph Off	Standard Deviations, mph On	Standard Deviations, mph Change	% Exceeding 65 mph Off	% Exceeding 65 mph On	% Exceeding 65 mph Change
1	All	56.7	56.3	-0.4	5.19	5.20	+0.01	3.6	3.4	-0.2
	Autos	56.9	56.7	-0.2	5.29	5.07	-0.22	4.1	3.7	-0.4
	Trucks	55.2	52.4	-2.8*	4.06	5.03	+0.97	0.0	0.0	0.0
2	All	56.1	55.3	-0.8*	5.37	5.51	+0.14	3.2	2.6	-0.6
	Autos	56.4	55.5	-0.9*	5.19	5.32	+0.13	3.3	2.7	-0.6
	Trucks	53.8	53.6	-0.2	6.21	6.80	+0.59	2.9	2.2	-0.7
3	All	58.8	58.3	-0.5	5.17	4.75	-0.42	8.8	5.6	-3.2
	Autos	59.1	58.4	-0.7	5.01	4.69	-0.32	8.5	5.6	-2.9
	Trucks	57.2	57.5	+0.3	5.68	4.99	-0.69	9.8	5.5	-4.3
4	All	58.1	60.1	+2.0	5.76	5.30	-0.46	10.6	13.7	+3.1
	Autos	58.6	60.5	+1.9	5.73	5.39	-0.34	11.7	16.3	+5.6
	Trucks	55.9	58.5	+2.6	5.38	4.64	-0.74	6.0	3.5	-2.5
5	All	57.7	57.4	-0.3	4.72	5.20	+0.48*	4.0	5.2	+1.2
	Autos	58.2	58.0	-0.2	4.65	5.08	+0.43*	4.7	6.0	+1.3
	Trucks	55.9	55.1	-0.8	4.59	5.07	+0.48	0.7	2.0	+1.3
6	All	57.6	56.8	-0.8*	4.95	5.51	+0.56*	4.4	3.9	-0.5
	Autos	57.9	56.9	-1.0*	4.93	5.57	+0.64*	5.1	4.0	-1.1
	Trucks	56.6	56.2	-0.4	4.91	5.09	+0.18	1.7	3.6	+1.9
7	All	51.9	53.0	+1.1*	5.75	6.05	+0.30	0.4	1.1	+0.7
	Autos	52.3	53.6	+1.3*	5.52	5.86	+0.34	0.4	1.3	+0.9
	Trucks	49.7	50.3	+0.6	6.54	6.20	-0.34	0.0	0.0	0.0
8	All	56.2	54.8	-1.4*	4.95	4.59	-0.36	2.8	0.9	-1.9
	Autos	56.3	55.3	-1.0*	5.14	4.55	-0.59	3.2	1.1	-2.1
	Trucks	55.9	52.7	-3.2*	3.49	4.17	+0.68	0.0	0.0	0.0

* Statistically significant (0.05 level of significance)
Average speeds evaluated using a comparison-of-means test
Standard deviations evaluated using an F-test comparison of the sample variances

