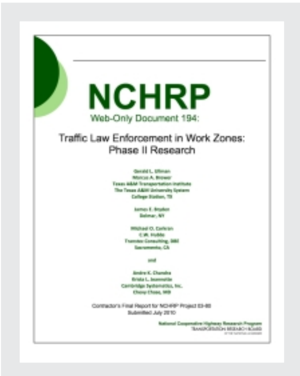
NCHRP
Web-Only Document 194:
Traffic Law Enforcement in Work Zones:
Phase II Research

Traffic Law Enforcement in Work Zones: Phase II Research

DETAILS

0 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-43430-0 | DOI 10.17226/22575

AUTHORS

Ullman, Gerald L.; Brewer, Marcus A.; Bryden, James E.; Corkran, Michael O.; Hubbs, C.W.; Chandra, Andre K.; and Jeannotte, Krista L.

ACKNOWLEDGMENT

This work was sponsored by the American Association of State Highway and Transportation Officials (AASHTO), in cooperation with the Federal Highway Administration, and was conducted in the National Cooperative Highway Research Program (NCHRP), which is administered by the Transportation Research Board (TRB) of the National Academies.

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ACKNOWLEDGMENTS

The research results documented in this report were developed based on research performed under National Cooperative Highway Research Program (NCHRP) Project 3-80 by the Texas Transportation Institute (TTI) of the Texas A&M University System, under the fiscal administration of the Texas A&M Research Foundation. The Mr. James E. Bryden, Cambridge Systematics, Incorporated (CSI) and Transtec served as subcontractors for this research. Gerald L. Ullman, senior research engineer with TTI, was the principal investigator. The other authors of this report were Marcus A. Brewer, assistant research engineer with TTI; James E. Bryden, highway safety consultant; Michael Cockran and C.W. Hubbs, law enforcement experts with Transtec Consulting; and Andre Chandra and Krista Jeannotte, senior research scientist with CSI. The work was performed under the general supervision of Dr. Ullman.

The researchers wish to express their gratitude to the members of the project panel for their guidance and patience during the performance of this research:

- Arthur Gruhn, Connecticut Department of Transportation (chair) (deceased);
- Rebecca Brewster, American Transportation Research Institute;
- James Halvorsen, New York State Police;
- Larry Holestine, Data Nexus, Incorporated;
- James D. McGee, Nebraska Department of Roads;
- Richard Raub, Raub Associates;
- Mitsuru Saito, Brigham Young University;
- Donald Williams, West Virginia Department of Transportation;
- Jacqueline Ghezzi, California Department of Transportation (deceased);
- Ken Opiela, FHWA; and
- Frank Lisle, Transportation Research Board.

In addition to the project panel members, the authors gratefully acknowledge the assistance of numerous state departments of transportation (DOT) personnel who participated in telephone surveys and on-site interviews regarding their work zone enforcement practices. Finally, this research could not have been completed without the special assistance of several members of the New York State DOT, New York State Police, California DOT, California Highway Patrol, New Jersey DOT, New Jersey State Police, North Carolina DOT, North Carolina State Highway Patrol, Kansas DOT, Kansas Highway Patrol, Tennessee DOT, and Tennessee Department of Safety who coordinated access to, and provided support at, work zone projects for the various field studies and driver surveys performed during the course of this research.

ABSTRACT

NCHRP Project 3-80 was initiated to develop guidance on the effective use of traffic enforcement strategies in highway work zones. Traffic enforcement is viewed by many as one of the most effective means available for reducing speeding and other undesirable driving behaviors that compromise safety in a highway work zone. However, practices nationally vary widely on the enforcement strategies and philosophies used in work zones, the administrative mechanisms applied to establish and maintain a work zone enforcement program, payment methods for work zone enforcement efforts, techniques applied to supplement work zone enforcement, and public information dissemination practices employed to support work zone enforcement in a region.

In this report, results are described of three research efforts performed to facilitate the development of guidance on this topic:

- Determination of whether driver opinions, perceptions, and behaviors related to the risk of violating traffic laws in work zones differ depending on whether work zone enforcement practices in a region are predominantly passive (positioned in the work zone with lights flashing to attract attention and reduce speeds) or active (pursuit of violators and issuance of citations);

- Determination of the effects of using an enforcement officer and vehicle in a traffic-calming (passive enforcement) mode upstream of work zones where traffic queues develop on the speed, deceleration, and erratic maneuvers of traffic approaching the traffic queue;

- A generalized economic analysis of the potential crash cost reductions associated with the provision of enforcement in work zones was undertaken to determine AADT thresholds at which the benefits of providing enforcement in work zones exceeds the costs of enforcement.

With respect to the first point, these studies indicate that the use of passive enforcement does not significant degrade driver perceptions of enforcement or driver response to enforcement compared to active enforcement use. Next, studies of enforcement upstream of work zone traffic queues were somewhat inconclusive, and did not indicate a clear effect of having enforcement deployed in this manner. Finally, the analysis of work zone crash costs suggests that enforcement safety benefits outweigh the costs of deployment in daytime work zones on roadways exceeding 5000 to 20,000 vehicles per day (depending on hourly enforcement costs), and at nighttime work zones on roadways exceeding 20,000 to 65,000 vehicles per day.

SUMMARY

Deploying traffic law enforcement in a work zone is viewed by many as one of the most effective means available for reducing speeding and other undesirable driving behaviors that compromise safety. Studies conducted over the past 30 years repeatedly verify the speed-reducing effects of work zone enforcement presence. Traffic enforcement strategies can be either overt in nature, in which the enforcement vehicle and officer are highly visible, or covert, in which the enforcement officer attempts to remain hidden until identifying a violator and initiating pursuit. Also, a number of different traffic enforcement methods can be used in work zones, such as

- circulating patrols,
- stationary patrols,
- police traffic controllers,
- camouflaged enforcement techniques,
- aerial patrols, and
- automated or semi-automated enforcement technology.

Perhaps more importantly, many highway agencies also make the distinction between law enforcement efforts to identify, pursue, and cite traffic law violators (active enforcement), versus efforts to increase driver attention, reduce speed, and generally calm traffic in the vicinity of the enforcement vehicle (passive enforcement). Opinions differ widely on the acceptability and desirability of passive enforcement techniques. There is widespread belief among highway workers and contractors that use of passive enforcement is preferable, as it allows the enforcement vehicle and officer to remain in the vicinity of the work activity and reduce speeds. The primary concern that highway and enforcement agencies have with passive enforcement is with the potential loss of enforcement credibility and subsequent loss of the influence of the enforcement symbol in improving driving behavior and reducing speeds through the work zone. Consequently, studies were performed to determine whether driver opinions, perceptions, and behaviors related to the risk of violating traffic laws in work zones differ depending on whether work zone enforcement practices in a region are predominantly passive or active. Driver opinion surveys and field study evaluations of driver speed reductions in response to enforcement vehicles positioned in work zones were performed in regions utilized passive work zone enforcement strictly for attention-getting purposes only, and in regions where enforcement in work zones is almost exclusively for the purpose of identifying, pursuing, and citing traffic law violators.

The results of these studies indicate that drivers appear to realize how enforcement is being used in work zones in a particular jurisdiction, especially if it is for visibility and traffic-calming purposes. Significantly higher percentages of drivers in the passive enforcement locations indicated that enforcement personnel sitting in a work zone with its lights flashing were there for attention-getting purposes than did those living in locations where active enforcement efforts in work zones were emphasized. However, although drivers are aware of how enforcement personnel are behaving in work zones, it does not appear that this awareness translates into a difference in how drivers think they react when encountering an enforcement vehicle in a work zone. In fact, the type of enforcement used in work zones had much less of an effect on driver's stated reaction to enforcement vehicles than did their age, education, and opinion about the reasonableness of work zone speed limits posted in their region. These variables were also more important than type of work zone enforcement practiced in the region in determining the distraction level of an enforcement vehicle sitting in a work zone. Drivers living in locations where work zone enforcement is primarily passive indicated that, although they were aware that an enforcement vehicle in a work zone was not likely to pursue them if they were exceeding the posted speed limit, the vehicle was present to raise their attention about a downstream hazard.

Field studies performed as part of this research further supported the contention that drivers do not react differently when encountering active or passive enforcement vehicles in work zones. At work zones in both types of enforcement locations, an enforcement vehicle generally resulted in an additional 4 mph drop in average speeds just downstream of the enforcement vehicle. Likewise, the percent of vehicles not compliant with the work zone speed limits dropped substantially, and the standard deviation of speeds was reduced when the enforcement vehicle was present. No statistically significant differences in these speed reductions or other speed parameters were found as a function of the type of enforcement used in work zones. Consequently, the use of passive enforcement does not appear to significantly degrade driver perceptions of enforcement or driver response to enforcement compared to active enforcement use (despite opinions to the contrary). Even so, it is recommended that highway agencies who do rely extensively on passive enforcement consider using occasional active enforcement in work zones as enforcement resources are available to ensure that drivers do not become overly confident that they will never be cited for violating a traffic law by enforcement located in a work zone.

Related to the above discussion, a number of states use passive enforcement to improve work zone safety by reducing speeds and improving driver vigilance and behavior as vehicles approach work zones where traffic queues have developed. Officers and vehicles positioned themselves on the side of the road with lights flashing just upstream of the queue, and move upstream and downstream on the shoulder attempting to remain just upstream of the queue. Although viewed positively by those agencies utilizing this strategy, no evaluations of its effectiveness had been performed. Unfortunately, field studies performed to evaluate this strategy encountered several unforeseen difficulties and were thus less than conclusive. The studies did indicate that speeds approaching a queue at a work zone when an officer is present are slightly (1-2 mph) lower than when the officer is not present. However, the influence of enforcement upon speed variability as vehicles approach a queue was inconsistent across the sites examined. Similarly, the distribution of deceleration rates at various distances upstream of a traffic queue did not differ significantly based on whether enforcement was or was not present, nor did the distance upstream of the traffic queue at which the maximum deceleration rate occurred. Although the results did not imply a significant benefit in using enforcement as a queue-end protection strategy, neither did they suggest any type of operational or safety problem created as a result of such use. Consequently, this strategy is still considered to be an acceptable use of enforcement in work zones (but may or may not be an optimal utilization of enforcement resources). Additional research will be necessary to actually quantify the safety benefits that might be achieved through this strategy.

Ideally, work zone enforcement would best be used where its benefits to the public equal or exceed the costs of providing that enforcement. Intuitively, the benefit of using enforcement in a work zone is an improvement in safety in terms of reduced work zone crash costs (although there may be some situations where the traffic-calming effect of enforcement could improve traffic flow and result in a reduction in motorist delay costs). A generalized economic analysis of the potential crash cost reductions associated with the provision of enforcement in work zones was undertaken to determine traffic volume thresholds at which the benefits of providing enforcement in work zones exceeds the costs of enforcement. The results of the assessment suggested that enforcement use in work zones during daytime work activities appear to be justified in most instances once roadway AADTs reach 5000 to 20,000 vehicles per day (vpd), depending on the costs being paid for enforcement efforts, and at work zones with night work activity once AADTs reach 20,000 to 65,000 vpd. However, these results should be considered as a general guide, a starting point for decision-makers regarding the types of conditions under which the use of enforcement may prove cost-effective. It is difficult to predict with any certainty the crash costs expected for a particular work zone. Consequently, the results of the analysis only provide order-of-magnitude indications of anticipated crash cost values.

Finally, these research results (and those previously completed under this project) have been utilized in the development of guidelines that have been published as a separate NCHRP document (NCHRP Report xxx).

CHAPTER 1 BACKGROUND

INTRODUCTION

Having traffic law enforcement at a highway work zone is viewed by many as one of the most effective means available for reducing speeding and other undesirable driving behaviors that compromise safety. Studies conducted over the past 30 years repeatedly verify the speed-reducing effects of enforcement presence in work zones (*1*,*2*,*3*,*4*,*5*,*6*,*7*,*8*,*9*,*10*,*11*). However, the magnitude of the speed reduction varies depending on type of enforcement method, roadway type, traffic volumes, difference between the posted speed limit and typical travel speeds, and other factors.

Several studies have cited "excessive speeds" as a contributing factor to a high percentage of work zone crashes (*12*,*13*,*14*,*15*). To the extent that a reduction in speed also implies heightened motorist awareness, improved ability to react to unexpected situations, and greater degree of compliance with other traffic laws and regulations, it is typically assumed that safety is improved as well by utilizing law enforcement in work zones. Enforcement activities in a work zone can also help identify and curtail other unsafe driving behaviors as well (reckless or careless driving, driving under the influence, etc.).

Federal regulations require state highway agencies (SHAs) to establish explicit policies and payment procedures for using law enforcement on federal-aid highway projects in their jurisdictions (*16*). This policy requires processes, procedures, and/or guidance on the following topics:

- Basic interagency agreements between the highway agency and appropriate law enforcement agencies to address work zone enforcement needs;
- Interactions between the highway and the law enforcement agencies during project planning and development;
- Conditions where law enforcement involvement in work zone traffic control may be needed or beneficial, and criteria to determine the project-specific need for law enforcement;
- General nature of law enforcement services to be provided, and procedures to determine project-specific services;
- Appropriate work zone safety and mobility training for the officers;
- Procedures for interagency and project-level communications between highway agency and law enforcement personnel; and
- Reimbursement agreements for the law enforcement service.

Whereas the regulations require SHAs to address these topics, they do not prescribe how the states are to address them. Rather, it is left up to the agencies themselves to determine how best to formulate their policies and procedures so as to fulfill the intent of the regulation. As a result, a need exists for practical, useful guidance on this topic. The information presented in this report has supported the development of that type of guidance.

TYPES AND EFFECTIVENESS OF ENFORCEMENT STRATEGIES USED IN WORK ZONES

In general terms, traffic enforcement strategies can be either overt in nature, in which the enforcement vehicle and officer are highly visible, or covert, in which the enforcement officer attempts to remain hidden until identifying a violator and initiating pursuit. The intent of overt enforcement is to alter the behavior of road users immediately and significantly at a location during the period when enforcement is visible. Conversely, covert enforcement is used to create a perception among road users that enforcement activities can occur at any time and place, thereby resulting in improved compliance with traffic laws at all times (even when enforcement is not actually present) (*17*). According to deterrence theory, the extent to which either type of enforcement results in changes in driving behavior depends on the perceived risk of citation as well as the swiftness, certainty, and severity of the punishment associated with the citation (*18,19*). Of these factors, perceived risk of apprehension has the greatest effect (*18*).

Within work zones, many highway agencies also make the distinction between law enforcement efforts to identify, pursue, and cite traffic law violators (active enforcement), versus efforts to increase driver attention, reduce speed, and generally calm traffic in the vicinity of the enforcement vehicle (passive enforcement). In a passive enforcement mode, officers usually remain at a location with or without lights flashing, but do not actively engage in identifying traffic violators and then pursuing and issuing citations.

A number of different traffic enforcement methods are used in work zones, and are summarized in Table 1 (*1-11*). For some of the methods, both overt and covert approaches can be used; for other methods, only one of the approaches is appropriate. The typical reductions in speed in work zones for these methods that have been reported in the literature are also shown in the table. Generally speaking, these results reflect an overt approach to these methods, as no evaluations of covert enforcement efforts in work zones were found in the literature. However, studies of covert enforcement in non-work zone situations indicate that the effect on speed will be lower than for the same method of enforcement performed as an overt activity (*20*).

Looking at the numbers listed in Table 1, considerable variation in the speed-reducing effect of any particular enforcement method is evident. Several site-specific factors affect how much influence enforcement can have on driving behavior (e.g., type of roadway, frequency and duration of enforcement activities, whether emergency flashing lights are on, whether radar or lidar are activated, etc.). In addition, two other factors believed to significantly influence behavior include:

- Traffic volumes – higher traffic volumes are believed to reduce a driver's perceived risk of apprehension when seeing an enforcement vehicle and officer than when traffic volumes are lower and the motorist feels more vulnerable to identification and citation;

- Prevailing speeds relative to the posted speed limit – speed limits that are more in line with actual operating speeds in the work zone require smaller speed reductions (if any) by drivers to come within perceived tolerances of the speed limit, thereby avoiding a citation by officers.

Table 1. Types and Effectiveness of Work Zone Enforcement Efforts

Method	Description	Reductions in Average Speed in Work Zones
Circulating (mobile) Patrols	Marked enforcement vehicles circulate in within and/or upstream of the work zone (this method could also be performed covertly in unmarked vehicles).	2-5 mph
Stationary Patrols	Marked enforcement vehicles are parked next to the roadway either within or upstream of the work zone (this method could also be done covertly by using unmarked vehicles or by parking the vehicle in a hidden location to monitor traffic).	3-13 mph
Police Traffic Controllers	Enforcement personnel are positioned outside of their vehicle next to roadway (speed control), or in travel lane (for intersection or other right-of-way control activities).	3-14 mph
Camouflaged Enforcement	Enforcement personnel wear vests and hardhats and stand on or near equipment to monitor speeds; violators are identified via radio for downstream apprehension by other officers. Typically, this method is supplemented with advance warning signs and media notification about the enforcement operation, making it an overt activity.	NA (likely similar to automated speed enforcement effects)
Aerial Speed Enforcement	Enforcement personnel track travel times between marked points, notify ground patrols of violators for apprehension. Traditionally, this method has been performed covertly (although static signs are typically posted to warn drivers of its use).	NA
Automated Speed Enforcement	Speed measuring devices and digital camera capture license plate of speed violator; ticket is sent to vehicle owner. This method is usually supplemented with advance warning signs and media notification about the enforcement location and/or operation.	3-8 mph

NA = data not available

Generally speaking, there have been few well-designed and conducted studies of work zone enforcement effectiveness on crashes. This is primarily because work zones tend to be fairly short in length and of limited duration. Furthermore, even if a work zone is long-term in nature, periodic changes in temporary geometrics and other roadway features within the work zone can influence crash likelihood and confound with the effects that enforcement presence may or may not have, and so make any estimates of enforcement effectiveness somewhat suspect (*21*,*22*). However, the limited data that are available are encouraging. Researchers evaluating the California Construction Zone Enhanced Enforcement Program (COZEEP), for example, did conclude that the provision of additional enforcement during construction resulted in an average 20 percent reduction in crashes, with most sites with enforcement showing at least a 10 percent reduction in crashes (*23*). Approximately 20 officer-hours per directional-mile per month of additional enforcement in the construction zone were required to achieve this magnitude of safety benefit. Interestingly, these results correlate fairly well to more recent efforts to develop accident modification factors (using empirical Bayesian techniques) for various types of traffic engineering applications, including those that result in reduced traffic speeds (*24*). According to that research, reductions in average speed of 5 mph (an amount clearly within the realm of observed enforcement effects) correspond to a 19 to 29 percent reduction in non-fatal injury crashes, depending on the original speeds on the facility. Fatal crashes are reduced even more (as much as 25 to 52 percent depending on original speed).

ALTERNATIVES TO ENFORCEMENT

Although enforcement is perceived to be highly effective in reducing speeds and promoting safety in work zones, limitations in funding and manpower often constrain agencies as to where and when it can be deployed. As a result, agencies have looked for strategies and technologies that can be deployed in work zones to reduce speeds and improve driver attention in lieu of enforcement. Theoretically, these alternatives accomplish their speed-reducing objectives in one of three ways:

- by implying enforcement presence at a work zone,
- by raising driver awareness that they are in a work zone and need to slow down, and
- by altering the driver’s perception of the work zone environment to create a natural desire to reduce their speed.

Alternatives tried to date in work zones include the following:

- dummy enforcement vehicles (with or without a mannequin dressed as an officer),
- drone (unmanned) radar,
- changeable message signs (with or without radar devices to detect approaching speeds),
- portable speed display trailers,
- CB wizard (an automated radio message presented over citizen band radio),

- rumble strips,
- reduced spacing of channelizing devices,
- transverse pavement markings, and
- narrowed lanes with channelizing devices.

A summary of the various studies that have been performed on these devices is shown in Table 2. Although no literature was uncovered that evaluated the use of a dummy enforcement vehicle upon driving behavior or safety, interview comments from highway contractors and from a few highway agencies indicate that this technique is used occasionally. However, these same individuals note that the effect, if one exists, is fairly short-lived. If the vehicle is left in the same place more than a few days, local (repeat) drivers on the facility realize it is only a decoy and begin to ignore it entirely. There are also concerns that this practice reduces the credibility of the visible presence of law enforcement over time, reducing the effect of this practice as well as the effect of actual law enforcement when present.

Table 2. Summary of Alternatives to Enforcement to Reduce Speed

Alternative	Roadway Conditions Tested	Average Speed Reduction
Drone Radar (*25,26,27,28*)	Freeway, US Highway	0-3 mph
Changeable Message Sign (*2,29,30,31*)	Rural Freeway Urban Freeway Urban Arterial	0-7 mph 0-2 mph 3 mph
Speed Display Trailers/Radar-Activated Portable Changeable Message Signs (*32,33,34,35,36,37,38,39*)	Rural Freeway/ Divided Highway Two-Lane Highway Two-Lane Highway	3-6 mph 2-9 mph 2-8 mph
CB Wizard (*40*)	Rural Freeway	0-2 mph
Rumble Strips (*2,34)*	Two-Lane Highway	1-2 mph
Transverse Pavement Markings (*2,41*)	Two-Lane Highway	0 mph
Narrowed Lanes (*2,42,43*)	Rural Freeway Urban Freeway Two-Lane Highway Urban Arterial	2-8 mph 0-3 mph 4-8 mph 2-4 mph

Drone radars work on the premise that motorists with radar detector-equipped vehicles believe they are approaching an officer and slow to the speed limit. The overall mean speed reduction of this technology is modest, generally less than three mph. However, some evidence suggests that radar drones affect the fastest portion of the vehicle stream, the portion of the driving stream of most concern in work zones. These devices are small and can easily be placed inside a work vehicle or on a traffic control device. However, several states ban the use of radar detectors, which would obviously limit the effectiveness of this technique in those states.

