



**A REVIEW OF TRAFFIC MANAGEMENT AND ENFORCEMENT
PROBLEMS AND IMPROVEMENT OPTIONS AT HIGH-VOLUME,
HIGH-SPEED WORK ZONES IN TEXAS**

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16. Abstract Project This report presents a review of possible safety problems commonly observed at work zones on high-volume, high-speed roadways in Texas. These included excessive speeds upstream and within the work zone, severe braking and lane-changing at the upstream end of a traffic queue, severe braking and lane-changing within the traffic queue, lane straddling by trucks, and erratic exit maneuvers upstream of and within the traffic queue. Available traffic management and enforcement strategies and technologies were assessed for their feasibility in addressing these problems. Testing of a real-time remote enforcement system, portable traffic management systems, and the late merge traffic control strategy are recommended for the next phase of this study.					
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1. INTRODUCTION

PROBLEM STATEMENT

Work zones on roadways accommodating high traffic volumes and high speeds can be particularly troublesome to transportation agencies, highway contractors, and enforcement agencies. The reasons for these troubles vary. From the transportation agency's perspective, work zones on these types of roadways can drastically alter the operating characteristics of traffic on that facility, quickly creating queues and large speed differentials that are unexpected by approaching motorists. From the highway contractor's perspective, high volumes and speeds increase the perceived risk of injuries to work personnel and can hamper the contractor's efforts to access the work site with construction equipment and materials. From an enforcement agency's perspective, work zones on high-volume, high-speed roadways can be difficult to enforce due to the restrictions in roadway cross-section (especially the removal of shoulders) that leaves no space to stop violators. Furthermore, unrealistically low speed limits or other significant changes in traffic control devices also add to the complexity of the enforcement task. In addition, high-volume facilities can often create a sense of immunity from enforcement activities (i.e., a "they can't ticket everyone" mentality). This can lead to a general disregard for work zone traffic control devices in general and ultimately to less safe driving conditions.

In an effort to combat the safety problem in work zones on high-volume, high-speed roadways, the Texas Department of Transportation (TxDOT) initiated a study with the Texas Transportation Institute (TTI) to identify and evaluate traffic management and enforcement options that may be applicable to these conditions. The first year of the project has focused on the identification of the types of safety problems that exist at high-speed, high-volume work zones, an assessment of the underlying causes and contributing factors to these problems, and identification of possible techniques and strategies to address these problems. The second and third years are devoted to testing the effectiveness of the techniques and strategies in improving work zone safety.

CONTENTS OF THE REPORT

The next chapter of this report (Chapter 2) summarizes the types of safety problems being experienced in high-volume, high-speed work zones. These problems were identified through a literature review; through surveys and discussions with highway agencies, contractors, and enforcement personnel; and through a limited number of observational studies conducted at work zones on high-volume, high-speed roadways in Texas. As part of the problem identification task, researchers hypothesize as to the underlying causes and factors that are ultimately contributing to this problem. Chapter 3 is a summary of various strategies, techniques, and methods that the researchers believe have potential to address the problems (and underlying causes/contributing factors) being experienced. Chapter 4 presents the studies that the researchers recommend conducting in the second and third years of the project. These studies will evaluate the techniques/strategies/methods believed to have the greatest potential for improving work zone safety in high-volume, high-speed roadways in Texas.

2. TYPES OF SAFETY PROBLEMS IN HIGH-VOLUME, HIGH-SPEED WORK ZONES

Strictly speaking, many traffic safety problems in high-volume, high-speed work zones have existed for many years. For example, excessive travel speeds in the work zone and speed differentials between vehicles at the upstream end of a queue caused by a work zone have long been a topic of concern (1-3). As another example, a number of studies have suggested that rear-end and side-swipe accidents tend to increase in work zones, indicating the presence of unsafe speed differentials and lane-changing difficulties for motorists (4-7). Of course, other problems are relatively new revelations, and so have not seen significant attention to date.