TABLE B-4. EFFECT OF RADAR UPON SPEEDS AT STATION 3

Site	Veh. Type	Mean Speeds, mph Off	On	Change	Standard Deviations, mph Off	On	Change	% Exceeding 65 mph Off	On	Change
1	All	46.3	45.7	-0.6	6.04	6.91	+0.87	0.0	0.0	0.0
	Autos	46.4	46.0	-0.4	6.16	6.86	+0.70	0.0	0.0	0.0
	Trucks	45.1	43.0	-2.1	5.12	6.85	+1.73	0.0	0.0	0.0
2	All	54.7	53.1	-1.6*	6.56	6.55	-0.01	2.7	2.1	-0.6
	Autos	55.0	53.3	-1.7*	6.38	6.48	+0.10	3.0	2.3	-0.7
	Trucks	52.4	50.9	-1.5	5.12	5.36	+0.28	0.0	0.0	0.0
3	All	54.5	53.7	-0.8*	5.49	5.50	+0.01	1.7	0.3	-1.4
	Autos	54.9	54.1	-0.8	5.28	5.49	+0.21	2.1	0.4	-1.7
	Trucks	52.9	52.2	-0.7	6.18	5.29	-0.89	0.0	0.0	0.0
4	All	56.8	56.5	-0.3	5.08	5.33	+0.25	4.1	3.9	-0.2
	Autos	57.5	57.1	-0.4	4.86	5.17	+0.31	4.7	4.5	-0.2
	Trucks	54.2	54.3	+0.1	5.12	5.36	+0.24	1.3	1.7	+0.4
5	All	55.4	54.9	-0.5	4.50	5.22	+0.72*	1.9	1.9	0.0
	Autos	55.8	55.4	-0.4	4.40	5.11	+0.71*	2.3	2.4	+0.1
	Trucks	53.9	52.3	-1.6*	4.60	4.93	+0.33	0.6	0.0	-0.6
6	All	54.1	53.9	-0.2	4.69	4.49	-0.20	1.7	0.4	-1.3
	Autos	54.4	54.2	-0.2	4.73	4.32	-0.41	1.8	0.3	-1.5
	Trucks	53.3	52.7	-0.6	4.41	4.88	+0.47	1.1	0.9	-0.2
7	All	52.7	52.7	0.0	5.70	5.89	+0.19	0.7	1.2	+0.5
	Autos	52.8	52.8	0.0	5.70	5.86	+0.16	0.7	1.3	+0.6
	Trucks	51.1	51.6	+0.5	5.68	6.10	+0.42	0.0	0.0	0.0
8	All	53.1	52.8	-0.3	5.26	4.85	-0.41	1.1	1.0	-0.1
	Autos	53.2	52.8	-0.5	5.28	4.85	-0.43	1.1	1.2	+0.1
	Trucks	51.4	53.3	+1.9	4.92	4.96	+0.04	0.0	0.0	0.0

* Statistically Significant (0.05 level of significance)
Average speeds evaluated using a comparison-of-means test
Standard deviations evaluated using a F-test comparison of the sample v

Table B-4 presents the same statistical comparisons for station 3, located within the actual work zone. At this location, the effects of the radar appear to be more consistent. Mean speeds decreased slightly (0.2 to 2.1 mph) at seven of the eight sites when the radar was transmitting. Meanwhile, the standard deviation of speeds increased slightly at seven sites. Although only a few of these changes were found to be statistically significant, the overall trend is apparent. Unfortunately, no clear trend was found with respect to the proportion of traffic exceeding 65 mph. It should be noted, however, that these proportions were extremely low at all of the sites to begin with, making any effect due to the radar extremely difficult to detect. Also, no patterns emerged with respect to the effect of radar upon automobiles or large trucks at this station.

Table B-5 presents a comparison of the changes in speed between data collection stations 1 and 3 (for vehicles who could be tracked through the study site). These data utilize the information collected at station 1 (the control station), and so are expected to provide stronger evidence about the actual effect of radar on vehicle speeds. These data indicate that the effect of radar was somewhat greater than suggested in Table B-4. The mean speed changes between these stations were negative, indicating that speeds decreased as vehicles approached the work zone (as would be expected). The difference in mean speed changes, representing the effect of radar, showed that an additional 0.2 to 5.0 mph mean speed change between stations occurred when the radar was transmitting. Also, the effect of radar did appear more significant for trucks than for automobiles at six of the eight sites. Meanwhile, the standard deviation of these speed changes for all vehicles and for each vehicle type increased at essentially every site, indicating that the variability of speed changes between stations was higher when the radar was in operation.

It is generally recognized that the primary purpose of radar detectors is to avoid ticketing by law enforcement for exceeding the posted speed limit (39). Therefore, one would assume that radar detectors would be in more prevalent use upon the higher-speed vehicles in the driving population. One would also expect the effect of radar upon these high-speed vehicles to be more pronounced. Table B-6 presents a final comparison of speed changes between stations 1 and 3 which support this hypothesis. Mean speed changes between stations 1 and 3 are shown for the entire speed sample taken at each site, and for the portion of the sample that exceeded 65 mph at station 1. As the table shows, radar generally had a larger speed-reducing effect upon those vehicles that were exceeding 65 mph as compared to the sample as a whole. At sites 1 through 4, the effect of radar was from 1 to 3 mph greater for the portion of traffic exceeding 65 mph than it was for the entire sample size overall. The influence upon high-speed vehicles is less pronounced at the other sites, although a small difference is still evident. Because of congestion and data collection problems, no vehicles exceeded 65 mph at station 1 of site 8. Also, the data from site 5 suggests that radar had less effect upon high-speed vehicles than upon the entire vehicle population. Given the consistent results at the other sites, it is likely that the results at site 5 are due to some extraneous factor not accounted for in the analysis.