The use of changeable message signs (CMS) that display an advisory speed or a constant message encouraging drivers to reduce speed have been used in some work zones, and results vary widely as to their influence in reducing vehicle speeds. If a portable CMS (PCMS) is outfitted with radar to detect approaching vehicle speeds and display that speed back to the motorist, it essentially functions as a speed display trailers that are in common use in many work zones nationwide. These devices have been shown to consistently reduce speeds by as much as 9 mph. In general, the effect of PCMS on speeds appears to be greater on two-lane highways or when there is only one lane per direction. Presumably, this makes it easier for individual drivers to recognize that the speed does indeed refer to them and not someone next to them.

Other devices that have been tried in an attempt to reduce vehicle speeds include the CB Wizard system that presents a pre-recorded message on citizens band radio, rumble strips placed transversely across the travel lanes approaching a work zone, transverse pavement marking patterns of unequal spacing to give the illusion that drivers are traveling faster than they should, and the use of channelizing devices to narrow the travel lane past a work zone. For the most part, such techniques also yield only small reductions in speed. In addition, the latter three techniques have significant maintenance issues (such as constantly having to reset the channelizing devices as they get knocked down by large trucks) to keep them effective in work zones. As a result, these approaches tend to be used only sparingly.

PUBLIC INFORMATION EFFORTS TO SUPPORT WORK ZONE ENFORCEMENT

It is believed that enforcement activities are more effective when accompanied by a well-designed and well-implemented public information and awareness campaign. Unfortunately, there have been no formal evaluations of work zone enforcement public information efforts or their effectiveness. A number of programs and slogans have been developed over the years to emphasize the need for motorists to be vigilant and reduce their speeds in work zones. In addition, advance and real-time public notification about work zone enforcement efforts are often incorporated into highway agency work zone enforcement programs to reduce public perceptions that such efforts are speed traps.

In several states, the increased fine law for work zones includes a stipulation that higher fines are in effect only when workers are present. This stipulation creates some difficulties for officers and for the public in knowing if workers are present within the work zone. A few states have therefore incorporated real-time-activated warning signs into their work zones that indicate when workers are present. Despite these efforts, though, concerns have arisen regarding the failure of the project personnel to turn off the sign at the end of the shift when workers have departed the site. This failure to turn off the sign when appropriate has degraded public credibility and trust, and has made it more difficult for officers to use the sign as an absolute indication of worker presence during enforcement actions.

REVIEW OF DEVELOPMENT AND ADMINISTRATION CONSIDERATIONS OF A WORK ZONE ENFORCEMENT PROGRAM

Surveys conducted as part of this research have shown that work zone enforcement can be administered in several different ways, each with its own set of advantages and disadvantages. The choice as to which approach is most appropriate for a given situation depends on several factors, such as the amount and type of work zone enforcement typically required by the highway agency, the amount of staff time and resources the highway and/or enforcement agencies can devote to management efforts of work zone enforcement, and the working relationship between the highway and enforcement agencies.

Generally speaking, the administration of work zone enforcement efforts begins with the development of a memorandum of understanding (MOU), which outlines roles and responsibilities, lines of authority and communication, and other administrative details between the highway and enforcement agencies. In most instances, the MOU is between the state highway and state enforcement agencies; in some cases, though, the highway agency and a local enforcement agency may enter into an MOU. Although the actual development and approval of an MOU can take some time and effort by both agencies, both will ultimately benefit by having this agreement in place. The MOU can be fairly brief with only a few major clauses, or be quite lengthy and detailed. The type of information contained in various MOUs nationally is summarized in Table 3.

Work zone enforcement can be funded in several ways, depending on the needs and priorities of the highway and enforcement agencies. As specified in federal regulations (*1*), costs for work zone enforcement are eligible for reimbursement through the federal-aid program. The regulations allow enforcement services to be funded on a project-by-project basis as part of the individual construction contracts, or on an overall program-wide basis by setting aside a portion of the overall construction budget of the agency for enforcement activities. Examples of both approaches exist across the country. In addition, a few states have enacted legislation that returns a portion of the fines received from work zone enforcement efforts back to fund future work zone enforcement. Program-wide work zone enforcement funding can be established at either the statewide or a district or region level. The amount of funding may be based on a preliminary assessment of work zone enforcement needs identified by project engineers and collated across the state or district for a funding cycle. Another approach followed by some agencies is to simply establish the program as a percentage of the anticipated letting budget by the agency for that cycle. This percentage may then be adjusted slightly in subsequent years if the allocated funds are found to be excessive or deficient to cover the actual enforcement costs that were incurred.

Table 3. Summary of MOU/Operating Agreement Contents for Work Zone Enforcement

Component	FL[a]	LA	MD	MI	NC	ND	NJ	NY	OR[a]	PA	WA	WI
Estimated amount of support to be provided under the agreement	✓				✓	✓	✓	✓	✓	✓	✓	✓
Required law enforcement participation in pre-construction meetings	✓	✓	✓				✓	✓				
Minimum notification time to schedule a shift			✓					✓		✓		
Minimum notification time to cancel a shift			✓					✓				
Types of costs to be charged	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Law enforcement agency right of first refusal for the enforcement activity			✓				✓	✓	✓			
Billing information requirements	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	
Payment schedule	✓		✓				✓				✓	
Specific officer responsibilities during shift	✓	✓	✓				✓	✓		✓		✓
Right to terminate agreement	✓		✓	✓			✓	✓		✓	✓	

[a] Information reviewed concerning the agreement was not complete: additional information may be contained in the actual agreement

A project-by-project work zone enforcement funding approach tends to be simpler in nature. Agencies that utilize this method estimate enforcement funding needs for individual projects as part of the overall project planning and bid preparation process. Each project engineer then has responsibility for ensuring that the allocated funds from the project budget are used appropriately. However, this approach is perhaps less flexible in terms of accommodating unexpected additional enforcement needs during a particular project. Also, differences may exist in how enforcement is used from one project to the next.

Finally, the use of increased fine revenues for work zone enforcement is an attractive funding approach conceptually for agencies, especially since most states already increase fines for traffic violations that occur in their work zones. The extra revenues that are generated can be assigned to fund work zone enforcement without adversely affecting other governmental operations that are based on enforcement revenue. As a result, the overall impact of providing work zone enforcement upon the highway construction budget for an agency would be reduced. However, one key disadvantage of this funding approach is that it inherently favors active enforcement efforts over passive, traffic-calming techniques. In addition, this type of funding approach can result in increased public scrutiny over the speed limits set in work zones, since there is a perceived benefit to the agency to establish speed limits that increase the number of speeding citations issued and thus the amount of increased work zone enforcement funding generated.

Different methods of paying for the work zone enforcement activities that occur are also available. In some cases, work zone enforcement efforts are paid by the highway agency on a program-wide or project-by-project basis to the enforcement agency as reimbursement of officer hours worked. In other states, work zone enforcement efforts are paid directly by the contractor to either the individual officer or to the enforcement agency as part of the construction contract for hours worked. In yet a few other states, the highway agency (or other part of state government) establishes a grant arrangement to go directly to the enforcement agency to fund the work zone enforcement efforts

Federal regulations allow contract pay items for enforcement work to be either unit price or lump sum items (*1*). Unit price items should be utilized when the highway agency can estimate and control the quantity of law enforcement services required on the project. The use of lump sum payment should be limited to situations where the quantity of services is directly affected by the contractor's choice of project scheduling and chosen manner of staging and performing the work. It is important to make sure that all parties (highway agency field personnel, enforcement officers, and highway contractor personnel) understand who has authority to decide how the officers are to be utilized while at the job site (i.e., for active enforcement or for traffic-calming purposes). In most locations, the highway agency retains the authority to make such decisions, even if the highway contractor is providing payment for services.

The use of grant arrangements for work zone enforcement transfers much of the administrative effort required to manage and document expenses from the highway agency to the enforcement agency. The arrangement is viewed positively by most enforcement agencies, as it allows them to better manage manpower resources and recoup some of its administrative expenses. In some locations, the arrangement allows the enforcement agency to hire officers in addition to those that would otherwise be possible with its existing budget, and thereby reduce the amount of enforcement that is done with overtime hours that come at a cost premium. In a few instances, these additional officers are dedicated exclusively to work zone enforcement efforts, and results in officers who are more trained and experienced in operating in work zones. Overall, this approach may provide an improved level of enforcement and cooperation between enforcement and highway agency personnel than could otherwise be obtained. In a few cases, the grant arrangement has been established with a requirement that the enforcement agency provide a certain funding match (such as 20 percent) to be dedicated to work zone enforcement. Once the grant is in place, the highway agency submits requests for enforcement support on specific projects as needed, the same way as is done under the other payment methods.

KNOWLEDGE GAPS PERTAINING TO WORK ZONE TRAFFIC ENFORCEMENT

A review of literature, the conduct of numerous telephone surveys, and performance of several on-site interviews of highway contractors, highway agencies, and enforcement agencies in various states revealed a number of knowledge gaps relating to the provision of traffic law enforcement in work zones. Studies were consequently performed under this research project to address some of the more critical ones that were within the funding and scope of the project. The remainder of this report describes the methodology and results of investigations by the research team on three issues:

- effect of passive versus active enforcement efforts in work zones (Chapter 2),
- enforcement effectiveness for queue-end protection (Chapter 3), and
- assessment of potential crash cost reductions due to enforcement use in work zones (Chapter 4).

The interviews uncovered highly differing opinions on whether it was acceptable or even preferable to utilize law enforcement primarily in a passive, traffic-calming manner in work zones, or whether work zone enforcement must involve active pursuit of traffic law violators and issuance of citations. There is widespread belief among highway workers and contractors that use of passive enforcement is preferable, as it allows the enforcement vehicle and officer to remain in the vicinity of the work activity and reduce speeds. The primary concern that highway and enforcement agencies have with passive enforcement is with the potential loss of enforcement credibility and subsequent loss of the influence of the enforcement symbol in improving driving behavior and reducing speeds through the work zone.

Somewhat related to the previous question, opinions also differed nationally as to the effectiveness and value of utilizing law enforcement personnel in a traffic-calming manner upstream of traffic queues that develop due to work zone lane closures or other work activities. For this particular strategy, the officer positions the enforcement vehicle on the shoulder (with emergency lights flashing) upstream of the work zone lane closure, and attempts to maintain an approximately 0.25 mile distance between the vehicle and any traffic queue that develops at the lane closure. If the queue begins to grow, the officer moves the vehicle backwards (upstream) along the shoulder; if the queue then dissipates, the vehicle is moved downstream. Given that rear-end collisions make up a significant percentage of crashes that occur in work zones, the goal is that motorists will slow down upon noticing the enforcement vehicle on the shoulder and thus reduce the speed differential between them and the downstream vehicles already slowed in the queue. However, opponents have questioned whether the strategy actually improves safety. Traffic queues can move significantly upstream and downstream as traffic demands fluctuate over time. Furthermore, it is hypothesized that an enforcement vehicle may attract so much attention from the approaching driver that their response to the queue they are approaching may actually be degraded because of this attention.

Finally, considerable expense is involved in the provision of law enforcement resources at work zones. The results of the interviews and literature review indicate that the demand and desire to utilize enforcement in work zones typically exceeds the funds and manpower resources available to meet that demand. Consequently, highway agencies must prioritize when and where enforcement is used. One of the underlying assumptions of work zone enforcement usage is that the benefits received by the public where enforcement is deployed in terms of reduced crash costs exceed the costs of providing that deployment. To date, this assumption has not been verified. Consequently, the last effort undertaken in this research was an analysis of crash costs expected in typical work zones and the potential for work zone enforcement to reduce those costs.

CHAPTER 2 EFFECT OF PASSIVE VERSUS ACTIVE ENFORCEMENT EFFORTS IN WORK ZONES

INTRODUCTION

Investigation of work zone traffic enforcement practices across the U.S. uncovered distinct differences in how certain highway and police agencies believe enforcement personnel should be utilized. Overall, two major schools of thought emerged:

- Work zone enforcement personnel, when deployed, should always actively monitor traffic behavior with the intent of identifying, pursuing, and citing offenders (active enforcement).
- Work zone enforcement personnel, when deployed, should remain at their established location in full view of approaching traffic, and remain there as a visible presence to encourage slower speeds and safer driving behavior approaching and immediately downstream of the enforcement vehicle (passive enforcement).

Both schools have seemingly valid concerns. For those always favoring active enforcement efforts through monitoring and citation issuance, the concern is a potential loss of enforcement credibility over time if citations are not issued. Specifically, the argument is made that drivers, as a group, will eventually learn that enforcement personnel in a work zone are not pursuing violators, which will ultimately reduce driver response when encountering work zone enforcement in the future.

For those favoring passive enforcement use in a presence mode only (without intent to monitor, pursue, and cite traffic law violators), the argument made is that pursuit and citation activities moves the enforcement vehicle away from its initial position, and so the effect in the vicinity of where the vehicle was initially located is lost. Given that enforcement is often located immediately upstream of a highway work crew to help reduce speeds and improve motorist attention approaching the work operation, this loss of effect occurs right where it is most desired.

Past research has indicated that stationary enforcement has a minimal localized halo effect on driving behavior (*5*,*44*,*45*). Consequently, the loss of influence on driving behavior once the enforcement vehicle leaves to pursue a traffic violator is a real concern. On the other hand, the question as to whether drivers actually learn that presence-only (no pursuit of traffic violators) enforcement is occurring in work zones and thus quit reacting to the enforcement vehicle has not been answered to date. Therefore, researchers developed and conducted a series of experiments to assess this issue in detail.

OBJECTIVE

The objective of this set of studies was to determine whether driver opinions, perceptions, and behaviors related to the risk of violating traffic laws in work zones (primarily a reduced speed limit) differ depending on whether work zone enforcement practices in a region are predominantly passive (positioned in the work zone with lights flashing to attract attention and reduce speeds) or active (pursuit of violators and issuance of citations).

METHODOLOGY

Overview

A two-part study methodology was employed, consisting of driver opinion surveys and field study evaluations of driver speed reductions in response to enforcement vehicles positioned in work zones. These two types of data collection were conducted in four separate regions of the country. Two regions reportedly utilized passive work zone enforcement strictly for attention-getting purposes only; in the other two regions, active work zone enforcement was provided almost exclusively for the purpose of identifying, pursuing, and citing traffic law violators. Comparison of the survey and field study data between the two regions would thus indicate whether drivers learn about how enforcement is used in work zones, whether it changes their opinions about the risk of being cited, and whether there are observable differences in how drivers respond to enforcement vehicles in work zones in either type of region.

Driver Survey

Survey Instrument

The survey instrument used in the study is provided in Appendix A. The survey included several questions to obtain basic driver demographics and exposure information from study participants, as well as the frequency of their exposure to work zones. Three questions were asked to identify survey respondents who had firsthand recent experience with active police enforcement in the region, and thus who may have had a much different set of expectations and attitudes about enforcement activities in the region than the other survey respondents:

- Have you received a traffic ticket during the past year?
- Have you received a traffic ticket in a work zone in the past year?
- Have you seen someone else receive a traffic ticket in a work zone in the past year?

Next, survey respondents were asked their opinions as to the fines expected for speeding violations of magnitudes ranging from 5 to 30 mph over the speed limit in the work zone in an attempt to characterize their expectations of the severity of the penalty associated with traffic violations. Unfortunately, most respondents had no idea what the fine structure was in their jurisdiction and so the responses offered little additional insights into driver perceptions (these responses were thus excluded from the analysis).

After answers to these base questions were obtained, the remainder of the survey asked a number of questions intended to explore driver attitudes and expectations regarding the frequency of enforcement used in work zones in their jurisdiction, recent experiences driving through work zones in the region, attitudes regarding the magnitude and appropriateness of speed limit reductions established in work zones, perceptions of enforcement tolerance (if any) in work zones in the region, and attitudes and self-reported (stated preference) reactions to various driving situations in a work zone with an enforcement presence:

- How often are police officers sitting in a work zone when you drive through it?
- When you see a police vehicle sitting in a work zone, are the lights on the police vehicle usually flashing?
- How much do you think speed limits are typically reduced in work zones in your area?
  - 20 mph below the normal speed limit
  - 10 mph below the normal speed limit
  - 5 mph below the normal speed limit
  - No reduction in normal speed limit
- What do you think about the speed limits that are posted in typical work zones in your area?
  - Set too low
  - Set about right
  - Set too high
- If you drive into a work zone with a reduced speed limit, do you:
  - Slow down below the lower speed limit?
  - Slow down almost to the lower speed limit?
  - Slow down a little?
  - Do not slow down?
- If you see a police vehicle sitting in a work zone by itself on the side of the road with its lights flashing, do you assume:
  - The officer has just finished writing a ticket and is getting ready to turn off the lights and pull back into traffic?
  - The officer is trying to get everyone to slow down and be careful, but is also looking for speeders to catch?
  - The officer is trying to get everyone to slow down, but is probably not looking for speeders to catch?

- If you are exceeding the speed limit and see a police vehicle sitting in a work zone, do you typically:
    - Slow down more if lights flashing?
    - Slow down the same regardless?
    - Slow down more if the lights are not flashing?

- How does the presence of a police vehicle in a work zone affect your level of attention and awareness to the roadway signs and other things in the work zone?
    - I am more alert and pay more attention to the work zone after I see the police vehicle
    - It has absolutely no effect on my attention and awareness of the work zone
    - I continue to pay attention to the police vehicle even after I pass it and pay less attention to the work zone

The survey instrument was pilot-tested prior to conducting the full study. Three versions of the survey were created by randomizing the order of the last set of questions. This randomization was done to partially control for any potential learning or question order effects that might occur.

Survey Administration

A total of 1200 drivers were targeted to participate in the study, 300 in each of four regions nationally. In all but one location, this target was met. The regions were selected based on the predominant enforcement approach utilized in its work zones. In two of the regions, the highway agency utilizes enforcement personnel within work zones to target traffic violator identification, pursuit, and citation (i.e., active enforcement presence). In the other two regions, enforcement personnel are used for attention-getting purposes upstream of work operations (i.e., passive enforcement presence); traffic violators are seldom, if ever, pursued unless the violator is an obvious serious safety threat to other motorists or workers. The following four regions were included in the study:

- Raleigh, North Carolina (active enforcement)

- Topeka, Kansas (active enforcement)

- Trenton, New Jersey (passive enforcement)

- Nashville, Tennessee (passive enforcement)

At each region, survey administrators worked with the local driver's licensing office(s) to secure permission and conduct the surveys within the office premises. Past research has shown these locations to be productive for subject recruitment and participation. Study administrators recruited potential subjects while waiting in line. However, the survey instrument was self administered by the participants. Of course, study administrators would offer clarification of a question if so asked by the participant.

Within each region, an attempt was made to obtain a random sample of drivers that would approximate the age, gender, and education levels of the driving population in that region. Table 4 summarizes the demographic characteristics of the study sample at each location, as well as the national distribution of the key demographic variables. Overall, the samples at each location are reasonably close to the national averages. The notable exceptions include an overrepresentation of females in the Tennessee sample, underrepresentation of drivers 65 and older across all study locations, overrepresentation of college graduates in the North Carolina sample, and underrepresentation of college graduates in the Kansas sample.

The responses to several other identifying questions are also presented in Table 4. A small amount of variation exists between regions for most of the responses. One sees that a significant portion of survey respondents in each region did travel through work zones on a regular basis (e.g., once a week or more). Interestingly, while very few individuals reported receiving a citation, significant numbers of respondents in all regions indicated that they had seen someone getting a citation within a work zone, including in New Jersey and in Tennessee where the emphasis is on the use of work zone enforcement in a passive, presence mode. Presumably, these motorists were observing enforcement efforts occurring as part of regular officer duties and not associated with actual work activities. It is also possible that the responses themselves do not represent specific recollections of citations in work zones, but simply of citations observed in general within and outside of work zones.