Regardless of whether a problem has only recently manifested itself or has been around for a long time, there have been enough changes in both the public mindset and in technological capabilities in recent years to warrant an objective investigation of the causes and potential countermeasures of these problems. For instance, it is likely that the increased availability of traffic information on dynamic message signs, commercial traffic reports, the Internet, and other venues in major urban areas has generated higher public expectations for accurate, real-time information at work zones as well. Likewise, higher truck volumes (due to the North American Free Trade Agreement and the continued economic expansion) on these roadways translates into the need to consider the potential safety consequences of countermeasures for trucks in greater detail.

In this chapter, TTI researchers document and discuss a number of special safety problems that have been identified as particularly troublesome at work zones on high-volume, high-speed roadways. Available statistics from the literature or from the observational studies are documented. An attempt is also made in this chapter to identify and discuss the possible underlying causes and factors contributing to these problems. This latter information is important for the following chapter in determining the possible strategies, methods, etc. that would have the greatest likelihood of successfully addressing some of these problems. The various problem behaviors have been grouped into the following five categories:

- excessive speeds upstream and within the work zone,
- severe braking and lane-changing at the upstream end of a traffic queue,
- severe braking and lane-changing within the traffic queue,
- lane straddling and side-by-side operations by trucks, and
- erratic exit maneuvers upstream of and within the traffic queue.

EXCESSIVE SPEEDS UPSTREAM AND WITHIN THE WORK ZONE

Characteristics

One of the problems cited most commonly in high-volume, high-speed work zones is that traffic speeds are often excessive and too fast for conditions. Some data exist to support this position. For example, studies of speed characteristics recently taken at a limited number of Texas work

zones on interstate highways showed that 70 to 90 percent of the vehicles were exceeding the posted speed limit in the work zone (8). According to TxDOT (9), approximately 18 percent of all work zone accidents involve vehicles that were speeding. Other studies have also suggested that excessive speeds contribute to work zone accidents (4,10).

However, it should be noted that speed limits in work zones are not always set properly. It is often the perception of traffic control planners that a lower limit will convey the need for drivers to slow down and be careful. Unfortunately, reduced speed limits alone do not significantly affect speeds. Furthermore, establishing an arbitrarily lower limit merely decreases the compliance rate (since drivers typically do not reduce their speeds in response to a lower limit) and makes it difficult for law enforcement officers to effectively enforce the speed limit. In fact, when an accident does occur in this type of zone, it is possible for the investigating officer to identify speeding as a contributing factor of the accident, even when other factors may have had a more direct causal relationship.

The above comments notwithstanding, it is important to note that a real concern does exist with those drivers who travel significantly faster than the regular traffic stream approaching and passing through the work zone. This is true regardless of whether or not an appropriate reduced work zone posted speed limit is established. It is known that such speeding behavior significantly increases accident risk (11). Furthermore, this risk is likely amplified by the presence of construction vehicles, increased traffic densities, and the other characteristics present at a work zone. These characteristics reduce available recovery areas for errant vehicles. Just as importantly, higher speeds reduce the time available for workers to move out of the way of an errant vehicle that may intrude into the work area.

Possible Causes/Contributing Factors

Studies have shown that the most effective means to control speeds in and out of work zones is through an enforcement presence (2,3,11). However, several difficulties mentioned by law enforcement officers in previous studies (8) and during surveys conducted for this project limit the ability of officers to effectively enforce certain work zones. These include the following:

- Due to ongoing budget tightening within agencies, available manpower to enforce work zone speed limits is more and more difficult to obtain without special contract funds to pay overtime wages to officers.
- The elimination of both shoulders through the work zone eliminates areas where officers can safely pull violators over to issue citations.
- The elimination of shoulders also limits the locations where officers can position themselves to monitor traffic and then move into the traffic stream if necessary.
- The “workers present” portion of the double-fine law is difficult to verify (and so many citations are not coded as occurring in a work zone).

Overall, observed driving behavior at work zones does suggest that there is little perceived threat of citation for noncompliance to work zone speed limits.