TABLE B-5. EFFECT OF RADAR ON SPEED CHANGES BETWEEN STATIONS 1 AND 3

Site	Veh. Type	Mean Speed Change, mph Off	On	Difference	Standard Deviation, mph Off	On	Difference
1	All	-12.1	-12.5	-0.4	6.82	7.83	+1.01
	Autos	-12.0	-12.4	-0.4	6.95	7.98	+1.03
	Trucks	-13.0	-12.8	+0.2	5.99	6.77	+0.78
2	All	-3.9	-5.4	-1.5*	6.03	6.64	+0.61
	Autos	-4.0	-5.3	-1.3*	6.08	6.60	+0.52
	Trucks	-3.9	-6.6	-2.7	5.72	7.01	+1.29
3	All	-5.4	-6.0	-0.6	6.00	6.50	+0.50
	Autos	-5.3	-5.8	-0.5	5.96	6.71	+0.75
	Trucks	-5.8	-6.8	-1.0	6.23	5.70	-0.53
4	All	-4.5	-5.3	-0.8*	6.21	7.01	+0.80*
	Autos	-4.2	-5.0	-0.8	6.27	7.04	+0.77*
	Trucks	-5.6	-6.6	-1.0	5.85	6.76	+0.91
5	All	-2.9	-3.1	-0.2	4.72	4.80	+0.08
	Autos	-2.9	-3.2	-0.3	4.82	4.77	-0.05
	Trucks	-3.0	-2.9	+0.1	4.47	4.94	+0.47
6	All	-3.0	-3.6	-0.6	4.72	4.88	+0.16
	Autos	-3.1	-3.6	-0.5	4.69	4.91	+0.22
	Trucks	-2.9	-3.6	-0.7	4.88	4.81	-0.07
7	All	-1.1	-2.8	-1.7*	5.80	6.30	+0.50
	Autos	-1.4	-2.8	-1.4	6.11	6.30	+0.19
	Trucks	+0.7	-2.4	-3.1	3.29	6.52	+3.23*
8	All	0.4	-4.9	-4.5*	2.37	4.39	+2.02
	Autos	-2.0	-4.4	-2.4	2.64	4.01	+1.37
	Trucks	+0.8	-5.8	-5.0*	1.50	5.04	+3.54

* Statistically Significant (0.05 level of significance)
Average speeds evaluated using a comparison-of-means test
Standard deviations evaluated using an F-test comparison of the sample variances

TABLE B-6. COMPARISON OF SPEED CHANGES FROM STATION 1 TO 3 ALL VEHICLES VERSUS VEHICLES > 65 MPH

Site	Veh. Type	Average Speed Change, mph Off	On	Difference
1	All	-12.1	-12.5	-0.4
	> 65 mph	-20.1	-23.5	-3.4
2	All	-3.9	-5.4	-1.5
	> 65 mph	-8.8	-11.8	-3.0
3	All	-5.4	-6.0	-0.6
	> 65 mph	-10.0	-13.6	-3.6
4	All	-4.5	-5.3	-0.8
	> 65 mph	-10.3	-12.4	-2.1
5	All	-2.9	-3.1	-0.2
	> 65 mph	-9.1	-6.0	+3.1
6	All	-3.0	-3.6	-0.6
	> 65 mph	-9.6	-10.4	-0.8
7	All	-1.1	-2.8	-1.7
	> 65 mph	-7.0	-9.3	-2.3
8	All	-0.4	-4.9	-4.5
	> 65 mph	-.-	-.-	-.-

-.- No observations

Effect of Radar on Vehicle Conflicts

Vehicle conflicts were recorded manually at each site during each study. Traffic volumes were recorded simultaneously so that conflict rates could be computed for comparison purposes (with and without the radar in operation). As stated previously, vehicle conflicts were categorized into three main types:

1. Severe braking (evidenced by a dramatic nosedive by vehicle or by vehicle skidding)

2. Last second or abrupt lane-changing

3. accelerations into work zone (to pass vehicle before lane closure or exit ramp)

A final category was simply labeled "other" to include any other maneuvers considered by data collection personnel to have resulted in conflict.