Table 4. Survey Participant Demographics

Demographic Variable	Percent of Drivers in Each Category				
	National	North Carolina (n=300)	Kansas (n=260)	New Jersey (n=300)	Tennessee (n=300)
Gender:					
Male	50.2	47.2	52.4	51.3	37.7
Female	49.8	52.8	47.6	48.7	62.3
Age:					
< 25	13.5	12.0	18.1	14.4	12.0
25-39	30.3	31.0	22.0	22.1	26.7
40-54	30.0	41.7	37.8	31.4	40.3
55-64	11.9	10.3	11.2	20.1	16.0
65-74	8.3	2.0	5.8	7.4	4.0
>75	6.0	3.0	5.0	4.7	1.0
Education Level:					
Some HS	2.1	2.0	4.6	1.0	2.0
HS/GED Grad	27.2	11.0	30.8	21.3	21.3
Some College	20.4	24.1	38.5	29.7	30.0
College Grad	50.3	62.9	26.2	48.0	46.7
Miles Driver Per Month:					
< 500		32.3	38.5	40.3	44.3
500-1000		42.0	33.5	37.3	36.0
>1000		25.3	28.1	22.3	19.7
Travel in Work Zones:					
≤once a month		12.4	22.7	22.3	16.1
2-3 times a month		24.2	27.5	26.0	24.2
1-2 times a week		25.2	18.0	18.7	18.5
Almost daily		38.3	31.8	33.0	41.3
Ticketed in Past Year?					
Yes		14.7	17.3	11.0	14.7
No		85.3	82.7	89.0	85.3
Ticketed in Work Zone?					
Yes		1.7	0.4	0.3	0.7
No		98.3	99.6	99.7	99.3
Seen Ticketing in Work Zone?					
Yes		40.3	41.9	28.0	43.0
No		59.7	58.1	72.0	57.0
Average Fines for Speeding:					
5 mph over		$154	$104	$90	$132
10 mph over		$196	$151	$138	$173
20 mph over		$239	$199	$211	$239
30 mph over		$360	$278	$291	$313

Field Study of Driver Reaction to Work Zone Enforcement

Field data from each region were also gathered in a sample of work zones both with and without an enforcement vehicle located on the shoulder. The purpose of the field studies was to determine actual changes in driving behavior that occur in response to work zone enforcement in each region. The studies were done during the day to maximize the visibility of the enforcement vehicle. However, the vehicle emergency warning lights were not activated during the study (in those locations where only active enforcement efforts are used, officers were restricted from operating their lights without having someone actually stopped for a citation). At each work zone study site, the officer and vehicle was positioned on the shoulder within the work zone. One researcher was positioned approximately 0.25 miles upstream of the officer, and a second researcher was positioned approximately 0.25 miles downstream. The two researchers communicated with each other via walkie-talkies to identify specific free-flowing vehicles for which speeds would be measured at both the upstream and downstream location. Light detection and ranging (lidar) devices were used to measure the speeds of each targeted vehicle at both locations, and these two speeds were then matched up back in the office. In this way, it was possible to directly measure a speed change made by a specific vehicle between locations. Speeds from at least 200 free-flow vehicles were desired from each study site. Consequently, the number of sites that could be studied in each region depended on the location and traffic volumes of available work zones.

Table 5 summarizes the field study data gathered in each region. In North Carolina and New Jersey, three work zones were identified and studied; conversely, one work zone was evaluated each in Kansas and in Tennessee. All total, more than 3200 vehicle speeds were recorded at these 8 sites.

Table 5. Summary of Field Study Data

Region	Site	Enforcement Type	Work Zone Length (mi)	Speed Limit Upstream (mph)	Work Zone Speed Limit (mph)	# Vehicles Tracked: No Enforcement	# Vehicles Tracked: With Enforcement
NC	I-40A	Active	5.0	70	60	188	183
	I-40B	Active	10.4	65	65	187	195
	I-40C	Active	3.0	65	65	198	213
KS	I-70	Active	2.0	70	60	323	275
NJ	I-295	Passive	10.3	50	50	190	183
	I-280	Passive	1.3	50	50	198	198
	I-287	Passive	5.9	50	50	209	202
TN	SR 840	Passive	1.0	70	60	144	144

RESULTS

Driver Survey Reponses

Table 6 and Table 7 summarize responses to those questions pertaining to participant perceptions of work zone speed limits and when encountering enforcement in work zones, respectively. The results are presented by region, and also consolidated by type of enforcement strategy utilized (active, passive). In Table 6, a higher percentage of respondents indicated that speed limits were reduced by 20 mph in work zones in the New Jersey and Tennessee regions where work zone enforcement practices are more passive in nature than in North Carolina and Kansas where active enforcement in work zones is emphasized. However, the responses to questions as to the adequacy of those speed limit reductions and participant-stated reaction to a reduced work zone speed limit were fairly consistent across both types of regions. In most regions, more than one-third of the participants indicated they reduced their speeds below the speed limit, and about one-half of the respondents indicated they slowed down "almost" to the speed limit. It is likely that most participants were overstating their degree of compliance to reduced work zone speed limits, as the field study data collected in each region (discussed later in this section) found significant percentages of drivers far in excess of the work zone speed limit at most sites.

Interestingly, the responses to questions pertaining to work zone enforcement (Table 7) varied by region type in most cases. Participants in regions associated with more passive enforcement practices reported encountering enforcement more regularly than those in regions with the more active enforcement practices. Whereas only 7.8 percent of participants in active enforcement regions reported seeing enforcement vehicles "almost always" in work zones, more than one-third (36.5 percent) did so from the active enforcement regions.

As expected, participants in regions with active enforcement also answered differently than those in regions with passive work zone enforcement efforts when asked whether the police vehicles they encountered in work zones had their lights flashing or not. Nearly twice as many participants in passive enforcement regions indicated encountering police vehicles in work zones with their lights on as participants in active enforcement regions (65.1 percent versus 32.6 percent, respectively). Given that the goal of utilizing passive enforcement approaches in work zones is to be highly visible to motorists, these higher responses are not surprising.

Table 6. Questions About Work Zone Speed Limit Perceptions

For work zones you have driven through recently…	Active Enforcement Regions			Passive Enforcement Regions		
	North Carolina	Kansas	**Combined**	New Jersey	Tennessee	**Combined**
How much are speed limits reduced in work zones?						
20 mph below normal speed limit	35.6	34.2	**34.9**	59.0	62.1	**60.5**
10 mph below normal speed limit	60.4	62.3	**61.3**	34.6	32.9	**33.7**
5 mph below normal speed limit	2.7	2.3	**2.5**	3.4	3.4	**3.4**
No reduction	1.3	1.2	**1.3**	3.1	1.7	**2.4**
How do you feel about the speed limits in work zones?						
Set too low	7.7	7.3	**7.5**	8.6	13.5	**11.1**
About right	84.8	80.6	**82.9**	86.2	81.3	**83.8**
Set too high	7.5	12.1	**9.3**	5.2	5.2	**5.2**
If you drive into a work zone with a reduced speed limit, what do you typically do?						
Slow down below the reduced speed limit	31.3	49.2	**39.6**	31.5	35.9	**33.7**
Slow down almost to the reduced limit	52.7	49.2	**51.4**	53.9	53.7	**53.8**
Slow down a little	14.3	1.6	**8.6**	12.2	9.7	**11.0**
Do not slow down at all	1.7	0.0	**0.4**	2.4	0.7	**1.5**

Table 7. Questions About Enforcement in Work Zones Perceptions

For work zones you have driven through recently…	Active Enforcement Regions			Passive Enforcement Regions		
	North Carolina	Kansas	**Combined**	New Jersey	Tennessee	**Combined**
How often are police sitting there?						
Almost never	52.8	60.1	**55.9**	11.2	26.9	**19.0**
About one-half of the time	38.2	34.7	**36.3**	39.6	49.3	**44.5**
Almost always	10.0	5.2	**7.8**	49.2	23.7	**36.5**
Is the police vehicle sitting with its lights on?						
Yes	44.4	19.4	**32.6**	75.1	55.3	**65.1**
No	43.4	62.4	**52.4**	20.4	37.3	**28.9**
Never seen a police officer in a work zone	12.2	18.2	**15.0**	4.5	7.5	**6.0**
If a police vehicle is sitting in a work zone with its lights flashing, what is officer doing?						
Just finished writing a ticket	34.7	51.0	**42.2**	15.7	22.3	**19.0**
Trying to get everyone to slow down, but is also looking for speeders to catch	44.3	33.6	**39.4**	43.1	49.0	**46.1**
Trying to get everyone to slow down, but not looking for speeders to catch	21.0	15.4	**18.4**	41.4	28.7	**34.9**
If you are exceeding the posted speed limit and see a police vehicle sitting in the work zone, do you slow down more if lights are flashing or lights are not flashing?						
Slow down more if lights flashing	25.7	17.8	**22.0**	30.7	32.8	**31.7**
Slow down the same regardless	68.7	79.8	**73.8**	68.3	65.6	**66.9**
Slow down more if lights not flashing	5.6	2.6	**4.2**	1.0	1.7	**1.3**
How does a police vehicle in a work zone affect your attention and awareness?						
I pay more attention to the work zone after I see the police vehicle	62.5	42.3	**53.1**	66.0	65.2	**65.6**
It has no effect on my attention	24.1	44.6	**33.6**	20.3	26.4	**23.4**
I pay attention to the police vehicle even after I pass and pay less attention to the work zone	13.4	13.1	**13.2**	13.7	8.4	**11.0**

Overall, it does appear that participants do recognize how work zone enforcement is being utilized in their region. When asked what they assumed a police vehicle sitting in a work zone with its lights on to be doing, more survey participants in the regions with active enforcement indicated that the officer was finishing up the issuance of a citation (42.2 percent compared to only 19.0 percent of survey participants in regions employing more passive enforcement efforts in work zones). Conversely, a much higher percentage of participants in regions emphasizing passive enforcement efforts indicated that the officer was trying to get drivers to slow down but not trying to pursue violators and issue citations (34.9 percent compared to only 18.4 percent of subjects in regions emphasizing active enforcement efforts in work zones).

Although it does appear that drivers do recognize differences and patterns in how enforcement is being utilized in work zones, this recognition does not appear to result in substantial differences in how drivers respond when encountering enforcement located within a work zone. Most participants in both types of regions indicated that they slowed down about the same when encountering an enforcement vehicle, regardless of whether or not its lights were flashing (73.8 percent in regions emphasizing active enforcement compared to 66.9 percent in regions emphasizing passive enforcement efforts in work zones). Only a slightly greater percentage of participants in passive enforcement regions reported slowing down more if the enforcement vehicle lights are flashing than did participants in active enforcement regions (31.7 percent versus 22.0 percent, respectively). Finally, less than 5 percent of participants in either type of region indicated slowing down more when encountering enforcement vehicles with their lights off.

When asked how enforcement vehicles affect their attention to the work zone, slightly more participants in regions emphasizing passive enforcement use noted that they paid more attention to the work zone than did participants in regions emphasizing active enforcement efforts (65.6 percent versus 53.1 percent, respectively). However, neither region had many participants indicate that they paid more attention to the enforcement vehicle and less attention to the work zone (13.2 percent of participants in active enforcement regions versus 11.0 percent of participants in passive enforcement regions).

Statistical significance of the responses shown in Tables 5 through 7 as a function of the type of work zone enforcement used in each region is presented in Table 8. The null hypothesis is that there is no difference in the response variable by type of enforcement region (active or passive); the alternative hypothesis is that the response variable does differ by type of enforcement region. Likelihood ratio chi-square statistics were computed, and the resulting approximate p-values (with a Bonferroni correction applied) are shown in the table. The p-values shown are approximate, as some of the categories for some response variables had very low expected counts, but do provide an indication of the level of statistical significance of each variable. Overall, age was the only demographic variable that was highly significant between the two region types, although the miles driven per month response variable was somewhat significant and not unexpected given the highly diverse regions of the country in which the data were collected. The frequency of travel in work zones, education, observed ticket issuance, gender, and previous citations were not found to be significant. Further down in the table, responses to the questions pertaining to perceptions of speed limits in work zones and enforcement practices in work zones were also significantly different between the two enforcement region types.

Table 8. Response Variable Differences by Enforcement Region Type

Response Variable	Approximate p-value[a]
Demographics:	
Age	< 0.01
Miles driven per month	< 0.03
Frequency of travel in work zones	> 0.05
Education level	> 0.05
Observed ticket issued in work zone	> 0.05
Gender	> 0.05
Received ticket in past year	> 0.05
Received ticket in work zone in past year	> 0.05
Speed limits in work zones:	
How much speed limits are reduced	< 0.01
Speed limit reductions reasonable	< 0.01
How much slow down	< 0.02
Responses to enforcement in work zones:	
How often police are seen in work zones	< 0.01
Are police lights flashing	< 0.01
What police are doing when lights flashing	< 0.01
Slow down if lights flashing	< 0.01
Attention to work zone if enforcement present	< 0.01

[a] Low expected counts in some categories affect the p-value calculation

Because the two region types vary in more ways than just the type of enforcement approach used, it is less clear whether the differences in some of the other responses above are due to the different enforcement approaches in each region or to differences in demographics and other driver opinions and perceptions in each region. Consequently, additional statistical analyses were carried out on three of the questions most indicative of the potential influence of the two possible types of enforcement strategies employed in a region:

- If you drive into a work zone with a reduced speed limit, what do you typically do?
- If you are exceeding the posted speed limit and see a police vehicle sitting in the work zone, do you slow down more if lights are flashing or lights are not flashing?
- Does a police vehicle in a work zone affect your attention and awareness of the work zone?

Researchers developed predictive models to estimate the importance of the following variables in explaining the responses to each of the above three questions:

- enforcement region type,
- age,
- education,
- whether a ticket had been received in the past year, and
- whether the participant believed the work zone speed limits in the region were reasonable.

The Classification and Regression Trees algorithm (in SPSS CRT) was applied to 20 random samples of one-half of the full dataset to obtain an importance measure of each of the potential predictive variables. The results of this analysis are presented in Tables 9 through 11. For each question, the responses obtained tended to be explained most significantly by variables other than the enforcement region type of the participant. In Table 9, responses about how participants react when encountering a reduced speed limit in a work zone were most significantly related to whether or not the participant felt the speed limit was reasonable, followed by the age of the participant. In fact, the type of enforcement region of the participant was the least important variable explaining the participant's response to that question.

The enforcement region type was only slightly more important in explaining how participants responded to the question as to whether they slow down more if the lights on the enforcement vehicle are flashing or not flashing. As shown in Table 10, participant age was the primary variable affecting this response followed by how reasonable the participant felt work zone speed limits in the region were and participant education level. The enforcement region type variable ranked four out of the five variables considered in the analysis.

Table 9. Variables Explaining Responses to Question "If You Drive Into a Work Zone With a Reduced Speed Limit, What Do You Typically Do?"

Variable	Importance Rank	Standard Deviation	Normalized Importance (most important = 100)
Speed Limit Reasonable	1.550	0.686	100.0
Participant Age	1.875	0.759	77.3
Participant Education	2.575	0.674	64.2
Received Ticket in Past Year	4.500	0.607	17.8
Enforcement Region Type	4.600	0.503	12.6

Table 10. Variables Explaining Responses to Question "Do You Slow Down More If Enforcement Lights Are Flashing or Lights Are Not Flashing?"

Variable	Importance Rank	Standard Deviation	Normalized Importance (most important = 100)
Participant Age	2.450	1.234	100.0
Speed Limit Reasonable	2.100	1.071	99.3
Participant Education	2.350	1.268	96.0
Enforcement Region Type	3.375	1.011	66.9
Received Ticket in Past Year	4.725	0.550	30.5

In Table 11, variables affecting participant responses to the question about how a police vehicle in a work zone affects attention and awareness of the work zone again indicates that participant age is the most important variable related to the participant's response. Participant education level was found to be the second most-important variable, followed by the enforcement region type. Although higher on the list of variable considered, it should be noted that the normalized importance of the enforcement region type variable is only slightly more than one-half of that of participant age, and is about as important as participants' perceptions of the reasonableness of work zone speed limits in their region.

Taken together, the participant responses suggest that drivers do recognize when enforcement is being used in work zones for active identification and citation of traffic law violators, and when it is being used in a passive manner to increase visibility and awareness of particular work zone hazards. However, this recognition does not appear to correspond to perceptions or responses that would be construed as less safe or as indicating that enforcement credibility decreases when passive enforcement efforts are used in work zones. Rather, drivers recognize the use of passive enforcement as a warning of potential downstream hazards in those instances. Survey response data suggests that participants believe they react similarly to reduced speed limits in work zones regardless of whether active enforcement or passive enforcement strategies are predominantly employed within work zones in the region.

Table 11. Variables Explaining Responses to Question "Does a Police Vehicle In a Work Zone Affect Your Attention and Awareness?"

Variable	Importance Rank	Standard Deviation	Normalized Importance (most important = 100)
Participant Age	1.200	0.523	100.0
Participant Education	2.800	1.196	63.4
Enforcement Region Type	3.325	1.055	53.8
Speed Limit Reasonable	3.175	1.017	53.4
Received Ticket in Past Year	4.500	0.827	32.7

Field Studies of Driver Response to Enforcement Vehicles in Work Zones

Tables 12 and 13 summarize the results of the field studies of driver response to enforcement vehicles located in work zones in each of the four regions studied. Table 12 presents average speeds and speed changes between data collection locations with and without enforcement present at field study sites in North Carolina and Kansas (active enforcement), and Table 13 presents similar study results from the New Jersey and Tennessee sites (passive enforcement). For both types of regions, the study sites represent a range of normal operating speeds and magnitude of speed reductions for the work zone. Upon closer examination of the data, one also notices that average speeds relative to the reduced speed limit also varied substantially by site and within the two regions of interest. At the active enforcement region sites, average speeds downstream when the officer was not present (indicative of non-influenced behavior) at the North Carolina and Kansas sites was much higher than the reduced speed limit at two sites (NC I-40A and KS I-70) but were only slightly higher than the posted speed limit at two others (NC I-40B and NC I-40 C). Conversely, average speeds downstream (when enforcement was not present) all four of the New Jersey and Tennessee sites were 5 to 8 mph higher than the posted speed limit. It should be noted that the work zone speed limit at the New Jersey sites was 10-15 mph lower than at the other sites, even though they were all on freeway-type facilities.

Table 12. Average Speeds With and Without Enforcement Present: Active Enforcement Regions

Site	Speed Limit near Officer (mph)		Speeds (mph)					
			Upstream of Officer (Control)		Downstream of Officer		Speed Change Between Locations	
	Up-stream	Down-stream	w/o Enf.	w/ Enf.	w/o Enf.	w/ Enf.	w/o Enf.	w/ Enf.
NC I-40A	70	60	73.7	72.9	69.3	61.5	-4.2	-11.4
NC I-40B	65	65	68.6	65.9	66.4	60.9	-2.3	-5.3
NC I-40C	65	65	70.0	69.9	68.9	66.0	-1.0	-3.8
KS I-70	70	60	70.7	70.8	68.9	60.3	-6.4	-10.5
Average Additional Speed Change When Enforcement Was Present							-4.3	

Table 13. Average Speeds With and Without Enforcement Present: Passive Enforcement Regions

Site	Speed Limit near Officer (mph)		Speeds (mph)					
			Upstream of Officer (Control)		Downstream of Officer		Speed Change Between Locations	
	Up-stream	Down-stream	Without Enf.	With Enf.	Without Enf.	With Enf.	Without Enf.	With Enf.
NJ I-295	50	50	64.4	63.9	58.1	54.4	-6.4	-9.0
NJ I-280	50	50	58.3	58.3	55.1	49.8	-3.2	-8.3
NJ I-287	50	50	61.4	60.8	58.0	52.2	-3.4	-8.4
TN SR 840	70	60	66.7	63.5	67.0	59.3	+0.3	-4.2
Average Additional Speed Change When Enforcement Was Present							-4.3	

In addition to the influence of work zone enforcement on average speeds, it is also important to examine its effect on the variability of speeds at a location. Speed variability has been linked to crash frequency in several studies, so its reduction is generally viewed as a positive safety effect (*46,47*). Speed variability, measured in terms of the standard deviation of speeds upstream and downstream of the enforcement vehicle location is provided in Tables 14 and 15. As would be expected, the standard deviation of speeds at the upstream location at each site in both tables remained relatively consistent between the without- and with-enforcement conditions. In other words, the upstream location at each site did serve as a good control point to verify that other external factors were not affecting speeds differently during the with- and without-enforcement conditions. However, when the with- and without-enforcement data downstream of the officers were compared, the standard deviation was found to be substantially lower in the with-enforcement condition. The magnitude of reduction in speed variability varies from site to site, but the overall trend is consistent. Furthermore, somewhat lower standard deviations in the with-enforcement period is evident in both tables, suggesting that the standard deviation of speeds is reduced when an officer and vehicle is present regardless of the type of work zone enforcement (active or passive) used in the region.

Table 14. Standard Deviation of Speeds With and Without Enforcement Present: Active Enforcement Regions

Site	Speed Limit near Officer (mph)		Standard Deviation of Speeds (mph)			
			Upstream of Officer (Control)		Downstream of Officer	
	Up-Stream	Down-stream	Without Enf.	With Enf.	Without Enf.	With Enf.
NC I-40A	70	60	4.5	4.5	5.1	3.9
NC I-40B	65	65	4.4	4.6	4.2	4.4
NC I-40C	65	65	3.9	4.0	4.3	3.5
KS I-70	70	60	4.6	4.6	4.6	3.8

Table 15. Standard Deviation of Speeds With and Without Enforcement Present: Passive Enforcement Regions

Site	Speed Limit near Officer (mph)		Standard Deviation of Speeds (mph)			
			Upstream of Officer (Control)		Downstream of Officer	
	Up-stream	Down-stream	Without Enf.	With Enf.	Without Enf.	With Enf.
NJ I-295	50	50	5.4	5.6	5.9	5.0
NJ I-280	50	50	5.3	5.4	5.6	5.1
NJ I-287	50	50	5.1	5.2	5.1	4.6
TN SR 840	70	60	5.3	5.6	5.5	4.8

Finally, Tables 16 and 17 display the percent of driver noncompliance with the posted speed limits at each test site with and without enforcement. In both region types, the enforcement vehicle located on the shoulder of the facility results in an 18 to 57 percent reduction in the rate of driver non-compliance with the speed limits, depending on the site. On average, sites in regions with active enforcement saw speed limit compliance increase from 26.3 percent without enforcement present to 66.1 percent when enforcement was present. For the passive enforcement regions, a similar change was observed (34.1 percent without enforcement, 73.5 percent with enforcement present). Thus, the amount of the reductions when enforcement is present are similar in both region types, suggesting that type of enforcement emphasized in the region does not significantly affect driver reactions when encountering an enforcement vehicle positioned in this manner.