SEVERE BRAKING AND LANE-CHANGING AT THE UPSTREAM END OF THE TRAFFIC QUEUE

Characteristics

Nationwide, several accident studies have documented higher frequencies of rear-end and/or side-swipe accidents at work zones (4,5,10). Researchers have observed similar results at urban freeway work zones in Texas (6). It is generally believed that most of these increases are the result of severe vehicle interactions at the upstream end of traffic queues that develop within these work zones. The observational studies conducted in Texas (see Appendix A) tend to verify these beliefs. For instance, TTI researchers observed between 1 and 16 hard braking maneuvers (where a significant “drop” in the nose of the vehicle could be seen) per 1000 approaching vehicles at two sites where this behavior could be monitored. The frequency also tended to be higher during the off-peak periods than during peak periods. Data from Illinois (12) suggest that as much as 5 percent of the traffic approaching a slow-moving queue may be traveling at an excessive speed and require a hard braking maneuver.

Causes/Contributing Factors

Driver expectancy plays a key role in this process. Although drivers can develop an overall expectancy of queuing along a roadway segment from day to day due to recurrent (i.e., peak period) congestion, the exact location of the beginning of the queue can vary by day and by time. The inability to accurately anticipate the location of the queue at a work zone is further magnified by a number of conditions that can temporarily affect the restricted capacity (construction vehicles entering and exiting a work area, unusual construction activity that causes rubbernecking, hourly variations in traffic demand, etc.).

In addition to difficulties attributable to a lack of driver expectancy of queue location, it appears from the observational studies that there also exists a conscious delay-minimization decision process impacting driver behavior as well. Some drivers appear to postpone their deceleration and/or their lane changes until the last second before reaching the queue as a sort of defensive maneuver to prevent other drivers from moving ahead of them. Maintaining a higher speed until the last possible moment presumably allows these drivers to make a quicker lane change if they perceive one lane moving significantly faster (albeit at a higher risk of having to brake severely at the last minute to avoid a rear-end or side-swipe collision).

SEVERE BRAKING AND LANE-CHANGING WITHIN THE TRAFFIC QUEUE

Characteristics

In addition to hard braking and lane-changing activity at the upstream end of the queue, TTI researchers also noted these activities occurring throughout the length of queue itself upstream of the various work zone sites studied. In many instances, it appeared that a motorist would accelerate quickly when a gap developed in front of them (as the lead vehicle moved forward),

followed by a hard braking maneuver to avoid a rear-end impact. In other cases, a vehicle would accelerate in order to change lanes into a short gap, again followed by a hard braking maneuver to avoid the vehicle in front. In some instances, two vehicles attempted to move into the same gap (when the gap was in a middle lane) at which time one or both vehicles swerved back into their original lanes. The swerving and hard braking was also evident as vehicles moved into and out of a closed lane.

Causes/Contributing Factors

There appears to be a deliberate effort on the part of some motorists (presumably the more aggressive drivers) to try and proceed through a work zone traffic queue by darting from lane to lane as gaps open in front of them in adjacent lanes. Motorists who are not adept at staying very close to the vehicle in front of them can actually have their progression through the queue hampered by these other drivers constantly cutting in front of them (this was actually observed quite regularly in front of large trucks). Consequently, the interactions between vehicles often appear quite adversarial.

LANE STRADDLING BY TRUCKS

Characteristics

The previous section implied that many automobile motorists tend to “defend” their position in queue through more aggressive acceleration/deceleration to keep up with the lead vehicle and not allow other vehicles to merge into the lane in front of them. Large trucks do not have similar acceleration/deceleration characteristics, and so appear to be at a distinct disadvantage when it comes to queue behavior. It has been observed that some truck drivers will deliberately block lanes (either by a pair of trucks traveling side by side down the roadway or by a single truck straddling two lanes and not allowing vehicles by) in an attempt to protect the area in front of them from continuously filling up with vehicles. Data taken at one site in Texas (see Appendix A) found that 21 percent of all trucks approaching the work zone were straddling a lane or traveling next to another truck to keep automobiles from passing them and merging in front of them. In one instance, an automobile passed the truck on the right shoulder in order to jump the queue.