Results of the conflict analysis is shown in Table B-7. The "other" category was used so infrequently that it was not included in this analysis (only three maneuvers total from all eight sites). Erratic maneuver rates varied significantly from site to site, presumably due to the differences in volumes, work zone activity and traffic control, roadway geometrics, etc. Nevertheless, basic trends do appear in the data. At all 8 sites, severe braking conflict rates increased substantially when the radar was transmitting. Although an attempt was made to determine whether these maneuvers occurred in isolation or because of another vehicle, the low sample sizes at some of the sites and extremely high volumes at the other sites often made this impossible to accomplish. The occurrence of last-second lane changes also increased at six of the eight sites, although not as dramatically as the increase in sudden braking maneuvers. There was evidence of a slight decrease in the frequency of vehicles accelerating into the work zone at the sites where a lane closure was present (sites 1 through 4). However, these rates actually increased slightly at sites 5 through 8, where no lane closures were present.

Discussion

The results just described indicate that a radar signal has some effect upon speeds at work zones. However, these effects are small, generally less than 2 to 3 mph. Because of these small changes, there is no way of discerning, either statistically or through engineering judgment, how the site-specific factors considered in this study (volumes, work zone type, work zone speed limit) influence the effectiveness of radar transmissions at work zones.

TABLE B-7. EFFECT OF RADAR UPON VEHICLE CONFLICTS RATE/1000 VEHICLES

Site	Severe Braking			Last-Second Lane-Changing			Accelerating Into the Work Zone			Total		
	Off	On	Change	Off	On	Change	Off	On	Change	Off	On	Change
1	11.9 (7)	18.3 (9)	+6.4	3.4 (2)	14.2 (7)	+10.8	15.3 (9)	14.3 (7)	-1.0	30.6 (18)	46.8 (23)	+16.2
2	27.8 (16)	47.8 (26)	+20.0*	6.9 (4)	20.2 (11)	+13.3	8.7 (5)	3.7 (2)	-5.0	43.4 (25)	71.7 (39)	+28.3*
3	2.5 (2)	4.9 (3)	+2.4	20.3 (16)	22.9 (14)	+2.6	17.8 (14)	14.9 (11)	-2.9	40.6 (32)	42.7 (28)	+2.1
4	29.9 (18)	40.6 (30)	+11.7	1.6 (1)	4.1 (3)	+2.5	6.6 (4)	5.4 (4)	-1.2	38.1 (23)	50.1 (37)	+12.0
5	4.6 (11)	2.7 (5)	-1.9	9.5 (23)	8.5 (16)	-1.0	3.7 (9)	6.9 (13)	+3.2	17.8 (43)	18.1 (34)	+0.3
6	8.5 (16)	12.1 (36)	+3.6	6.9 (13)	9.1 (27)	+2.2	0.5 (1)	1.7 (5)	+1.2	15.9 (30)	22.9 (68)	+7.0*
7	15.5 (45)	18.7 (78)	+3.2	15.5 (45)	12.2 (51)	-3.3	0.0 (0)	0.0 (0)	0.0	31.0 (90)	30.9 (129)	-0.1
8	40.2 (207)	51.6 (238)	+11.4*	48.1 (196)	49.3 (181)	+1.2	0.0 (0)	0.4 (2)	+0.4	88.3 (403)	101.3 (421)	+13.0
Total	21.7	26.6	+4.9*	21.6	20.6	-1.0	3.8	3.6	-0.2	47.1	50.8	+3.7

Numbers in parentheses () are number of maneuvers observed

Off = radar off condition
On = radar on condition

Overall, the small reductions in mean speeds found in this study are consistent with those obtained in other studies of unmanned radar (at non-work zone locations). It is safe to assume that radar, in most situations, will not reduce speeds overall in any dramatic way. Radar does appear to have the capability of affecting the behavior of certain drivers, specifically those using radar detectors who are exceeding the posted speed limit by a large amount.