Table 16. Driver Compliance to Speed Limits With and Without Enforcement Present: Active Enforcement Regions

Site	Speed Limit near Officer (mph)		Percent Not Complying with Speed Limits			
			Upstream of Officer (Control)		Downstream of Officer	
	Up-stream	Down-stream	Without Enf.	With Enf.	Without Enf.	With Enf.
NC I-40A	70	60	100.0	99.5	81.4	38.8
NC I-40B	65	65	75.0	49.3	42.2	2.6
NC I-40C	65	65	86.6	82.2	71.2	53.5
KS I-70	70	60	57.6	59.4	78.3	37.8
All Active Sites			22.9	28.7	26.3	66.1

Table 17. Driver Compliance to Speed Limits With and Without Enforcement Present: Passive Enforcement Regions

Site	Speed Limit near Officer (mph)		Percent Not Complying with Speed Limits			
			Upstream of Officer (Control)		Downstream of Officer	
	Up-stream	Down-stream	Without Enf.	With Enf.	Without Enf.	With Enf.
NJ I-295	50	50	94.7	93.6	66.3	39.3
NJ I-280	50	50	69.6	68.2	44.4	13.1
NJ I-287	50	50	86.0	84.0	68.4	23.3
TN SR 840	70	60	90.3	67.8	91.0	33.6
All Passive Sites			15.3	20.6	34.1	73.5

KEY FINDINGS

Studies were conducted in four regions of the U.S. to determine whether driver opinions, perceptions, and behaviors related to the risk of violating traffic laws in work zones differ depending on whether work zone enforcement practices in a region are primarily passive or active. Both driver opinion surveys and field studies in work zones with and without enforcement vehicles located on the shoulder were conducted. Two of the regions studied emphasized active enforcement efforts within its work zones; in the other two regions, passive enforcement was provided in work zones primarily to increase visibility and driver awareness of downstream hazards.

The results of the surveys indicate that drivers do indeed realize how enforcement is being used in a particular region, especially if it is for visibility and attention-getting purposes. Compared to the responses from the active enforcement regions, significantly higher percentages of drivers in the passive enforcement regions believed that enforcement personnel sitting in a work zone with its lights were there for attention-getting purposes than did those living in regions where active enforcement activities in work zones were emphasized. In contrast, a greater percentage of drivers in the active enforcement regions believed the officer had just finished writing a citation. However, although drivers were aware of how enforcement personnel were behaving in work zones, this did not translate to a difference in how drivers perceived how they reacted when they encountered an enforcement vehicle in a work zone. In fact, the type of region (indicative of the type of enforcement used in work zones) had much less of an effect on driver's response to this question than did their age, education, and opinion about the reasonableness of work zone speed limits posted in their region. These variables were also more important than type of work zone enforcement practiced in the region in determining how distracting an enforcement vehicle was when located in a work zone.

The results of the field studies in each region further support the contention that drivers do not react differently when encountering active or passive enforcement vehicles in work zones. At work zones in both types of regions (active or passive enforcement practices emphasized), an enforcement vehicle generally resulted in an additional 4 mph drop in average speeds just downstream of the enforcement vehicle. Likewise, the percent of vehicles not compliant with the work zone speed limits dropped substantially, and standard deviation of speeds was reduced when the enforcement vehicle was present (but only slightly).

The field study results support comments received by several survey participants who resided in regions where passive work zone enforcement efforts were emphasized. Those participants indicated that although they were aware that the enforcement vehicle was not likely to pursue them if they were exceeding the posted speed limit, the enforcement vehicle were present to raise driver attention about a downstream hazard and so the participant was likely to reduce their speed anyway. It should also be noted that while a highway agency may work with law enforcement to provide passive enforcement presence when so desired in a work zone, this does not preclude that enforcement agency (or other enforcement agencies in the region) from continuing to perform its regular enforcement activities in that work zone as part of its overall monitoring program for its jurisdiction. In other words, drivers in regions emphasizing passive enforcement efforts in work zones may not be completely sure that an enforcement vehicle would not pursue them and issue a citation (although the driver may believe that the probability of that occurring is relatively low).

CHAPTER 3 ENFORCEMENT EFFECTIVENESS FOR QUEUE-END PROTECTION

INTRODUCTION

A number of states have used enforcement in a traffic-calming manner, where the enforcement vehicle and officer are positioned on the side of the road with lights flashing, in an attempt to improve work zone safety by reducing speeds and improving driver vigilance and behavior as vehicles approach work zones where traffic queues have developed. Even though transportation and enforcement agencies that use these techniques are generally positive about their perceived effects, little objective data have been collected to quantify its actual effectiveness on safety.

OBJECTIVE

The objective of this research effort was to investigate the effects of using an enforcement officer and vehicle in a traffic-calming mode upstream of work zones where traffic queues develop on the speed, deceleration, and erratic maneuvers of traffic approaching the traffic queue. Changes in these measures-of-effectiveness (MOEs) serve as indicators of the potential improvement in safety that could be achieved by the use of enforcement when traffic queues are anticipated at the work zone.

METHODOLOGY

Overview

Researchers traveled in 3-person teams to work zone locations where state DOT and law enforcement agencies were willing to participate in the study and could provide a suitable project site for evaluation. A suitable project was one where a temporary lane closure was expected to create a traffic queue for some period of time. Each work shift, the three-person research team positioned themselves at approximate 0.25 to 0.5 mile intervals (creating a 0.75 to 1.5 mile data collection region) upstream of the lane closure. The researchers used hand-held lidar devices and “locked” onto a selected vehicle approaching the traffic queue that had developed. The lidar then fed speed and distance measures once or twice per second to a laptop connected to the lidar through a serial communication cable. Back in the office, researchers normalized the distances and speed measurements to a point at which it was judged that the vehicle had slowed down and joined the queue (setting that corresponding distance as “zero”). In this way, a decelerating speed profile was developed for each vehicle as it approached the traffic queue. As queues lengthened and shortened over time due to normal fluctuations in traffic demand, the research team had to “hopscotch” backwards and forwards, attempting to keep someone within a reasonable distance of the upstream end of queue so as to maximize the collection of vehicle speeds. These speed data were obtained for a period of time at each site when no enforcement was present, and again when a law enforcement vehicle and officer were positioned upstream of the queue. The intent was to develop a with-without enforcement comparison at each site. Comparison of speeds at various distances upstream of the queue and deceleration rates approaching the queue between the no-enforcement and enforcement-present conditions would allow the researchers to assess the relative effectiveness of this enforcement strategy.

Unfortunately, researchers encountered a number of difficulties in carrying out this experimental plan. Years ago, when work activities tended to be scheduled strictly during daylight hours, work sites on higher-volume roadways regularly experienced queuing, which would have made site identification and data collection efforts for this project relatively simple. However, with the increased emphasis on minimizing work zone impacts to road users, many state DOTs have now moved most work activities that may create traffic congestion to nighttime hours when traffic volumes are lower. Although the creation of traffic congestion and queuing still occurs occasionally in a few locations, it is much less frequent and predictable these days, which made it extremely difficult to locate suitable study sites nationally.

Another impediment to this data collection methodology was the lack of available advance notice as to when a potential project location/work activity might occur that would allow testing of this enforcement strategy. Often, state DOTs were aware of work activities that "might" create congestion when lane closures were in place, but were unable to identify with any certainty when such lane closures might be required. Contractors often provided a general timeline of their plans (including when lane closures will be needed), but these plans could change significantly in time depending on weather, productivity rates, equipment problems, etc. Consequently, only a few types of projects were available that offered a reasonable chance of having a lane closure once the data collection crew made arrangements to travel to that particular site.

A third significant impediment to data collection efforts was the reluctance on the part of some state DOTs to use law enforcement in a "part-time present, part-time not present" manner. To some states, this testing protocol created a perception of increased agency risk (a common question was "what if something happens while the officer is away from the work area?"), and resulted in some non-participation. This was particularly true of locations that typically use enforcement personnel immediately upstream of a work crew. A suggestion to utilize a second enforcement crew that could be moved around (and occasionally removed) upstream was not perceived any more favorably because of the challenges in obtaining enough enforcement officers to cover the work that was already underway.

One final issue encountered with the data collection process for this study was the ability of researchers to effectively track and collect speeds over the entire deceleration process approaching a traffic queue. Often, drivers changed lanes, passed next to large trucks, and made other maneuvers as they decelerated that made it very difficult for researchers to maintain a constant lidar lock on the vehicle. Consequently, many more efforts were initiated to collect speed profiles at each site than are documented below, but were ultimately not usable in the analysis.

Site Descriptions

Despite these substantial impediments and after months of contacts and re-contacts of officials in several states, researchers were finally able to locate and conduct studies at five locations:

- I-5 southbound at Williams, CA;
- I-35 northbound just prior to the I-35E/I-35W split in Hillsboro, TX;
- I-390 northbound in Rochester, NY;
- I-490 eastbound in Rochester, NY; and
- I-86 eastbound at Painted Post, NY.

I-5 Southbound, Williams, CA

The site was located on I-5 four miles north of Williams, CA (approximately 50 miles north of Sacramento, CA). The study site was on I-5 in the southbound direction. At this location, the interstate is a four-lane facility. The normal speed limit on this facility is 70 mph, and was not reduced through the work zone. The work zone consisted of a lane closure (right lane) for a length of about 1000 feet.

The study was conducted over a three-day period in June 2007. Upon traveling to the study site, the researchers found that traffic on the I-5 corridor was much lighter than expected for the study, and so the formation of queues in the lane closure was rather sporadic. This resulted in very few opportunities to collect speed profiles when congestion was present. Figure 1 illustrates the study site.

Over the three days, only 235 speed profiles were obtained where the vehicle speed reduced by at least 10 miles per hour, and only 30 were obtained where speeds dropped to 20 mph (considered indicative of a true queued condition). A California Highway Patrol vehicle was positioned near the start of the lane closure for the entire duration of the study. At this site, the officer was reluctant to leave the area, even for a short period of time to allow without-enforcement data to be collected. However, there were occasions when the vehicle departed for a few minutes. Consequently, approximately 80 percent of the speed profiles were collected when the highway patrol car was present at the scene and the remaining 20 percent of the profiles were obtained without law enforcement officer presence. Of those 20 percent of the speed profiles, none occurred during times where traffic congestion and queuing were present and so could not be used to directly compare speeds between an officer-present and an officer-not-present condition. No unusual or erratic maneuvers were recorded during the three days of data collection at this site.

Figure 1. Enforcement Vehicle at I-5 Study Site near Williams, CA.

I-35 Northbound, Hillsboro, TX

At this study site, data were collected in conjunction with night work activities that necessitated a lane closure in August 2007. Considerable queuing developed at this site, and data were collected with an enforcement vehicle located upstream and also when the enforcement vehicle was not present. I-35 in this location consists of two 12-ft lanes in each direction. The speed limit upstream of the work zone is 70 mph, but was reduced to 60 mph through the entire work zone, which extended several miles upstream of where the lane closure was positioned.

Although no unusual or erratic maneuvers were identified by data collection personnel at this site, the location of the upstream end of the queue changed very quickly during the closure. This made it extremely difficult for the data collection crew to maintain suitable positions upstream of the queue where speed profiles of vehicles approaching the queue could be obtained. Furthermore, some difficulties were encountered in coordinating the location of the officer (when present) to maintain a presence approximately 0.25 miles upstream of the end of queue as desired. In a few instances, the officer would establish a position upstream of the queue, only to have the queue quickly propagate upstream beyond the location of the officer. Then, as discussions about having the officer move were occurring, the queue would dissipate and the officer would again be upstream of the queue. In some instances, the end of queue moved over a mile in a very short period of time.

Figure 2 illustrates this work zone. A total of 61 usable speed profiles were obtained from this site, all of which occurred when a law enforcement officer was present (the officer was reluctant to leave the work area, even for a few minutes at a time). Consequently, it was not possible to directly compare driver behavior at this site when an officer was present to a no-officer condition. Once again, the data collection team did not identify any erratic maneuvers occurring during either the enforcement-present or the enforcement-not-present conditions.

Figure 2. Traffic Queuing at the I-35W Site near Hillsboro, TX.

I-390 in Rochester, NY

The third study site was on I-390 in the north bound direction just north of Exit 16 in Rochester, NY. I-390 was a 6 lane facility in this section with 3 lanes in each direction. The work zone consisted of a lane closure (left lane) followed by a lane shift to the left to facilitate work in the rightmost lane. The on-ramp immediately upstream of the work zone was about 2,000 feet south of the lane closure. There was an off-ramp immediately downstream of the work zone. The normal speed limit on this facility is 55 mph, but was stepped down to 45 mph in the work zone. The study was conducted over three days at this location in August 2007. Figure 3 illustrates the study site.

This location proved to be the only site where researchers were able to obtain speed profiles of vehicles approaching a queue when an officer was present upstream and when the officer was not present upstream. Unfortunately, intermittent rain over the data collection period may have partially influenced driver behavior both with and without enforcement present. Over the three-day period, researchers collected 63 speed profiles when law enforcement was present upstream of the queue and 26 profiles when enforcement was not present.

Figure 3. Vehicles Approaching I-390 Site in Rochester, NY Prior to the Onset of Queuing.

I-490 in Rochester, NY

The other site in Rochester was on I-490 in the east bound direction. I-490 is a 6 lane facility in this section with 3 lanes in each direction. The work zone consisted of a lane closure (left lane). The on-ramp immediately upstream of the work zone was about 3,600 feet west of the lane closure. There is an off-ramp (Exit 10) just at the beginning of the work zone. The speed limit on I-490 was 65 mph approaching the study site, and was dropped to 45 mph through the work zone. Figure 4 illustrates the study site.

Figure 4. Traffic Queuing at the I-490 Study Site in Rochester, NY.

The study was also conducted during the mornings, noon, and evenings in August 2007. Generally speaking, queuing developed during the peak periods, allowing researchers to measure speed profiles of vehicles decelerating as they approach the queue. Unfortunately, an officer was often not present at the site when a queue developed at this location (their decisions to arrive and leave the site were not under the control of the data collection team). Consequently, only 3 speed profiles were captured during the time a queue was present and an officer was located upstream of the queue. On the other hand, the data collection team obtained 53 speed profiles. Once again, no erratic maneuvers were documented by the data collection team.

I-86 in Painted Post, NY

The fifth site, I-86 in Painted Post (south of Rochester, NY), was located in the east bound direction of travel. I-86 at this location is a 4 lane facility with 2 lanes in each direction. The work zone consisted of a lane closure (right lane) to facilitate construction in the rightmost lane. An on-ramp was located 4,500 feet upstream (west) of the lane closure. The normal speed limit on I-86 was 65 mph, which was also reduced to 45 mph within the work zone. The study was conducted during the mornings, noon and the evening peak in August 2007. Traffic volumes at this location were very light most of the time (as suggested in Figure 5). Overall, 65 speed profiles of decelerating vehicles were obtained at this site. Unfortunately, none occurred during the times that an officer was present at the site (officer arrival and departure times each day were dependent on their availability).

Figure 5. Traffic Conditions at the I-86 Study Site in Painted Post, NY.

Data Reduction and Analysis

After each field study, researchers downloaded and collated the individual electronic speed profile files according to times when the officer was or was not present at the site. All profiles obtained during each time period were then manually reviewed to determine if they provided continuous speed tracking of a vehicle down to a speed of 20 mph or lower. As described previously, researchers selected 20 mph as the indicator that a vehicle had joined the traffic queue, and normalized all distance measurements relative to the location at which the vehicle first reached that 20 mph threshold.

For example, Figure 6 presents a plot of the speed profiles collected when enforcement was present and queuing occurred at the I-5 site in Williams, CA. The duration of the queuing was usually fairly short, limiting the number of speed profiles generated. Furthermore, no queues developed when enforcement was not present, so data only exists for the with-enforcement condition. As can be seen in the figure, only a few vehicles could be tracked from as far as 1500 feet upstream of the queue until that vehicle reached the queue. Generally, data collectors were most successful with tracking vehicles in the last 700 feet approaching the queue.

Overall, the profiles show considerable variability in deceleration behavior of drivers. A few motorists appeared to decelerate nearly 1,000 feet upstream of the queue, whereas others waited until they were within 300 or 400 feet of the queue. In general terms, though, the more common trend was for motorists to begin their deceleration approximately 500 to 600 feet upstream of the queue and decelerate at a fairly consistent rate until they had reached the 20 mph operating speed of the queue. Interestingly, it is in this same 500-to-600-foot region where the variability of traffic speeds appears to be the greatest.

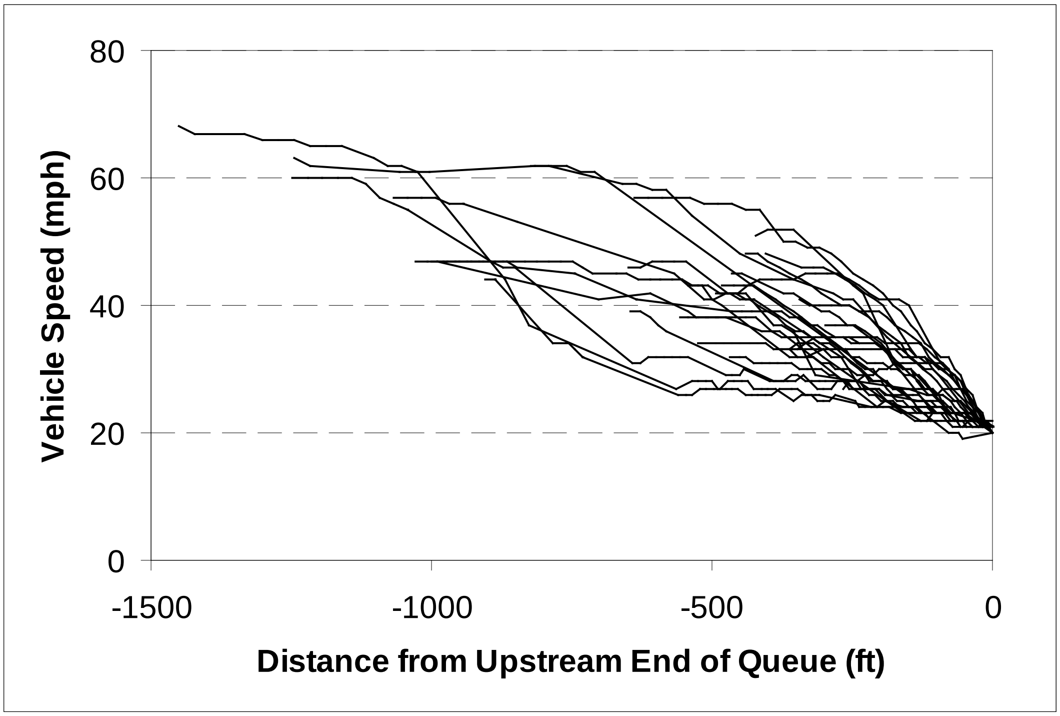


Figure 6. Speeds Approaching the Queue when Enforcement was Present at the I-5 Site.

The speed profiles collected when enforcement was present at the I-35 site are presented in Figure 7. At this site, the researchers had slightly better vantage points available and so could track more of the approaching vehicles for a longer distance (i.e., 1,000 feet or more). Generally speaking, the trends in Figure 5 are replicated in Figure 6. If anything, the region where the variance in speeds is highest may extend a little farther upstream in Figure 6, encompassing the entire 500-1,000 feet range upstream of the queue. At this site, researchers did record a few instances where vehicles waited until relatively close (i.e., less than 500 feet) from the queue before decelerating. Many drivers, though, initiated deceleration more than 500 feet upstream of the queue, and decelerated gradually and continuously until they reached the 20 mph threshold that indicated the start of the queue.

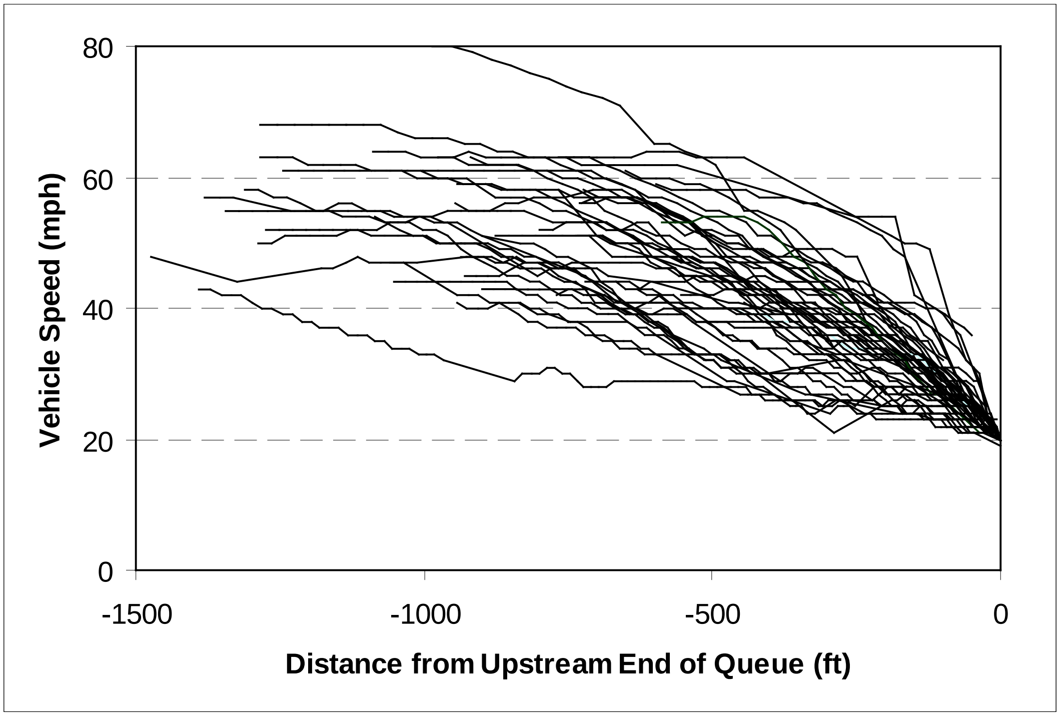


Figure 7. Speeds Approaching the Queue when Enforcement was Present at the I-35 Site.