Causes/Contributing Factors

It is hypothesized that most of these types of maneuvers are performed to reduce the number of vehicles who cut in front of them. These actions do appear to reduce the effective capacity of the work zone, as long spaces develop between the trucks and the vehicles in front. Furthermore, the practice may lead to unsafe driving behaviors by automobile drivers who still attempt to bypass the truck and move into the open area.

ERRATIC EXIT MANEUVERS UPSTREAM OR WITHIN THE TRAFFIC QUEUE

Characteristics

A final category of safety problems noted during the observational studies was the prevalence of erratic exiting maneuvers that occurred at the upstream end of the traffic queue, or within the queue itself. At one location, the queue had developed back upstream to a particular exit ramp. The frontage road was relatively uncongested at that location, and so appeared to be a preferable alternative route. Researchers observed a number of severe lane changes (across two or three lanes, sometimes across the painted gore area) at that location as drivers attempted to make a last-second exit onto the frontage road. Often, this also caused following vehicles in adjacent lanes to apply their brakes as well.

Another related exit maneuver observed at one site involved vehicles crossing the grassy median between the freeway and adjacent frontage road. This occurred at a rate of approximately 15 per 1000 approaching vehicles. Strangely, a few drivers were observed making the opposite maneuver (frontage road to freeway) at that same location. This behavior was even observed with a police vehicle parked on the median shoulder in the vicinity of these maneuvers. In fact, the officer eventually moved his vehicle over to the shoulder to block vehicles from making that exiting maneuver.

Causes/Contributing Factors

The most probable cause for this type of observed behavior is a perception that one can improve his or her travel time by moving from the freeway to the frontage road (and then possibly to a nearby arterial street). A driver approaching a queue appears to assess whether the frontage road is less congested (from their perspective) and offers a quicker route. Because these exit maneuvers are made erratically, drivers are either waiting until the last possible moment before deciding to make the exit maneuver, or are not perceiving the queue and the possibility of exiting to the frontage road until they are relatively close to the queue.

SUMMARY

Table 1 summarizes the basic safety problem categories observed at high-volume, high-speed work zones.

Table 1. Summary of Identified Safety Problems.

Problem Category	Types of Behaviors	Causes/Contributing Factors
Excessive speeds upstream and within the work zone	• Motorists traveling faster than speed limit • Motorists traveling significantly faster than others in the traffic stream	• Perception of inappropriate speed limits, that lower speeds not necessary (i.e., workers not present) • Perception that apprehension of speed violation is not a significant threat
Severe braking and lane-changing upstream of queue	• Large decelerations as vehicles move into queue • Last-second lane changes as vehicle joins queue	• Driver surprised as speeds into the work zone queue reduce quicker than expected • Driver tries to protect his/her position in queue by delaying deceleration as long as possible • Driver tries to maximize his/her travel into the beginning of queue by selecting a lane at the last minute
Severe braking and lane-changing within queue	• Accelerate to move up behind lead vehicle, followed by rapid deceleration • Accelerate to quickly move into adjacent lane, sometimes aborted when another vehicle moves for the same spot	• Desire to protect position in queue (prevent someone from changing lanes in front of them) • Desire to move through the queue faster than others
Lane straddling by trucks	• Trucks straddle two lanes • Two trucks travel side by side	• Desire to reduce frequency of queue jumpers • Desire to protect area immediately in front of the truck for deceleration
Erratic exits upstream of and within the traffic queue	• Across multiple lanes and/or the painted gore • Across grassy median between freeway and frontage road	• Last-minute selection of frontage road to avoid freeway queue • Insufficient warning of queue presence • Indecision as to whether the frontage road offers a travel time benefit

3. POTENTIAL STRATEGIES TO ADDRESS SAFETY PROBLEMS

As noted in Chapter 2, it is hypothesized that the potential safety problems at high-volume, high-speed work zones reflect both non-deliberate and deliberate driving behaviors. Consequently, TTI researchers examined both enforcement strategies (that can address certain deliberate unsafe driving behaviors) and strategies that could help provide information to motorists in order to encourage them to make better driving decisions (and reduce the frequencies of the non-deliberate driving behaviors).