Interestingly, the results of this study are not consistent with those other studies with respect to the effect of radar upon speed variability. While the past studies found speed variance lower when radar was transmitting, this study suggests that the variability of speeds at locations immediately upstream and within the work zone may actually increase in some cases. The results of the comparison of speed changes between stations clearly suggests that the variability of these speed changes increase when radar is present. Presumably, this increased variability is due to drivers with detectors who decelerate dramatically upon receiving a signal from their detector. Evidence collected during this study suggests that these drivers tend to be the high-speed motorists, and radar appears to have a more pronounced speed-reducing effect upon these drivers.

An analysis of vehicle conflict data indicates that the presence of a radar signal increases the frequency of severe braking maneuvers. Intuitively, one would expect this increase to be related to the work zone speed limit posted and the actual driving speeds at the work zone. Specifically, situations where drivers travel considerably faster than the posted work zone speed limit would be expected to result in higher vehicle conflict rates, as drivers with detectors try to quickly slow down to below the posted limit, and any vehicles following are forced to respond in a similar fashion. Table B-8 presents the posted speed limits and mean speeds (without radar present) observed at the eight sites. Data are presented for station 1 (the control station upstream of the work zone) and at station 3 within the work zone. As the table shows, mean speeds at sites 1 and 2 were above the posted speed limit by 6 to 14 mph, while mean speeds at the other sites were only slightly higher than the posted limit, or even below the speed limit. If one then refers back to Table B-7, the increase in erratic maneuvers during radar transmissions was indeed much higher (proportionally) at sites 1 and 2 than they were for the other six sites.

SUMMARY

This study has examined the effect of radar signals (without visible enforcement) upon vehicle speeds and vehicle conflicts at eight work zone locations on multilane roadways in Texas. The work zones varied with respect to the amount of traffic present, type of work zone (with or without a lane closure), and the reduction in normal speed limits through the work zone. Overall, it has been shown that the effect upon speeds is small, as mean speeds at the study sites were unaffected or reduced by less than 3 mph. By analyzing the changes in speeds between data collection stations as vehicles approach the work zone, it was shown that there may be, in some cases, a greater effect

TABLE B-8. COMPARISON OF SPEED LIMITS AND MEAN SPEEDS (NO RADAR TRANSMITTING)

	Station 1 (Control)			Station 3 (Within Work Zone)		
Site	Speed Limit (mph)	Ave. Speed (mph)	Diff. (mph)	Speed Limit (mph)	Average Speed (mph)	Diff. (mph)
1	55	58.5	+3.5	40	46.3	+6.3
2	55	59.3	+4.3	40	54.7	+14.7
3	55	60.3	+5.3	55	54.5	-0.5
4	55	61.3	+6.3	55	56.8	+1.8
5	65	59.2	-5.8	55	55.4	+0.4
6	55	57.3	+2.3	55	54.1	-0.9
7	55	53.9	-1.1	55	52.7	-2.3
8	55	56.2	+1.2	55	53.1	-1.9

of radar upon trucks (in comparison to automobiles) and upon high-speed vehicles (in comparison to the entire vehicle sample). Such results correlate well with expectations that radar would have a more pronounced effect upon trucks than for automobiles and upon high-speed vehicles than for the overall vehicle population.

Vehicle conflicts were found to increase at the eight sites when radar was operating in comparison to when the radar was not in operation. The increases were larger for the four sites where lane closures were present, and were the highest at the two sites where mean speeds were normally much higher than the posted limit. Although there was evidence that (in the presence of radar) fewer vehicles accelerated to get around slower vehicles as they approached the work zone this reduction was overshadowed by larger increases in the frequency of severe braking and last-second lane changing. Overall, it appears that radar results in additional conflicts on the approach to the work zones, particularly if the posted speed limit is considerably lower than what drivers wish to travel.

It would have been desirable to compare the effects of radar with the effects of flagging and of law enforcement at each site, particularly with respect to how these other speed control methods would affect vehicle conflicts. Unfortunately, such a comparison was not possible in this study. The results of this study suggest, however, that the overall effect of speed control methods, and not just the effects on vehicle speeds, should be considered when selecting and implementing speed control techniques at work zones.