The speed profiles from the I-390 site are illustrated graphically in Figures 8 and 9 for the with-enforcement and without-enforcement conditions, respectively. This is the first site where no-enforcement data were available, and thus where a direct comparison of the with- and without-enforcement conditions can be made. In general terms, it does appear that the speed profiles in both figures are fairly similar. The data collection team did capture a few more higher-speed vehicle profiles (i.e., speeds beginning at greater than 60 mph) within 1,000 feet of the queue when enforcement was present than when it was not present. However, the number of such vehicles was not enough to be considered significantly different. In both cases, the maximum variance in speeds appears to exist in the 500-600 foot range, just as in the previous speed profile plots. Likewise, it appears that most drivers initiated deceleration at about 600 feet upstream of the queue and decelerated gradually and continuously to 20 mph.

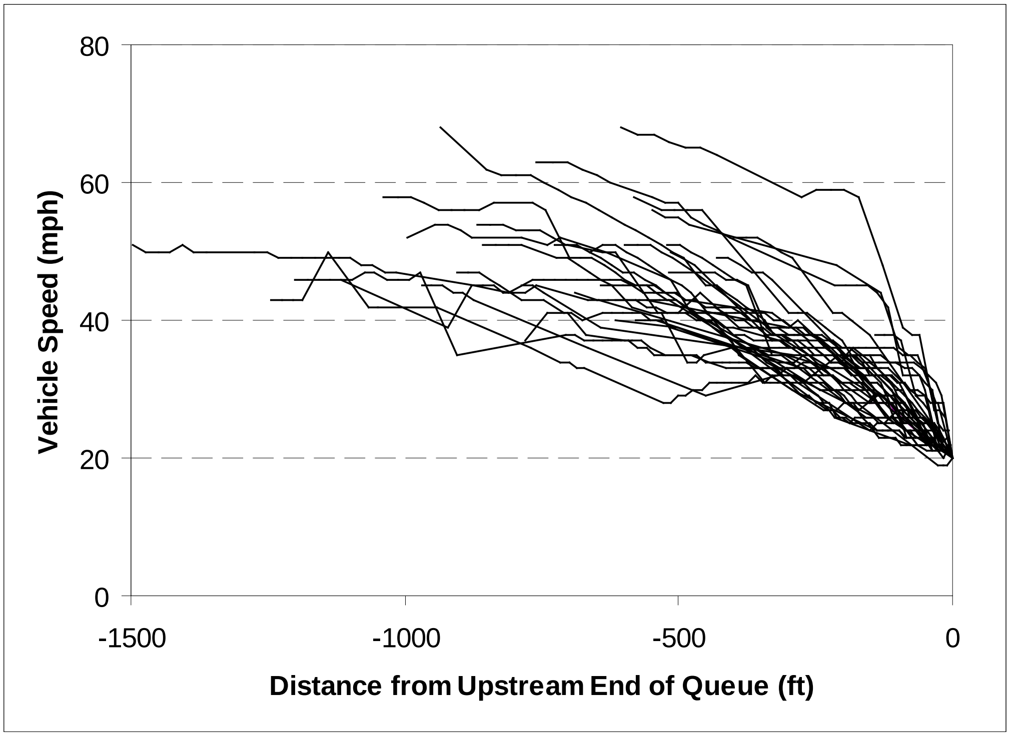


Figure 8. Speeds Approaching the Queue when Enforcement was Present at the I-390 Site.

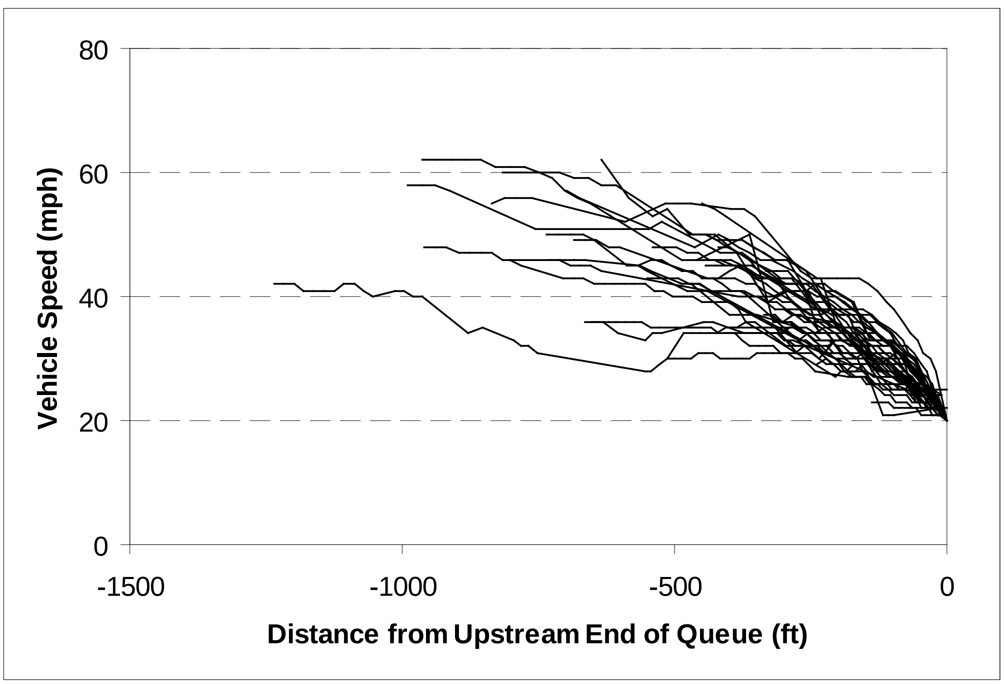


Figure 9. Speeds Approaching the Queue when Enforcement was not Present at the I-390 Site.

The speed profiles obtained from the I-490 site are depicted graphically in Figures 10 and 11. Although both the with-enforcement and without-enforcement conditions are presented, one sees that the data collectors were only able to obtain 3 usable speed profiles during the time that enforcement was present at the site and a traffic queue developed. In both figures, one once again sees the initiation of deceleration occurs in the 500-600 foot range, and that the region of maximum speed variance appears to be in that same distance range. It does appear that the amount of variability in speed profiles (at least in Figure 11) is slightly less than in the previous figures, but this again may be somewhat due to the lower number of usable profiles available at this site.

The speed profile for the I-86 site in Painted Post, NY is provided as Figure 12. At this site, law enforcement was never in place during the occasional times when a queue would develop. Consequently, speed profiles were available only during the times when enforcement was not present. At this site, it appears that vehicles began decelerating slightly farther upstream of the queue than at the other site, approximately 600-700 feet upstream. It was hypothesized that the presence of the work zone and traffic queue (when it developed) was visible from a slightly greater distance due to a flatter topography, a generally less demanding driving environment, and lower traffic volumes that reduced the frequency of vehicle occlusion of downstream conditions by large trucks.

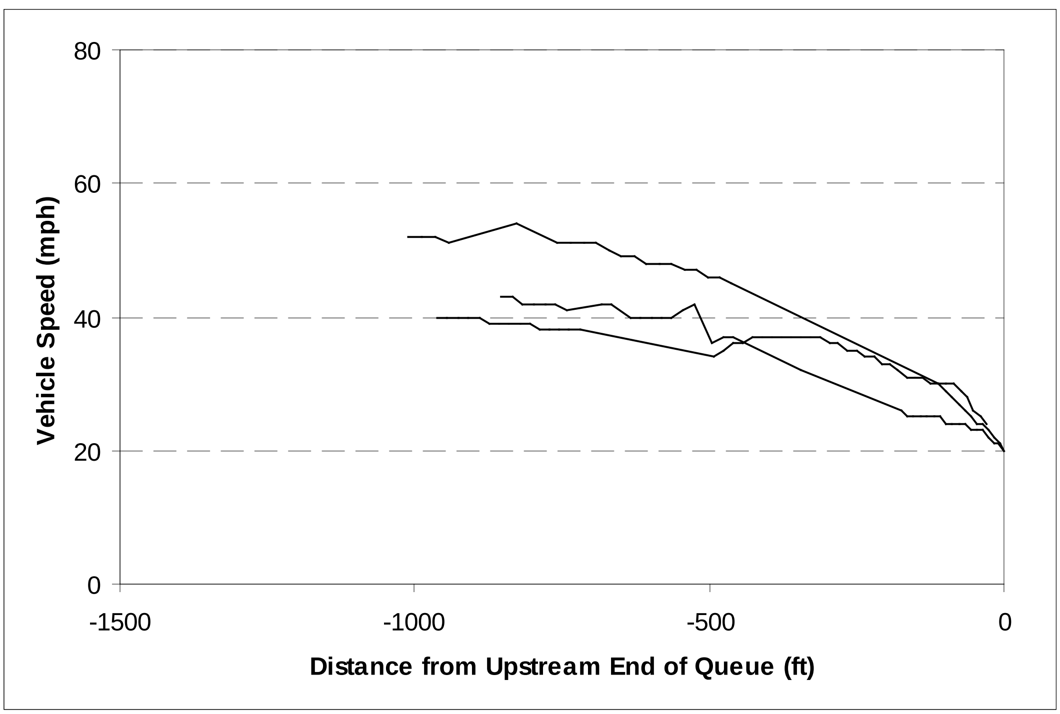


Figure 10. Speeds Approaching the Queue when Enforcement was Present at the I-490 Site.

Figure 11. Speeds Approaching the Queue when Enforcement was not Present at the I-490 Site.

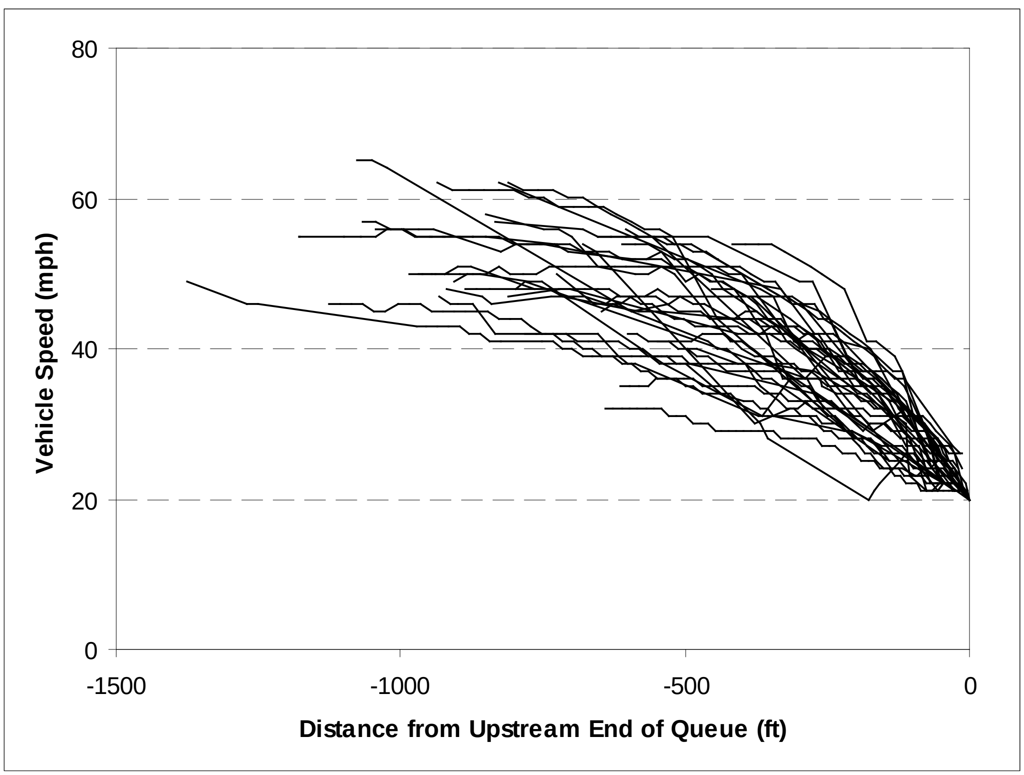


Figure 12. Speeds Approaching the Queue when Enforcement was not Present at the I-86 Site.

RESULTS

Effect of Enforcement Presence on Speeds

The limited sample sizes notwithstanding, the available data were analyzed to determine how enforcement presence may have influenced driver behavior approaching the upstream end of the queue. First, average speeds were computed at various distances upstream of the queue at each site. These values are provided in Table 18. The numbers in parentheses are the sample sizes available at each distance. In some cases, delays in lidar communication of speed and distance data to the computer created a significant gap in the speed profile. If the gap was less than 50 feet, speeds were simply extrapolated between points. However, if the gap was greater than 50 feet, no speed was estimated. Consequently, the maximum sample size at any one distance is typically less than the total number of available speed profiles from that site.

Examining the values in Table 18, one sees few clear trends. Average speeds at a 1000 foot distance upstream of the defined start of the queue were fairly consistent across four of the sites. At both the I-390 and the I-490 sites, the data collected when an officer was present upstream was slightly lower than when an officer was not present, which is consistent with expectations. Of course, it is a very small sample size of with-enforcement profiles at the I-490 site, and so the differences must be interpreted with caution. The overall trend across the sites is shown in graphical form in Figure 13. The heavy dashed line, indicating the average speed profile with enforcement present, is slightly below the heavy solid line that indicates the average speed profile without enforcement present. The thinner lines represent speeds at each site with and without enforcement. At farther distances upstream of the queue, considerable site-to-site variation in average speeds is evident, which implies that the difference in the two trend lines is not of practical significance.

Researchers attempted to further isolate the effects of driver speed reductions by normalizing each speed profile by setting the speed at 1000 ft away at a maximum equal to 100 (i.e., approach speed) and the speed at the queue at a minimum equal to zero (i.e., the vehicle has reached the queue speed). Presented in this way, the values shown in Figure 14 still imply only small differences between the with-enforcement and the without-enforcement conditions. One does see more of a relative speed drop farther upstream for the average "without enforcement" condition, but this disappears once vehicles are within 600 feet of the queue. However, this drop more likely indicates that vehicle speeds in the without-enforcement condition were initially a little higher, and decreased speeds a greater amount more as they recognized the slowdown in front of them.

Table 18. Comparison of Average Speeds of Vehicles Approaching the Queue, With and Without Enforcement Present

Distance Upstream of Queue[a]	I-5		I-35		I-390		I-490		I-86		All Sites Combined	
	With Enf.	W/O Enf.	With Enf.	W/O Enf.	With Enf.	W/O Enf.	With Enf.	W/O Enf.	With Enf.	W/O Enf.	With Enf.	W/O Enf.
1000 ft	52.4 (8)	---	52.5 (29)	---	50.5 (11)	53.7 (6)	45.0 (3)	48.4 (7)	---	51.4 (14)	50.1	51.2
700 ft	45.6 (9)	---	49.1 (43)	---	47.2 (17)	45.3 (11)	43.7 (3)	42.0 (12)	---	49.5 (22)	46.4	45.6
600 ft	41.5 (13)	---	46.8 (47)	---	46.3 (25)	46.0 (21)	42.0 (3)	41.9 (16)	---	46.0 (29)	44.2	44.6
500 ft	39.0 (16)	---	43.0 (50)	---	43.6 (34)	43.1 (28)	38.7 (3)	42.4 (27)	---	43.5 (32)	41.1	43.0
400 ft	38.3 (23)	---	39.6 (53)	---	40.2 (35)	41.6 (43)	39.7 (3)	39.9 (34)	---	40.0 (39)	39.5	40.5
300 ft	35.4 (24)	---	35.9 (55)	---	37.4 (31)	37.7 (57)	32.7 (3)	37.2 (54)	---	37.2 (49)	35.4	37.4
200 ft	31.8 (25)	---	33.4 (55)	---	33.5 (47)	34.1 (60)	29.7 (3)	33.4 (56)	---	33.4 (48)	32.1	33.6

() Numbers in parentheses are the available sample sizes at each distance at each site

[a] the start of queue was assumed to be where speeds dropped to 20 mph

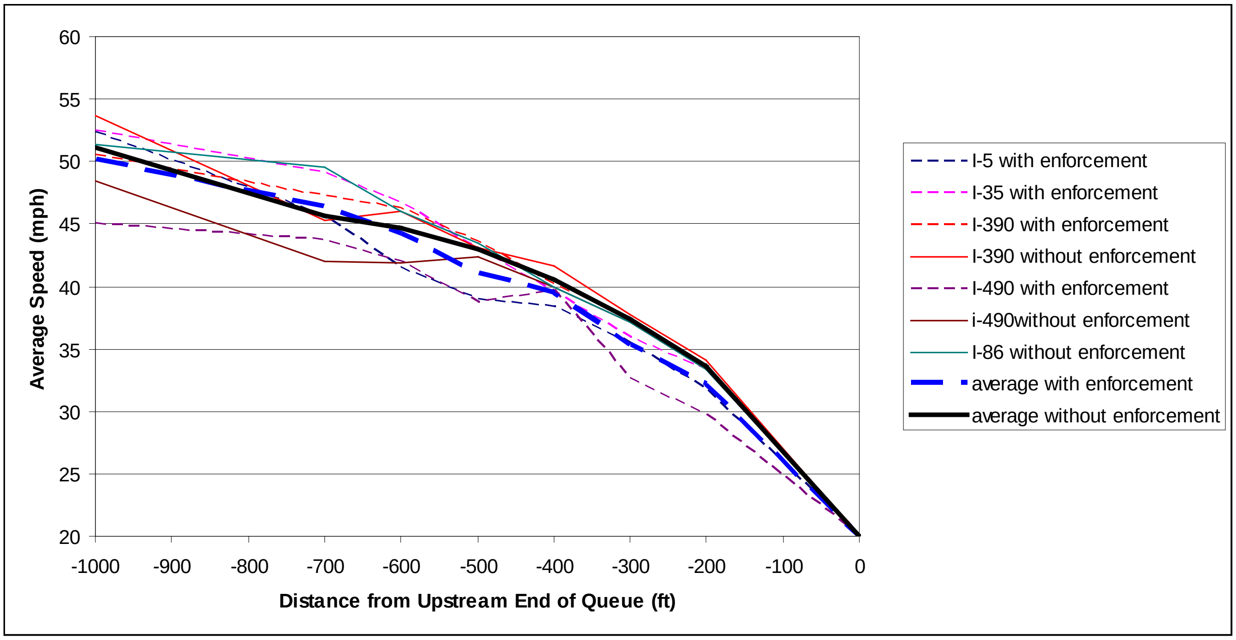


Figure 13. Average Speeds of Vehicles Approaching the Queue With and Without Enforcement Present.

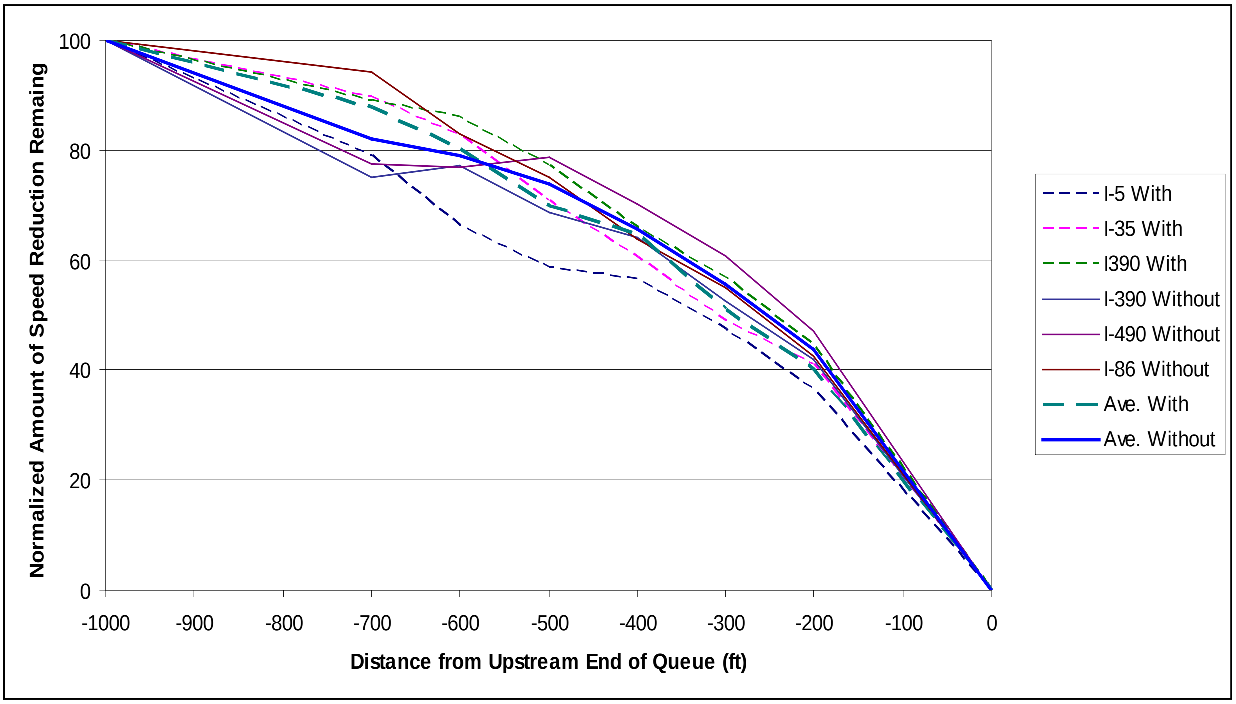


Figure 14. Normalized Reductions in Speed as Vehicles Approach the Queue With and Without Enforcement Present.