POTENTIAL STRATEGIES TO ENHANCE ENFORCEMENT

Surveys of law enforcement personnel (Appendix B) and a review of new and upcoming technologies in the U.S. yielded the following strategies for possible consideration for applications in Texas:

- restrict work zone lane closure lengths or provide shoulder segments periodically throughout the work zone for enforcement areas,
- provide special staging pads for enforcement vehicle at beginning of the work zone,
- provide upstream real-time notification of the presence of workers at the site, and
- real-time remote speed enforcement.

The first two strategies are actually addressed during the design stage of the work zone and are intended to promote the enforceability of the work zone area. The latter strategy focuses facilitating work zone enforcement in situations where adequate space for enforcement activities is not provided in a work zone.

Work Zone Length Restrictions/Shoulder Enforcement Areas

One approach that was suggested as a potential strategy to promote work zone enforceability was to limit the actual length of work zones where no shoulders are provided, or to periodically provide a segment of shoulder within a work zone where vehicles could be pulled over. This concept is used in Dallas for high-occupancy vehicle (HOV) lane enforcement with a fairly high degree of success. Other states have considered limiting work zone project lengths to assist enforcement agencies as well (i.e., South Dakota). Anecdotal information from the Dallas experience indicates that a shoulder segment approximately 0.25 miles long appears to be enough to allow vehicles to pull over and stop, and then to accelerate back up to speed and enter the traffic stream after receiving a citation.

The question that cannot be answered from the HOV lane enforcement experience is how frequent these shoulder segments should be within a work zone. Intuitively, these shoulder segments will have an added cost associated with them in terms of added materials and more complex project phasing. If they are established too frequently, it becomes more cost-effective (or possibly even less expensive) to retain a continuous shoulder throughout the various phases

of the project. On the other hand, establishing the segments too far apart will negate their effectiveness to enforcement personnel and the segments may not be used at all. An economic benefit-cost or cost-effectiveness evaluation is required to provide implementation guidance to work zone traffic control designers about this strategy.

Special Staging Pads for Enforcement Personnel

Somewhat related to the previous strategy, special staging pads for enforcement vehicles can be established at the beginning or elsewhere within the work zone area to facilitate enforcement efforts. Elevating these pads would provide greater enforcement visibility but increase construction costs considerably.

The potential implementation of this strategy would need to be coordinated with design efforts to allow enforcement activities downstream (either by providing a shoulder enforcement area or by limiting the length of the work zone). In addition, concerns over enforcement vehicles having to slow too significantly to enter the area would require that the pad be fairly extensive in size, possibly as large as the shoulder enforcement segment described in the previous section. Pad design and location would also need to be critiqued from a crashworthiness perspective.

Provide Real-Time Notification of the Presence of Workers

The ability to verify the presence of workers as part of a work zone double-fine law has been cited as a difficulty for enforcement personnel in several states. Both Tennessee and Illinois have utilized flashing warning lights on the worker presence sign to indicate when a double-fine law is in effect. An illustration of the device used in Illinois is shown in Figure 1.

The proposed sign assembly does offer the ability to denote to both motorists and to enforcement personnel that workers are present and that fines are doubled. Presumably, the work crew would be responsible for activating the sign when they arrive at a site, and deactivating it when they left the site. However, this type of operation could result in the work crew leaving without deactivating the sign, which would place enforcement personnel in the same difficult position in testifying whether they knew for sure that workers were present downstream. These concerns notwithstanding, such as device could possibly yield additional speed-reduction benefits if used with a visible and regular enforcement presence.