Next, the standard deviations of speeds extracted from the speed profiles were examined at various distances upstream of the traffic queue. These values are presented in Table 19. The lack of data for both with- and without-enforcement conditions at three of the sites again makes it difficult to draw any meaningful conclusions. At the I-390 and I-490 sites, it does appear that the with-enforcement condition at most of the upstream distances (other than the 300 and 200 foot distances at the I-390 site) is generally associated with slightly lower standard deviations than for the without-enforcement condition.

Effect of Enforcement Presence on Deceleration Rates

The speed profile data were also used to assess whether the presence or absence of enforcement upstream of a traffic queue had any measurable effect upon vehicle deceleration rates. As noted previously, the lidar unit downloaded speed and distance data several times per second. However, the lidar rounded the speed data to the nearest mph and to the nearest full second in the downloaded data file, which reduced the accuracy of the data in calculating deceleration or acceleration rates between each two lidar readings. To overcome this limitation of the equipment, each speed profile was divided into 100-foot segments and average deceleration rates were calculated for each segment. The average deceleration rates within each 100-foot region upstream of the traffic queue were then analyzed, as was the distribution of deceleration rates within 700 feet of the upstream end of the queue, and the distance from the traffic queue at which the maximum deceleration occurred.

With regards to the average deceleration rates, Table 20 presents values by site and consolidated across sites for both the with-enforcement and without-enforcement conditions. In all cases, the averages are very small, generally less than 2.5 feet/sec^2. As a comparison, recent studies of drivers approaching a stop-controlled intersection found average deceleration rates to be even higher, between 4.0 and 4.5 feet/sec^2 (*48*). Some site-to-site differences are evident, and the consolidated average deceleration rates at distances of 400 feet or farther upstream of the queue tend to be higher for the with-enforcement condition. However, once vehicles were closer to the queue, the average deceleration rates were very comparable between the with- and without-enforcement conditions.

Table 19. Comparison of Standard Deviations of Speeds With and Without Enforcement Present

Distance Upstream of Queue	I-5		I-35		I-390		I-490		I-86	
	With Enf.	W/O Enf.	With Enf.	W/O Enf.	With Enf.	W/O Enf.	With Enf.	W/O Enf.	With Enf.	W/O Enf.
1000 ft	6.9	---	10.0	---	7.4	8.0	6.2	6.7	---	6.0
700 ft	11.2	---	9.8	---	7.5	8.3	6.7	7.1	---	7.2
600 ft	9.7	---	9.6	---	8.0	8.4	5.3	6.8	---	7.5
500 ft	7.7	---	9.3	---	7.6	7.7	6.4	7.5	---	7.5
400 ft	8.1	---	8.0	---	6.2	6.9	4.6	6.7	---	7.3
300 ft	6.8	---	7.4	---	5.7	5.4	3.1	6.6	---	6.1
200 ft	5.9	---	7.0	---	6.2	4.6	3.5	6.5	---	5.2

() Numbers in parentheses are the available sample sizes at each distance at each site

Table 20. Average Deceleration Rates of Vehicles Approaching a Traffic Queue With and Without Enforcement Present.

Distance Upstream of Queue	Average Deceleration Rate (feet/second^2)											
	I-5		I-35		I-390		I-490		I-86		All Sites Combined	
	With Enf.	W/O Enf.	With Enf.	W/O Enf.	With Enf.	W/O Enf.	With Enf.	W/O Enf.	With Enf.	W/O Enf.	With Enf.	W/O Enf.
800-700 ft	-0.67 (3)	---	-1.44 (18)	---	-0.50 (4)	-2.00 (2)	-0.67 (3)	-0.80 (5)	---	-0.50 (4)	-1.00 (28)	-0.91 (11)
700-600 ft	-1.00 (4)	---	-2.69 (29)	---	-1.00 (4)	0.29 (7)	-1.33 (3)	-0.80 (5)	---	-0.67 (6)	-2.25 (40)	-0.33 (18)
600-500 ft	-1.14 (7)	---	-2.79 (33)	---	-0.67 (6)	-0.17 (12)	-1.33 (3)	-0.50 (8)	---	-0.80 (10)	-2.04 (49)	-0.47 (30)
500-400 ft	-1.09 (11)	---	-1.69 (39)	---	-2.00 (10)	-0.76 (21)	-2.00 (3)	-1.47 (15)	---	-1.43 (14)	-1.65 (63)	-1.16 (50)
400-300 ft	-1.30 (20)	---	-2.09 (46)	---	-1.56 (18)	-1.95 (42)	-1.33 (3)	-1.52 (25)	---	-2.32 (25)	-1.77 (87)	-1.96 (91)
300-200 ft	-1.84 (25)	---	-2.08 (52)	---	-1.71 (34)	-2.26 (62)	-2.00 (3)	-1.86 (42)	---	-1.70 (40)	-1.91 (114)	-2.00 (143)
200-100 ft	-2.47 (30)	---	-2.25 (55)	---	-2.12 (49)	-2.11 (72)	-2.367 (3)	-2.35 (52)	---	-2.52 (54)	-2.23 (137)	-2.30 (178)

The research team also examined the overall distribution of deceleration rates computed across the sites to determine if a higher percentage of larger decelerations occurred when enforcement was not present. It was hypothesized that the presence of enforcement upstream of the queue would increase overall driver attention and lead to fewer panic stops or hard braking actions in order to avoid a rear-end collision at the queue. Because of the limited number of profiles that could be obtained at each site, the cumulative distribution plots of deceleration rates by site and enforcement condition (provided in Figures 15 and 16) did show some variation. For example, the percentage of computed decelerations that equaled or exceeded 5 ft/sec^2 when enforcement was present ranged from a low of about 10 percent at the I-490 site to a high of 20 percent at the I-35 site. However, in both figures one sees that the vast majority of decelerations were less than this 5 ft/sec^2 rate. Furthermore, when all sites for each enforcement condition are combined and presented in a cumulative plot as in the previous figures, the with-enforcement and without-enforcement lines match almost exactly, indicating essentially no difference in deceleration behavior between these two conditions (see Figure 17). It should also be noted that AASHTO recommends 11 feet/sec2 as the maximum comfortable deceleration rate that is acceptable to drivers (*49*). From the figures below, it is clear that very few deceleration measurements in this study even reached that level.

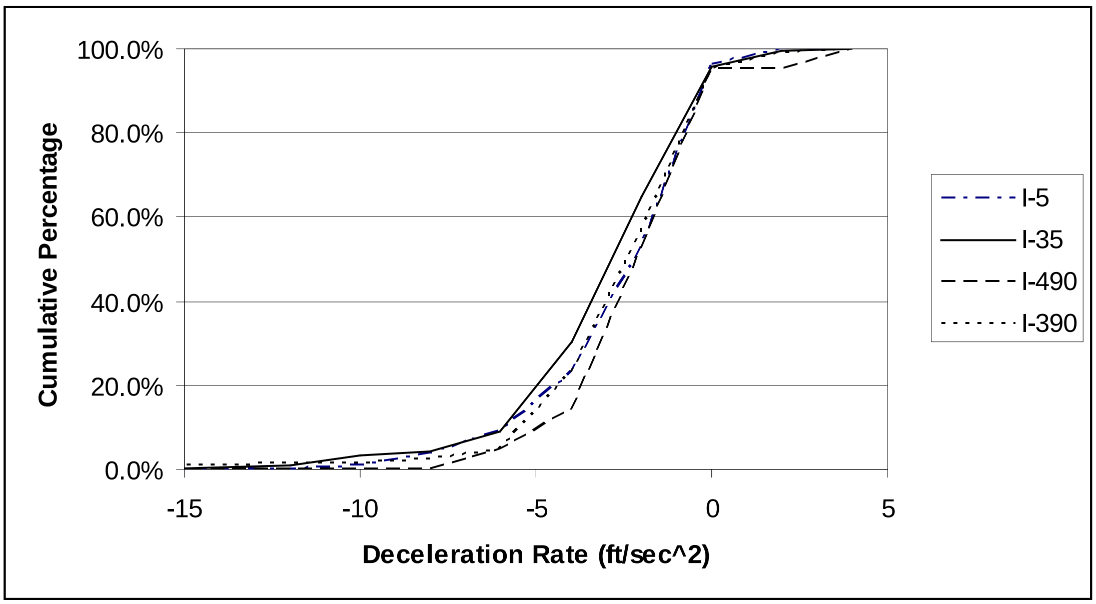


Figure 15. Distribution of Deceleration Rates by Site when Enforcement was Present.

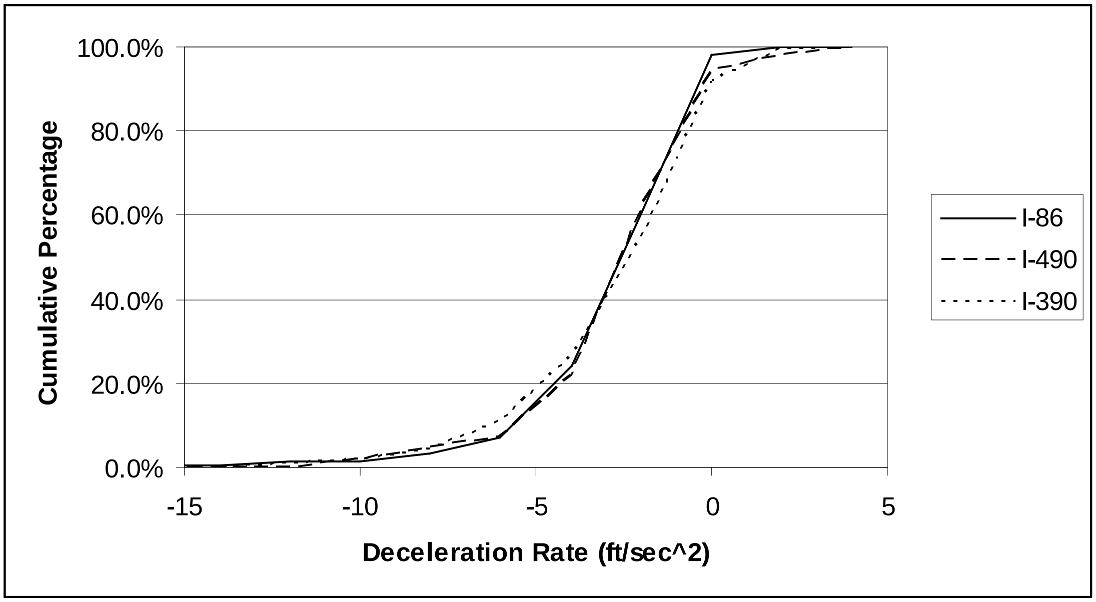


Figure 16. Distribution of Deceleration Rates by Site when Enforcement was not Present.

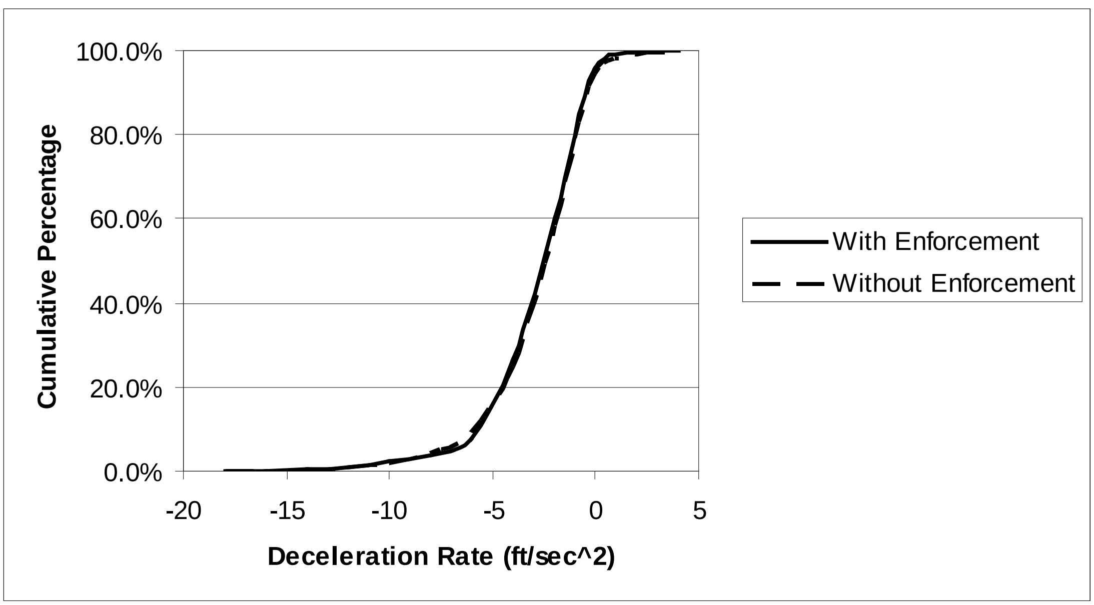


Figure 17. Distribution of Deceleration Rates With and Without Enforcement Presence.

The last measure examined was the distance from the queue where the maximum deceleration rate was observed in a particular speed profile. It was hypothesized that the presence of enforcement upstream of the queue may cause significant decelerations around the enforcement vehicle rather than closer to the upstream end of the queue. This would result in the higher decelerations occurring farther upstream of the start of the queue. The results of this analysis are provided in Table 21.

Table 21. Distance from Queue at Which Maximum Deceleration Occurs

Site	Average Distance, Ft	Standard Deviation, Ft	Sample Size
With Enforcement:			
I-5	360	177	20
I-35	448	201	55
I-390	405	182	29
I-490	350	141	2
All Sites Combined	418	192	106
Without Enforcement:			
I-86	293	162	45
I-490	318	183	31
I-390	344	165	31
All Sites Combined	315	169	109

To avoid unduly biasing the analysis towards those profiles that were very short (i.e., those where the researchers were only able to capture vehicle speeds the few hundred feet before the queue), researchers only used the speed profiles that had three or more 100-foot segments for which average deceleration rates could be computed. Again, substantial site-to-site variation is evident for both enforcement conditions. Considering the combined datasets, researchers found that the average distance where the maximum deceleration rate occurred was slightly higher for the with-enforcement conditions (consistent with researcher expectations). However, the difference was not enough to be considered statistically significant at a 0.05 level of significance.

The potential effects of enforcement presence on more severe braking maneuvers is examined in Figure 18, which illustrates the percentage of decelerations computed in each distance interval that were higher than 8 feet/sec^2. These are the upper range of what drivers typically use in non-emergency situations, as well as those used for emergency braking maneuvers (greater than 11 feet/sec^2) (*49*). Farther upstream of the traffic queue, these severe decelerations were more frequent during periods when enforcement was present. At distances 600-700 feet upstream of the queue, nearly 8 percent of all decelerations computed in this interval when enforcement was present exceeded 8 feet/sec^2. Whether these decelerations were the result of drivers attempting to slow down dramatically as they passed the enforcement vehicle on the side of the road is unknown (but is certainly a plausible explanation for these decelerations). In contrast, none of the decelerations that occurred when enforcement was not present exceeded this threshold at those distances. Then, at distances 200 to 400 feet upstream of the queue, the percentage of decelerations that exceeded the 8 feet/sec^2 threshold was higher when enforcement was not present. This suggests that the presence of enforcement may be shifting the higher deceleration rates farther upstream and (presumably) would reduce the chance of a rear-end crash at the upstream end of the queue. However, the percentage of these higher decelerations when enforcement was present was also slightly higher (relative to the without-enforcement condition) in the 100-200 feet upstream of the queue. Consequently, it is not clear whether the enforcement presence had any measurable effect on deceleration rates at all. In fact, the far right columns of Figure 18 present the percentage of all measured decelerations that exceeded 8 feet/sec^2, both when enforcement was present and when it was not, regardless of where the deceleration actually occurred. Overall, the percentages are essentially the same.

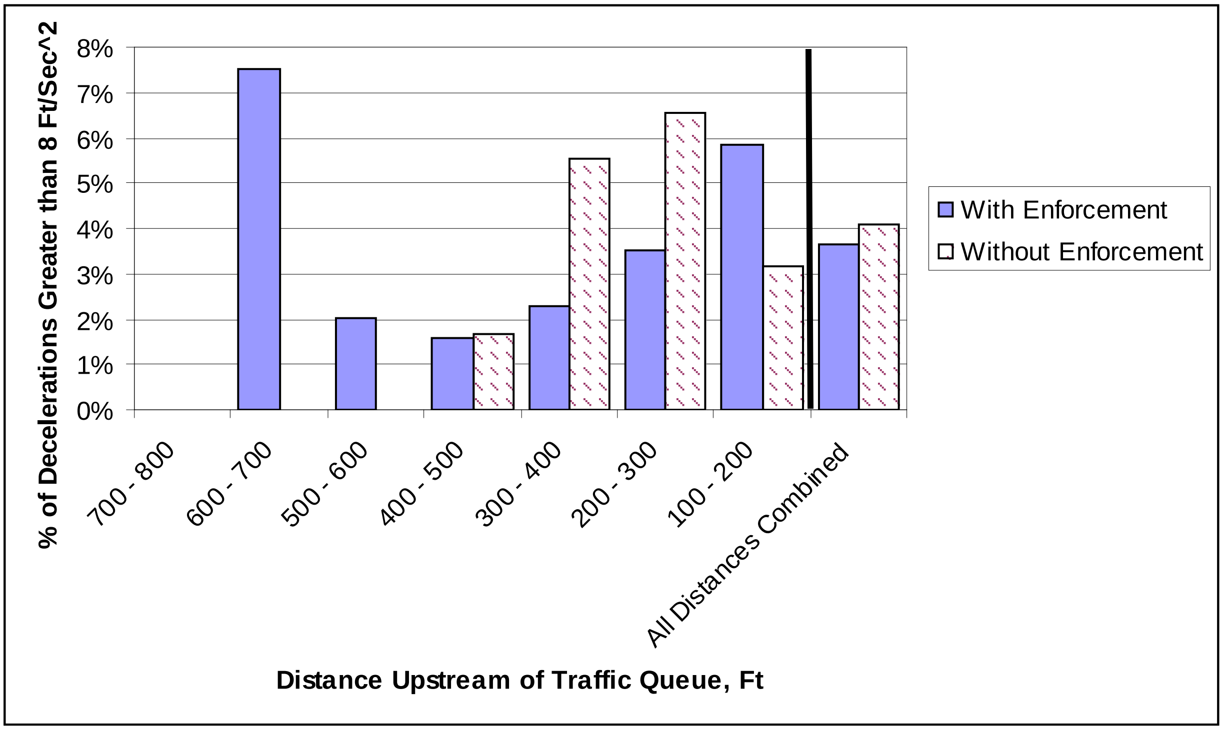


Figure 18. Effect of Enforcement Presence on Severe Decelerations Upstream of the Traffic Queue

SUMMARY

Taken together, these results still paint a rather inconsistent picture as to the effect of enforcement presence upstream of traffic queues due to lane closures. The data do not suggest that the strategy is totally ineffective, but neither do the data indicate that it consistently results in traffic behavior that could be taken to suggest that safety is dramatically improved. The primary cause of this lack of conclusiveness is the high degree of variability in the data caused by the need to consolidate across study sites rather than matching data with and without enforcement at each site as originally planned.

The inconclusive positive results notwithstanding, it should be noted that no adverse behaviors or events associated with the use of enforcement personnel and vehicles in this application were observed during these studies. Despite some concerns expressed that enforcement may be overly distracting and lead to a higher likelihood of erratic maneuvers as drivers decelerate rapidly to avoid rear-end collisions with traffic already in the queue, no evidence of this type of response was detected at any of the sites where data were collected. Furthermore, there is ample evidence in the literature that drivers do indeed slow down when encountering a stationary enforcement vehicle. While it does appear safe at this time to suggest that the practice of using enforcement for queue-end protection is a reasonable alternative, a different analytical approach (perhaps based on crash data or other operational data collection and analysis techniques) will be needed to actually quantify any benefits associated with this strategy.

CHAPTER 4 ASSESSMENT OF POTENTIAL CRASH COST REDUCTIONS DUE TO ENFORCEMENT USE IN WORK ZONES

INTRODUCTION

Ideally, work zone enforcement would best be used where its benefits equal or exceed the costs of providing that enforcement. Intuitively, the benefit of using enforcement in a work zone is an improvement in safety in terms of reduced work zone crash costs (although there may be some situations where the traffic-calming effect of enforcement could improve traffic flow and result in a reduction in motorist delay costs). Unfortunately, it is difficult to assess the crash cost reductions due to enforcement with any certainty. The extent to which enforcement can influence driver behavior (and ultimately safety) depends on many site-specific factors such as:

- the type of enforcement strategy being employed;
- the number of travel lanes, traffic volumes, percentage of local and non-local motorists, and vehicle mix on the facility;
- the difference between the work zone speed limit that is posted and the current operating speeds of drivers; and
- the type and amount of public information disseminated about the work activity, traffic conditions, and associated enforcement efforts.

Other work zone factors may also influence enforcement effects on motorists. Despite these challenges, a generalized economic analysis of the potential crash cost reductions that could be achieved through the provision of enforcement in work zones is possible.

It must be emphasized here that these analyses should be considered as a general guide, a starting point for decision-makers regarding the types of conditions under which the use of enforcement may prove cost-effective. It is difficult to predict with any certainty the crash costs expected for a particular work zone. Current crash prediction models generally use traffic volume, roadway type, and maybe one or two road geometric variables as independent variables. In reality, many other site characteristics can ultimately affect the likelihood and severity of a crash occurring at a location. Add to this the fact that decisions regarding how a particular work zone is set up or moved along the roadway can likewise influence crash frequency and severity, and one can see that the potential exists for large deviations from an “average” estimate. Consequently, the results of the analysis only provide order-of-magnitude indications of anticipated crash cost values.

COMPUTATION OF CRASH COSTS

Overview

A series of crash prediction models previously developed from another research study of daytime and nighttime freeway work zones was utilized in this analysis (*50*). These data reflect the best current estimates of the impacts of freeway work zones on crash costs, and were developed in the form of crash modification factors to crash frequencies expected under normal conditions (e.g., when a work zone is not present). The expected crash frequencies were estimated through the formulation of freeway safety performance functions (SPFs) from several states. Recent cost estimates of traffic crashes were then applied to the predicted crash frequencies to yield expected crash costs.

Methodology

Currently, most efforts to predict crash frequencies on a given roadway segment or to estimate the effectiveness of a particular countermeasure in reducing crash frequencies rely on empirical Bayesian (EB) techniques. EB techniques increase the precision of estimation and correct for regression-to-the-mean bias (*51*). The technique involves the creation of a safety performance function (SPF), based on data from several roadway segments as a reference group, to provide a generalized estimate of the expected crash frequency as a function of roadway type, geometric features, and traffic volumes. In the absence of site-specific crash data, these SPFs are the estimated crash frequency expected on a given type of facility over a given time period.

For freeway facilities in four states (California, North Carolina, Ohio, and Washington), separate SPFs were initially estimated for daytime and nighttime periods (6 am to 7 pm and 7 pm to 6 am) on freeways with 4 or 5 lanes, 6 or 7 lanes, and 8 or more lanes. The SPFs were negative binomial (NB) regression models (consistent with the state of the art in the safety field) developed with crash frequency as the dependent variable and site characteristics as independent variables. The analysis focused on total injury and fatal crashes and total property damage only (PDO) crashes. The model form was log-linear. With this model form, the expected crash frequency is related to the independent variables as follows:

$$Y = L * \exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + ...\beta_n X_n) \quad (1)$$

where:

Y is the expected frequency of crashes per year;

L is the length of the section (miles);

X_1 through X_n are independent variables (e.g., traffic volume shoulder width, etc.); and

β_0 through β_n are coefficients that need to be estimated.

In a negative binomial model, the variance is related to the mean as follows:

$$Var(y_i) = E(y_i) + k(E(y_i))^2 \tag{2}$$

where:

$Var(y_i)$ is the variance,

$E(y_i)$ is the mean, and

k is the dispersion parameter.

Models were estimated using PROC GLIMMIX in Statistical Analysis Software (SAS).

The SPF model coefficients developed through that effort can be found in the project documentation (*50*). These SPFs represented normal non-work zone conditions. A series of crash modification factors (CMFs) were then applied to these models to account for the increased crash risk that exists when a work zone is in place. Separate CMFs were developed for daytime and nighttime periods, and for each of the three following work periods:

- work activity occurring in the work zone, temporary lane closures in place;
- work activity occurring in the work zone, no temporary lane closures in place; and
- work zone inactive, no temporary lane closures in place.

The CMFs were developed for injury and fatal crashes, for property-damage-only (PDO) crashes, and for all crash severity types combined. The work zone CMFs are presented in Table 22. Generally speaking, the CMFs are higher for PDO crashes than for injury and fatal crashes. For inactive and active work zones when temporary lane closures are not in place, the nighttime CMFs are slightly higher than the daytime CMFs. However, when work activity with a temporary lane closure is required, the CMFs are approximately equal for both time periods, and are higher than for the other two work zone conditions. Multiplying the appropriate CMF by the SPF provides an estimate of the crash frequencies expected on a given type of roadway for a given work zone condition.

Table 22. Freeway Work Zone Crash Modification Factors (*48*).

Work Zone Condition	Crash Modification Factor (CMF)	
	Nighttime	Daytime
Work Zone Active with Temporary Lane Closures[a]:		
PDO Crashes	1.748	1.808
Injury and Fatal Crashes	1.423	1.455
All Crashes Combined	1.609	1.663
Work Zone Active without Temporary Lane Closures:		
PDO Crashes	1.666	1.398
Injury and Fatal Crashes	1.414	1.174
All Crashes Combined	1.577	1.314
Work Zone Inactive without Temporary Lane Closures:		
PDO Crashes	1.330	1.196
Injury and Fatal Crashes	1.114	1.051
All Crashes Combined	1.237	1.127

[a] It is assumed that these crash modifications can also be used to characterize the increased crash risks that exist at mobile operations when located in an actual travel lane

The crash frequencies estimated using the appropriate SPF and work zone CMF were then multiplied by a per-crash cost value. The following recent crash cost values on facilities with operating speeds of 50 mph or higher were used (*52*):

- injury crash (fatality or injury) – $206,015 and
- PDO crash – $7,800.

The computations yielded estimates of the crash costs per year's worth of exposure under each work zone condition as a function of roadway average annual daily traffic (AADT). These yearly costs ultimately were then converted to an hourly cost to allow comparison to costs of enforcement on an hourly basis. Researchers recognize that, especially for active enforcement efforts that are intended to result in improved driving behaviors at all times, there are crash cost reductions (theoretically) even during times when enforcement personnel are not present. However, it is believed that the improvement in driving behavior is greatest during times when enforcement personnel are present and visible, and so a comparison of costs to actual hours of enforcement being provided is a worthwhile (and conservative) assessment.

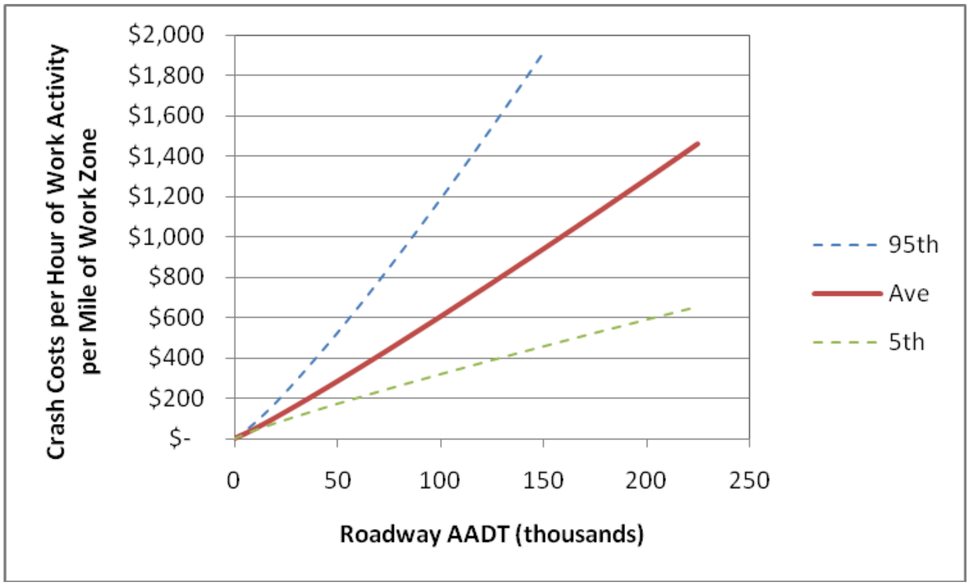
For the freeway SPFs, the resulting hourly crash costs computed from the individual functions were so similar that it became unnecessary to retain separate functions by number of lanes and adjacent land use (rural versus urban). Consequently, a generalized function relating work zone crash costs per hour versus roadway AADT was developed for freeways, irrespective of the number of lanes on the freeway. Functions were estimated for the best-fit SPF model parameters and multiplied by the CMFs associated with work zones and crash cost values. Next, researchers approximated the 5th and 95th percentile values using the standard errors of both the SPF parameters and CMFs.

Initially, the intent was to replicate this process using SPFs for other roadway types as well, based on recent research in support of the upcoming release of the *Highway Safety Manual* (*53*,*54*). However, given that there are currently no good work zone CMFs developed for any roadway types other than freeways, the value of such an assessment would be very limited. In addition, since freeways typically experience the lowest crash rates (but highest crash severities) of the various road types, an evaluation of enforcement cost-effectiveness at freeway work zones could also be considered a conservative assessment of its potential at work zones on other roadway types as well. Finally, as will be shown in the results section, the confidence interval associated with this type of analysis is so large as to make a more rigorous assessment at this time unnecessary.

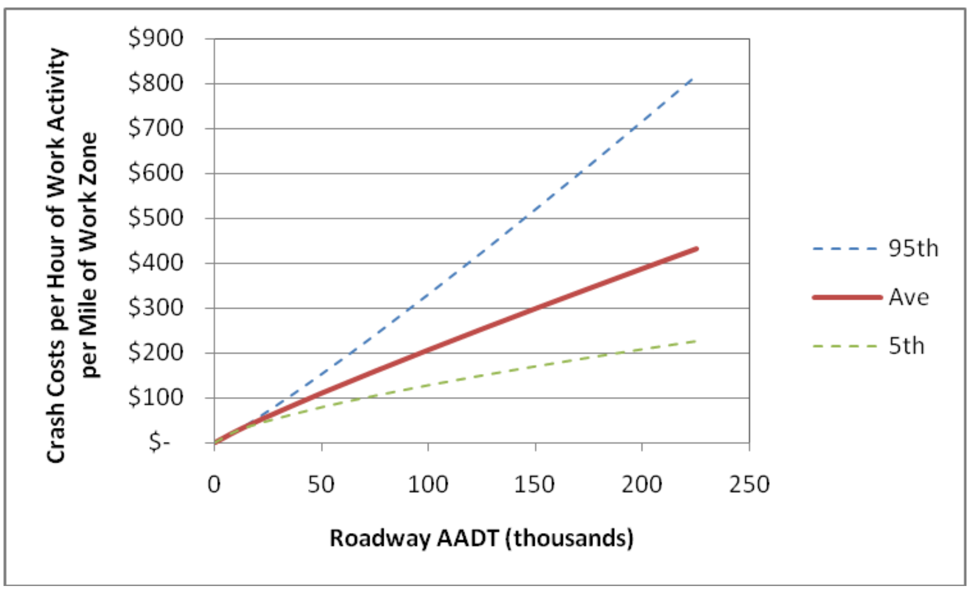
RESULTS

Figure 19 presents the results of the analysis of hourly crash costs estimated on freeway facilities at work zones where work activity is occurring and where a temporary lane closure has been installed to allow the work to occur. Separate graphs are shown when the work occurs during daytime hours and when it occurs at night. Although nighttime crash rates on a per-mile driven basis are typically higher than daytime rates, the much lower traffic volumes that are present on roadways at night generally result in much lower numbers of crashes at night than during the day on any given freeway section. Consequently, it is useful to assess daytime and nighttime conditions separately. Similar analyses were also performed for work zones where (1) work activity is occurring but where it was not necessary to temporarily close a travel lane, and (2) where work zone exists but no work activity is occurring (i.e., the work zone is inactive). These graphs can be found in Appendix B.

As the graphs in Figure 19 illustrate, the estimated crash costs per hour per mile of work zone during daytime hours are two to three times the costs estimated during nighttime hours. More importantly, the size of the confidence interval regarding the estimate of crash costs increases exponentially as the AADT of the freeway is increased. In other words, the precision of the estimates of crash costs in the work zone diminishes with increasing AADT. Furthermore, estimated on an hourly basis, it is clear that work zones have a fairly significant economic impact in terms of public safety, especially on higher-volume facilities.



(a) Daytime



(b) Nighttime

Figure 19. Total Crash Cost Functions for Freeway Facilities: Work Zone Active with Temporary Lane Closures.

To assess the cost-effectiveness of providing work zone enforcement at a given location, one must estimate the amount of these crash costs that would be reduced through the provision of enforcement to compare to the hourly costs of providing enforcement. The goal is for the crash cost reductions to meet or exceed the enforcement costs. Thus, hourly enforcement costs and expected reduction in crash costs attributable to enforcement being present must be estimated. As noted previously, the literature is quite limited as to the safety benefits of work zone enforcement, but an estimate of a 25 percent reduction in crashes appears fairly reasonable, and could be much higher (*21, 25*). Therefore, two potential crash cost-saving levels were considered, a “conservative” 25 percent reduction and “favorable” 50 percent reduction. Also, a review of MOUs in place between highway and enforcement agencies for work zone enforcement nationally shows a fairly wide range of costs, from as low as $25 per officer-hour to as much as $100 per officer-hour.

As stated previously, the goal is for crash cost reductions to equal or exceed the costs of enforcement:

(% crash cost reduction) × (hourly expected crash costs) ≥ hourly enforcement costs

Therefore, dividing the hourly enforcement costs by the expected crash cost reduction level anticipated yields the crash cost value needed to exist at a location that will offset the cost of enforcement:

Hourly expected crash costs ≥ (hourly enforcement costs) ÷ (% crash cost reduction)

Table 23 summarizes the breakeven hourly crash cost values that are thus required as a function of hourly enforcement costs and assumed level of crash cost reductions that are believed to be achieved when enforcement is provided. Overall, the work zone crash cost requirements range from a low of $50 per hour per mile of work zone to a high of $400 per hour per mile. Once these values are calculated, it is a simple matter of identifying the conditions at which such work zone crash costs are first reached. As an example, consider the work zone crash costs required to offset $50 per hour of enforcement costs. Depending on whether a typical or liberal assumption of effectiveness is assumed, it will require $100 or $200 in work zone crash costs at a location in order to offset such costs. If one further assumes that the average crash cost function shown in Figure 19 can be considered a typical cost, whereas the 95th percentile crash cost function is considered a more liberal assumption, one sees that enforcement costs are offset by expected crash cost reductions during daytime work zone operations on freeways where the AADT is 70,000 vpd or higher under the typical assumptions, and only 5000 vpd under the more liberal assumptions. This is illustrated in Figure 20. Similar analyses can be done for the other enforcement cost values and for nighttime work zone operations. The resulting AADT thresholds for this analysis are shown in Table 24. Review of the AADT values suggests that it is fairly easy to justify enforcement use in work zones under the favorable-benefit scenarios, even when enforcement costs are fairly high. Conversely, use of the more conservative-benefit assumptions implies that only the higher-volume roadways would see crash cost reductions that would offset the enforcement costs.

Table 23. Work Zone Crash Costs Required to Offset Costs of Providing Enforcement

Enforcement Costs/Hr	Hourly Work Zone Crash Costs Required if 25% Crash Reduction is Assumed (Conservative-Benefit Scenario)	Hourly Work Zone Crash Costs Needed if 50% Crash Reduction is Assumed (Favorable-Benefit Scenario)
$25	$100	$50
$50	$200	$100
$75	$300	$150
$100	$400	$200

Table 24. Comparison of Enforcement Benefits and Costs at Freeway Work Zones

Enforcement Costs	AADT Where Enforcement Benefits are Approximately Equal to Enforcement Costs	
	Favorable-Benefit Scenario	Conservative-Benefit Scenario
$25 per hour		
Daytime work zone	5000 vpd	20,000 vpd
Nighttime work zone	20,000 vpd	45,000 vpd
$50 per hour		
Daytime work zone	10,000 vpd	35,000 vpd
Nighttime work zone	35,000 vpd	100,000 vpd
$75 per hour		
Daytime work zone	15,000 vpd	50,000 vpd
Nighttime work zone	50,000 vpd	150,000 vpd
$100 per hour		
Daytime work zone	20,000 vpd	70,000 vpd
Nighttime work zone	65,000 vpd	200,000 vpd

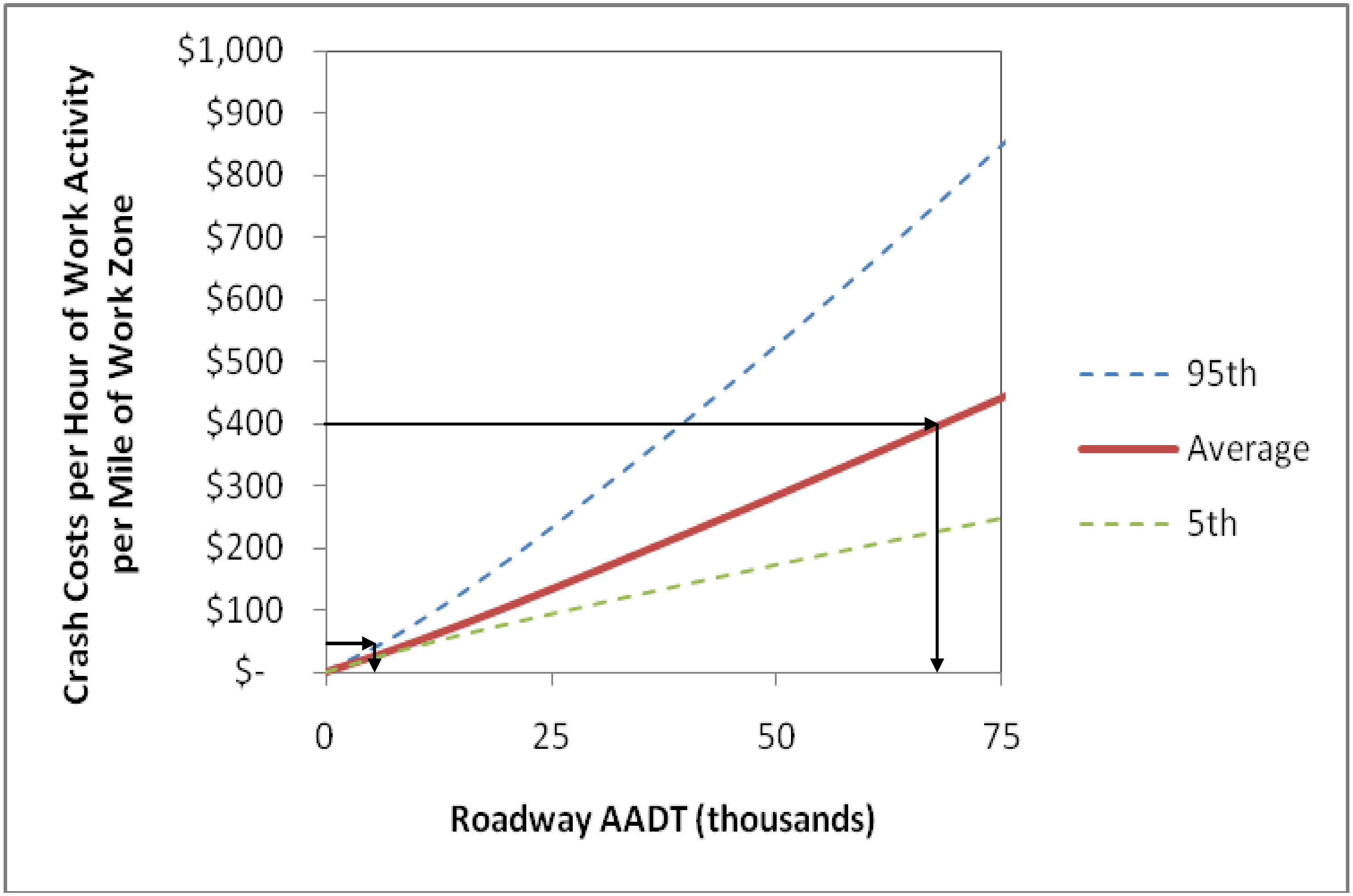


Figure 20. Estimation of AADTs Needed to Offset Enforcement Costs in Daytime Freeway Work Zones when Work Activity is Occurring and a Temporary Lane Closure is Present.

DISCUSSION OF RESULTS

The wide range of values shown in Table 24 further illustrate the challenges associated with the prediction of crash costs in work zones and of the possible crash reduction benefits that the provision of enforcement in those work zones can provide. Based on this analysis, the values shown in the table under the favorable-benefit scenario are suggested as minimum values needed to justify enforcement use in most instances. Certainly, though, unique situations do arise in work zones on occasion that may justify enforcement use at even lower AADT levels than are shown in the table. It should be recognized, however, that the controlling factor in work zone enforcement use in most jurisdictions will not be in the justification of use from an economic perspective, but in the limitations of funding and manpower availability. From that perspective, both types of values shown in Table 24 may prove useful to highway and enforcement agencies during planning and programming efforts in prioritizing which work zones will receive enforcement attention each construction season and in setting budgets for enforcement support that are in line with the overall cost-benefit goals of the agency.

CHAPTER 5 FINDINGS AND RECOMMENDATIONS

The provision of traffic law enforcement at a highway work zone is viewed by many as one of the most effective means available for reducing speeding and other undesirable driving behaviors that compromise safety. Federal regulations require state highway agencies (SHAs) to establish explicit policies and payment procedures for using law enforcement on federal-aid highway projects in their jurisdictions. As a result, a need existed for guidance on this topic, and the research described in this report was undertaken to address that need.

This report documents the results of three research activities performed in Phase II of this project:

- effect of passive versus active enforcement efforts in work zones,
- enforcement effectiveness for queue-end protection, and
- assessment of potential crash cost reductions due to enforcement use in work zones.

The key findings and recommendations resulting from each of these three activities are described below.