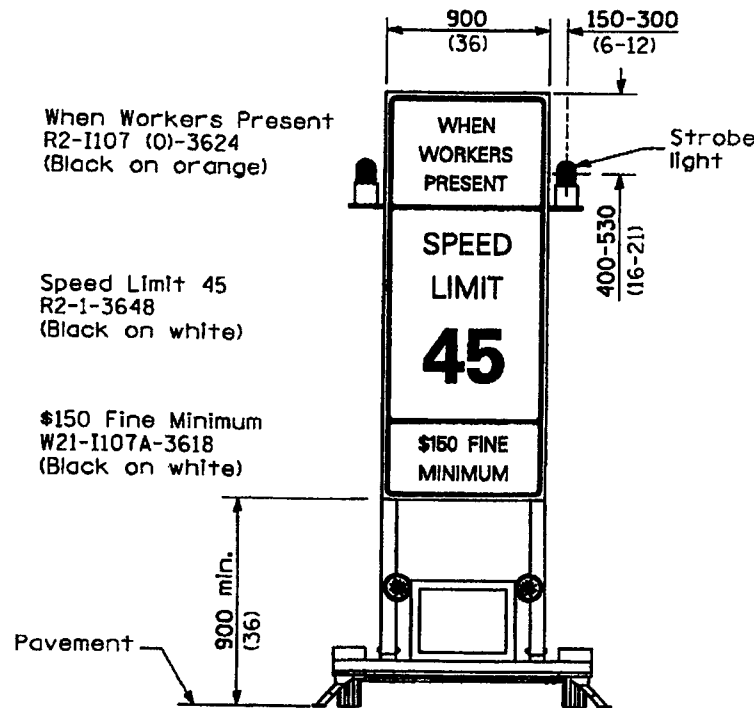


Figure 1. Special Sign to Denote When Workers are Present.

Real-Time Remote Speed Enforcement

Some authorities have proposed automated speed enforcement (ASE) systems for work zone speed enforcement. These devices utilize a radar or lidar unit that is aimed either across a road or directly at oncoming traffic. When a vehicle crosses through the radar/lidar beam of an ASE system while traveling above a preset speed threshold, a photograph is taken of the vehicle's license plate. Photos of the driver are also sometimes taken if needed for evidentiary reasons. Typically, these photographs are used to mail traffic citations to the registered owner of the vehicle. The ASE system offers the potential to act as a deterrent in much the same way as a law enforcement officer, but also offers a chance to improve safety within the work zone since officers will not have to attempt to pursue offenders within the high speed work zone. Figure 2 shows an example of an image captured by ASE technology.

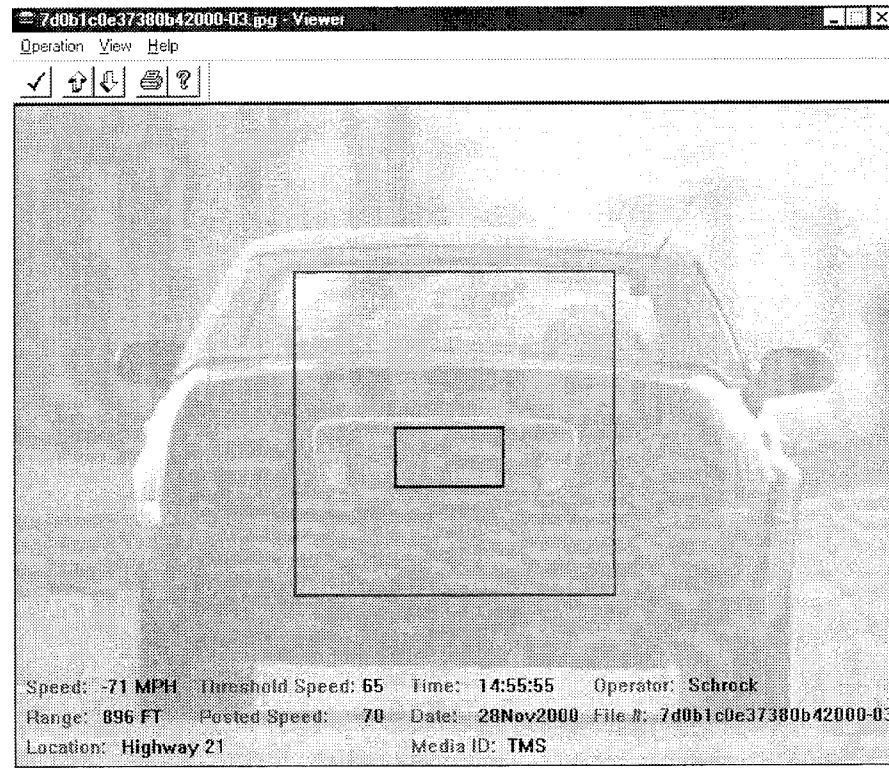


Figure 2. Example of an ASE Image Capture.

Unfortunately, several potential legal barriers must be overcome before ASE units can be used in Texas. Under current Texas law, registered owners cannot be presumed to be responsible for the unlawful operation of their vehicle by another driver. Thus, the identity of the driver must be known so that they can be charged with the offense. In order for ASE systems to be usable in Texas, legislation must be passed in order to allow the registered owner of the vehicle to be charged with the offense. In August 1990, the TxDOT General Council noted that the only possible recourse to force an owner to identify the driver in an ASE photograph would be contempt of court (13). The 5th Amendment to the U.S. Constitution could also be used to challenge citations under the due process clause if the owner is assumed to be liable for violations. Finally, in Texas spouses cannot be forced to testify against their husband or wife, which may make it difficult to enforce the program (13). The lack of enabling legislation and the potential for frequent legal challenges make it unlikely that an ASE system could be implemented on the state system anytime soon.

Because of these concerns, the concept of a real-time remote speed enforcement system has been proposed. The proposed system combines the advantages of ASE systems with actual enforcement at the scene by a law enforcement officer. The system photographs vehicles that are exceeding the posted speed limit approaching or within the work zone. The picture of the violator is transmitted to an officer stationed at a location downstream that permits safe enforcement of violations. The distance between the officer and the speed detection and imaging station must be sufficient to allow for data transmission, but should not be so long as to interfere with the officer accurately identifying the offender. Thus, it is hoped that by transmitting images

in real time, the officer will be able to set up in a safe location beyond the limits of the work zone and enforce the speed limits within the confines of the existing Texas law. Additional detail about ASE and the proposed real-time application are provided in Appendix C.

TTI researchers performed some feasibility testing of the concept of real-time speed enforcement using ASE technology. Feasibility was assessed in terms of the ability of TTI researchers to be able to identify speed violators up to 1.5 miles downstream of the ASE camera system. The test locations were not access-controlled. Consequently, some of the vehicles may have left the roadway between the upstream system photograph location and the downstream vehicle identification location. Nonetheless, the process did appear to work quite effectively. As shown in Table 2, TTI researchers were able to correctly identify approximately 85 percent of the vehicles they attempted to identify based on an image sent from the ASE system.

Table 2. Vehicle Identification Rates.

Site	Distance Downstream from Camera	% Successfully Identified
Site 1	1 mile	88.0%
Site 1	1.5 miles	84.0%
Site 2	0.5 miles	86.7%
Site 2	1 mile	88.0%

TTI researchers also met with both Texas Department of Public Safety (DPS) officers and an officer from the Harris County Sheriff's office about the potential applicability of the real-time remote enforcement concept. Overall, the officers' impressions of the technology were favorable. They noted that the approach had potential merit not only in work zones, but anywhere where the roadway cross-section was restricted (such as on long bridges). The attempts made to identify vehicles whose images were transmitted downstream were generally successful. Officers noted that the black-and-white display image made vehicle identification slightly more difficult, but not extremely so. One of the key issues raised by the officers was the ability to monitor the actual video in real-time from the downstream laptop location. They were concerned that they would not be able to establish visual verification that a violator did indeed appear to be exceeding the speed limit. According to their comments, it would be necessary for the officer to establish probable cause (which the technology could then verify with the video image and imprinted speed data) upon which to stop the violator and issue the citation. Some of the DPS officers actually believed that continuous visual tracking would be required from the point of violator identification until stopped by the officer in order to ensure that the citation was not thrown out in court. This opinion was not expressed by all of the officers, however.