EFFECTS OF ACTIVE AND PASSIVE ENFORCEMENT USE IN WORK ZONES

The objective of research efforts on this issue was to determine whether driver opinions, perceptions, and behaviors related to the risk of violating traffic laws in work zones (primarily a reduced speed limit) differ depending on whether work zone enforcement practices in a region are predominantly passive (positioned in the work zone with lights flashing to attract attention and reduce speeds) or active (pursuit of violators and issuance of citations). Motorist surveys and field studies of driver response to enforcement vehicles in work zones were performed in two locations where enforcement use in work zone is almost exclusively active, and in two locations where enforcement use in work zones is almost exclusively passive. The following are key findings from those studies:

- Drivers appear to realize how enforcement is being used in work zones in a particular jurisdiction, especially if it is for visibility and traffic-calming purposes.
- Significantly higher percentages of drivers in the passive enforcement locations believed that enforcement personnel sitting in a work zone with its lights flashing were there for attention-getting purposes than did those living in locations where active enforcement efforts in work zones were emphasized.
- Although drivers are aware of how enforcement personnel are behaving in work zones, it does not appear that this awareness translates into a difference in how drivers think they react when encountering an enforcement vehicle in a work zone. In fact, the type of

enforcement used in work zones had much less of an effect on driver's stated reaction to enforcement vehicles than did their age, education, and opinion about the reasonableness of work zone speed limits posted in their region. These variables were also more important than type of work zone enforcement practiced in the region in determining the distraction level of an enforcement vehicle sitting in a work zone.

- Drivers living in locations where work zone enforcement is primarily passive indicated that, although they were aware that an enforcement vehicle in a work zone was not likely to pursue them if they were exceeding the posted speed limit, the vehicle was present to raise their attention about a downstream hazard.

- Field studies further support the contention that drivers do not react differently when encountering active or passive enforcement vehicles in work zones. At work zones in both types of enforcement locations, an enforcement vehicle generally resulted in an additional 4 mph drop in average speeds just downstream of the enforcement vehicle. Likewise, the percent of vehicles not compliant with the work zone speed limits dropped substantially, and the standard deviation of speeds was reduced when the enforcement vehicle was present. No statistically significant differences in these speed reductions or other speed parameters were found as a function of the type of enforcement used in work zones.

- The results of these studies indicate that the use of passive enforcement does not significant degrade driver perceptions of enforcement or driver response to enforcement compared to active enforcement use (despite opinions to the contrary). Even so, it is recommended that highway agencies who do rely extensively on passive enforcement consider using occasional active enforcement in work zones as enforcement resources are available to ensure that drivers do not become overly confident that they will never be cited for violating a traffic law by enforcement located in a work zone.

ENFORCEMENT EFFECTIVENESS FOR QUEUE-END PROTECTION IN WORK ZONES

Some agencies use an enforcement vehicle and officer positioned on the roadside with lights flashing in an attempt to improve work zone safety by reducing speeds and improving driver vigilance and behavior as vehicles approach work zones where traffic queues have developed. The officer moves the enforcement vehicle along the shoulder forward or backward to remain some distance upstream of the traffic queue (approximately 0.25 miles is cited as a target by some agencies). The objective of studies in this part of Phase II research was to investigate the effects of using an officer and vehicle in a passive enforcement mode upstream of work zone traffic queues on the speed, deceleration, and erratic maneuvers of traffic approaching the traffic queue. Unfortunately, difficulties during data collection severely limited the amount and quality of data available to assess this use of enforcement in work zones. The following findings were obtained as a result of these research efforts.

- Speeds approaching a queue at a work zone when an officer is present are slightly (1-2 mph) lower than when the officer is not present.
- The influence of enforcement upon speed variability as vehicles approach a queue was inconsistent across the sites examined.
- The distribution of deceleration rates at various distances upstream of a traffic queue did not differ significantly based on whether or not enforcement was present.
- Likewise, the distance upstream of the traffic queue at which the maximum deceleration rate occurred was not affected by whether or not enforcement was present.
- Although the results did not imply a significant benefit in using enforcement as a queue-end protection strategy, neither did they suggest any type of operational or safety problem created as a result of such use. Consequently, this strategy was still considered to be an acceptable use of enforcement in work zones. Additional research will be necessary to actually quantify the safety benefits that might be achieved through this strategy.

ASSESSMENT OF POTENTIAL CRASH COST REDUCTIONS DUE TO ENFORCEMENT USE IN WORK ZONES

Intuitively, a major benefit of using police enforcement in a work zone is an improvement in safety and reduced work zone crash costs. In addition, the use of enforcement in some situations may also improve traffic flow and reduce motorist delay and its associated costs. A generalized economic analysis of the potential crash cost reductions associated with the provision of enforcement in work zones was undertaken to determine AADT thresholds at which the benefits of providing enforcement in work zones exceeds the costs of enforcement. Freeway work zone crash cost models from a previous NCHRP project were used to evaluate enforcement cost values and crash reduction potential. The results of the assessment suggested that enforcement use in work zones during daytime work activities appear to be justified in most instances once roadway AADTs reach 5000 to 20,000 vpd (depending on the costs being paid for enforcement efforts), and at work zones with night work activity once AADTs reach 20,000 to 65,000 vpd (also dependent upon enforcement costs).

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APPENDIX A: SURVEY INSTRUMENT

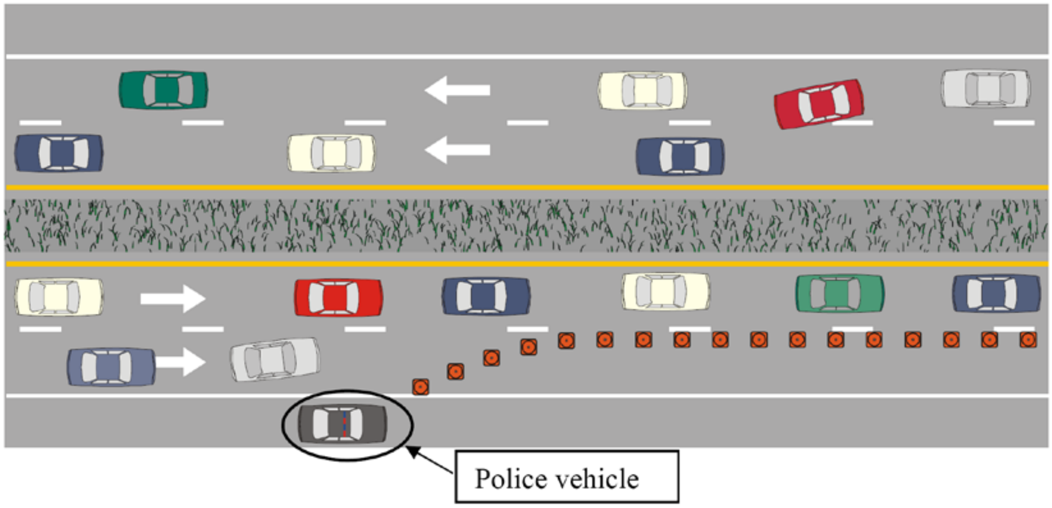
Texas Transportation Institute

NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM

NCHRP 3-80: TRAFFIC ENFORCEMENT STRATEGIES IN WORK ZONES

Date and Time: ______________________ Form: **A**
Location: ______________________ Researcher: __________

This survey is part of a research project sponsored by the National Cooperative Highway Research Program (NCHRP) and performed by the Texas Transportation Institute (TTI). This study is being conducted to better understand driver thoughts about police traffic enforcement in highway work zones. We want you to think about the times you have been driving through a work zone and saw a police officer sitting on the side of the road, such as in the drawings below. The officer might be sitting before or in a work area.



Your responses to this survey are strictly anonymous; there are no "right" or "wrong" answers. We would like you to be as honest as possible about your thoughts and likely driving behaviors when responding to the questions. This survey should take less than 10 minutes to complete.

First, some basic questions about you…

1. What is your gender? ❐ Male ❐ Female

2. What is your age?

16-25	26-39	40-54	55-64	65-74	75+
❐	❐	❐	❐	❐	❐

3. How much education have you completed?

Some high school	High school graduate/GED	Some college	College graduate
❐	❐	❐	❐

4. How many miles do you drive in a typical month?

Less than 500	500-1000	More than 1000
❐	❐	❐

5. How often do you travel through work zones?

Once a month or less	2-3 times a month	1-2 times a week	Almost every day
❐	❐	❐	❐

6. Have you received a traffic ticket during the past year? ❐ Yes ❐ No

7. Have you received a traffic ticket <u>in a work zone</u> in the past year? ❐ Yes ❐ No

8. Have you seen someone else receive a traffic ticket <u>in a work zone</u> in the past year? ❐ Yes ❐ No

9. How much do you think the fine is for speeding:
   5 mph over the speed limit in a work zone? $________
   10 mph over the speed limit in a work zone? $________
   20 mph over the speed limit in a work zone? $________
   30 mph or more over the speed limit in a work zone? $________

Now, please think about the work zones that you have driven through recently…

10. How often are police officers sitting in a work zone when you drive through it?

Almost never		About half the time		Almost always
❐	❐	❐	❐	❐

11. When you see a police vehicle sitting in a work zone, are the lights on the police vehicle usually flashing?

Yes	No	Have never seen a police vehicle in a work zone
❐	❐	❐

12. How much do you think speed limits are typically reduced in work zones in your area?

20 mph below the normal speed limit	10 mph below the normal speed limit	5 mph below the normal speed limit	No reductions in normal speed limits
❐	❐	❐	❐

13. What do you think about the speed limits that are posted in typical work zones in your area?

Set too low		Set about right		Set too high
❐	❐	❐	❐	❐

14. If you drive into a work zone with a reduced speed limit, which of the following do you typically do?

Slow down below the new lower speed limit	Slow down almost to the new lower speed limit	Slow down a little	Do not slow down at all
❐	❐	❐	❐

15. If you see a police vehicle sitting in a work zone by itself on the side of the road with its lights flashing, which of the following would you assume is happening?

the officer has just finished writing a ticket to a driver and is getting ready to turn off the lights and pull back into traffic	the officer is trying to get everyone to slow down and be careful, but is also looking for speeders to catch	The officer is trying to get everyone to slow down, but is probably not looking for speeders to catch
❐	❐	❐

16. If you are exceeding the speed limit and see a police vehicle sitting in a work zone, do you typically slow down more if they have their lights flashing or no lights are flashing?

Slow down more if lights flashing	Slow down the same regardless	Slow down more if lights not flashing
❒	❒	❒

17. How does the presence of a police vehicle in a work zone affect your level of attention and awareness to the roadway signs and other things in the work zone?

I am more alert and pay more attention to the work zone after I see the police vehicle	It has absolutely no effect on my attention and awareness of the work zone	I continue to pay attention to the police vehicle even after I pass it and pay less attention to the work zone
❒	❒	❒

Do you have any other comments regarding police enforcement practices in work zones?

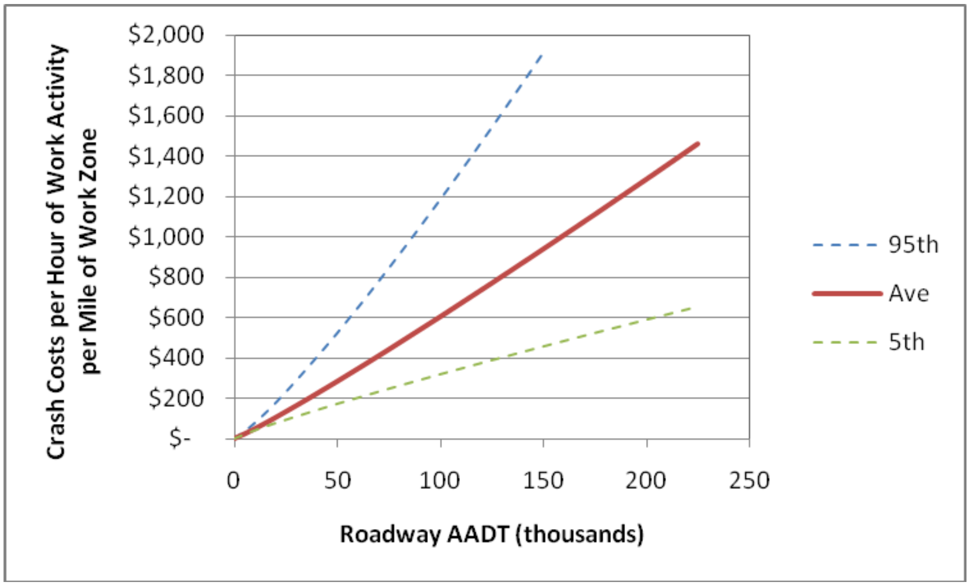
____

____

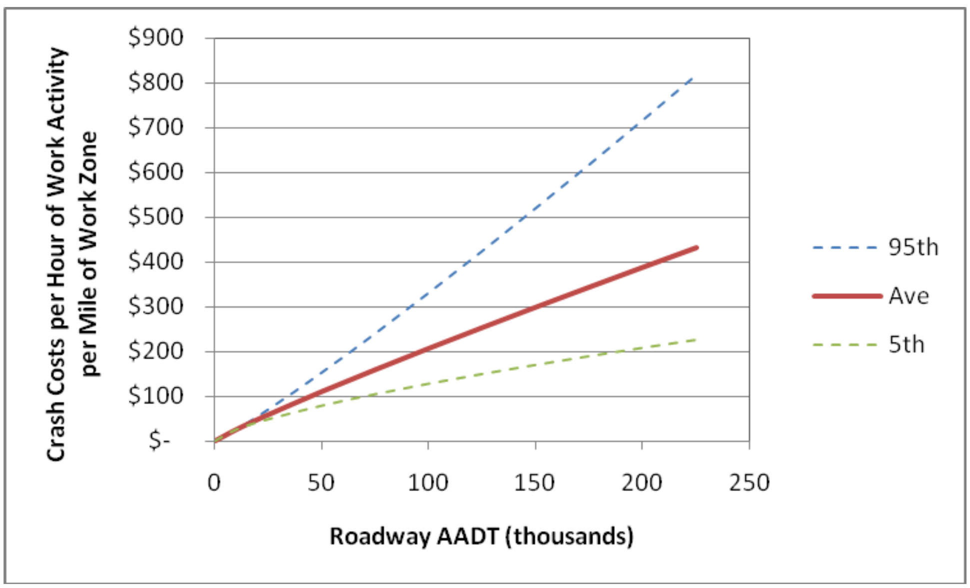
Thank you for your time and answers!

Please return the completed survey form to the researcher.
You may also pick up a complimentary gift at the table.

APPENDIX B: CRASH COST FUNCTIONS

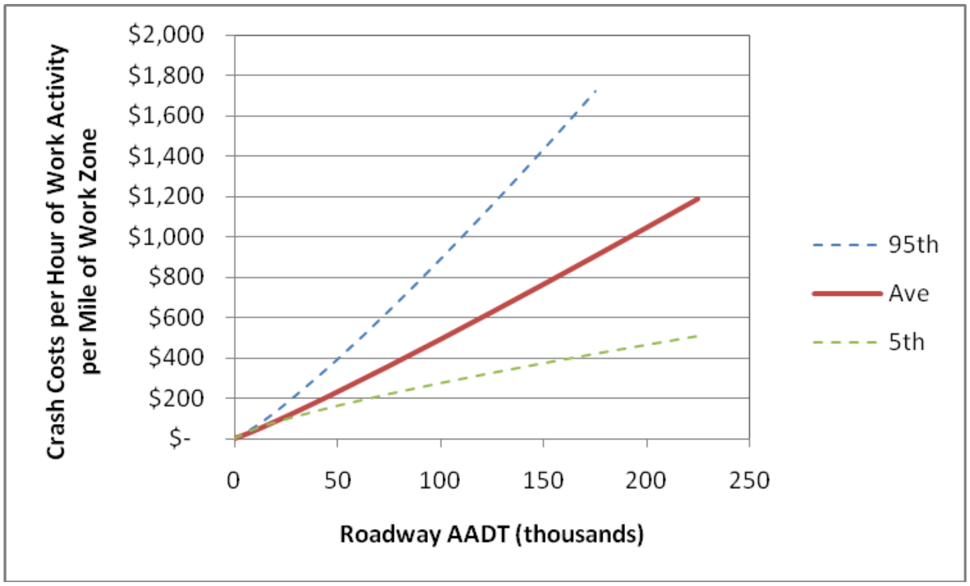


(a) Daytime

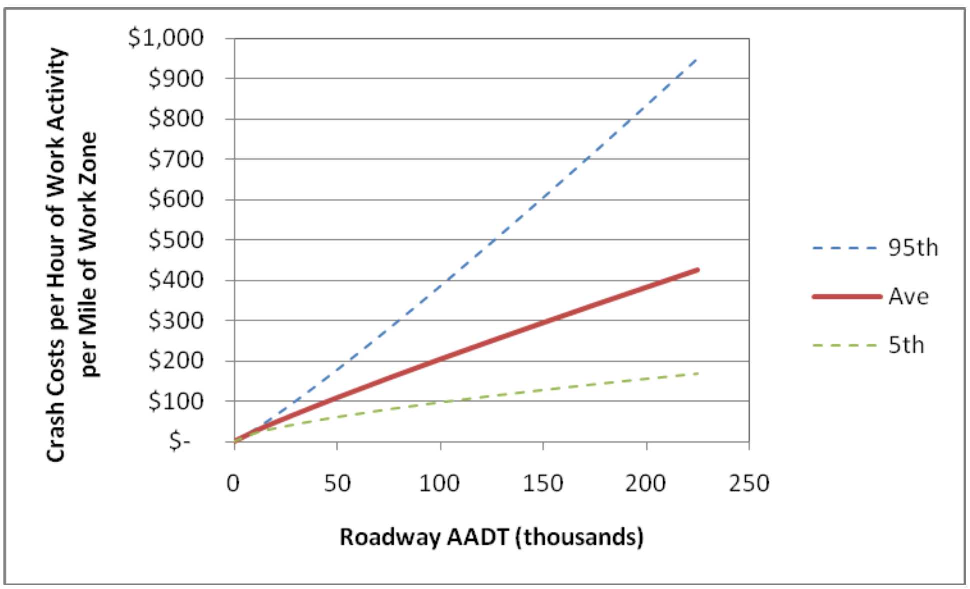


(b) Nighttime

Figure B-1. Total Crash Cost Functions for Freeway Facilities: Work Zone Active with Temporary Lane Closures

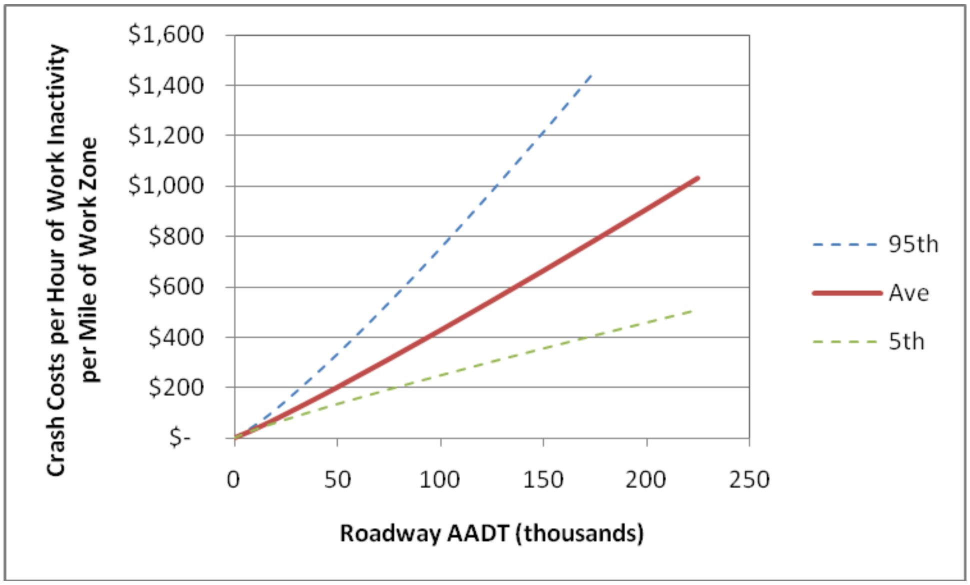


(a) Daytime

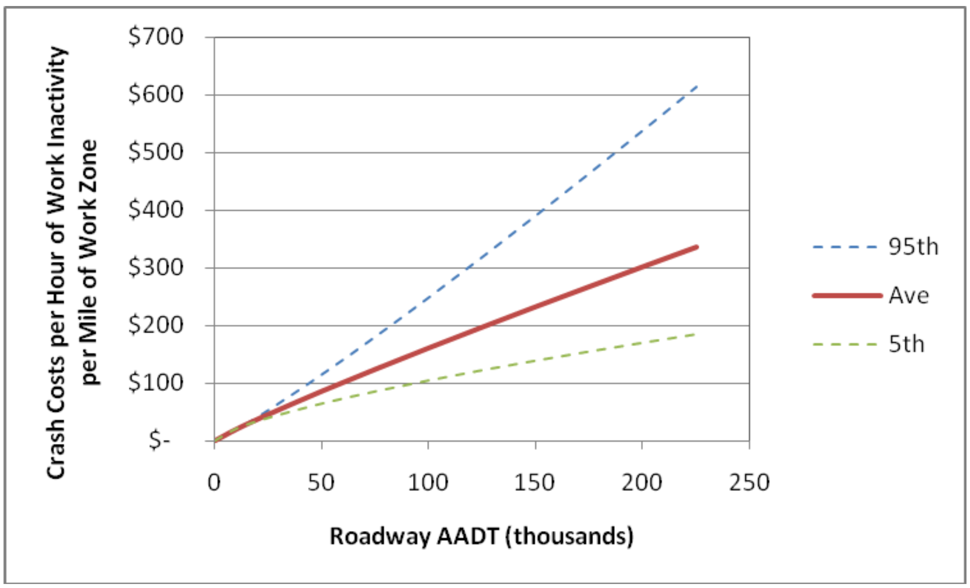


(b) Nighttime

Figure B-2. Total Crash Cost Functions for Freeway Facilities: Work Zone Active without Temporary Lane Closures



(a) Daytime



(b) Nighttime

Figure B-3. Total Crash Cost Functions for Freeway Facilities: Work Zone Inactive without Temporary Lane Closures