A system that can operate in a real-time remote mode is still under development. Issues concerning accuracy, durability, and flexibility of use still require investigation. Perhaps more importantly, such a system must also be evaluated with actual enforcement officer usage to determine its effectiveness as a deterrent and determine the ability of the system to withstand legal scrutiny.

POTENTIAL STRATEGIES TO ENHANCE MOTORIST AWARENESS

The second category of strategies that have been identified to address the safety problems identified at work zones on high-volume, high-speed roadways is that which offers potential assistance to motorists in reducing some of the non-deliberate types of behaviors that lead to safety problems. Items identified in this category include the following:

- signing and work zone design options used in other countries,
- systems to minimize “queue jumping,”
- systems to provide individualized feedback of speeding behavior, and
- portable traffic management systems to enhance motorist decision-making upstream and within the work zone traffic queue.

Signing and Work Zone Design Options Used in Other Countries

FHWA recently sponsored a European scanning tour designed to determine practices in use in other countries regarding work zone traffic control and operations. The report, *Methods and Procedures to Reduce Motorist Delays in European Work Zones (14)*, was reviewed by TTI staff as part of this research effort to determine whether any of the ideas uncovered by the scanning team had applicability to Texas and the safety problems experienced in work zones on high-volume, high-speed roadways. Table 3 summarizes the options considered from that FHWA effort.

As shown in Table 3, the items that were judged to have possible applicability to Texas work zones were the following:

- locating some work zone information on overhead signs,
- displaying lane dependent information on signs (i.e., speed information),
- increased use of symbol signs,
- use of portable sign gantries to hold a dynamic message sign (DMS) upstream of work zones,
- dedication of primary and secondary alternative routes on permanent trailblazer signs,
- use of portable queue detection and warning systems, and
- use of narrowed lanes within the work zone.

Table 3 also illustrates that not all of these possible strategies are ready for immediate implementation within Texas, only that they may have applicability if conditions arise or if technology develops sufficiently in the near future. For example, portable gantries to support larger DMS would likely offer an advantage in only a few situations where existing permanent DMS were not available and where geometrics precluded use of portable roadside DMS on the left side of the roadway.

Table 3. Summary of European Work Zone Strategy Applicability to Texas.

EUROPEAN WORK ZONE PROCEDURE	POTENTIAL BENEFIT IN WORK ZONE OPERATIONS	ISSUES TO RESOLVE PRIOR TO DEPLOYMENT OR TESTING	POTENTIAL FOR TESTING WITHIN THIS RESEARCH PROJECT
Yellow pavement markings (with and without removal of other markings)	Delineation through work zones	Does not currently conform to the Manual of Uniform Traffic Control Devices (MUTCD)	Not at this time
Overhead sign locations for information	Increased driver communication; lane-specific communication	Deployment on existing sign bridges impact driver workload and ease of sign installation/adjustment	Consider field test in conjunction with lane-specific information
Sign information specific to travel lane	Operational and flow characteristics adjustable by lane	Depending upon information provided, check compliance with MUTCD	Consider field test for trucks assigned to right lane only
Prevalence of symbol signs due to diverse languages	Potential positive impact on driver comprehension	Check compliance with MUTCD	Consider simulator test, then possible field test
Portable sign gantries	Location specific information	Equipment availability; deployment and operation guidelines	Consider a field test if equipment becomes available
Dedication of primary and secondary alternate routes on permanent trailblazer signs	Identifies major desirable alternate routes in advance	Check compliance with MUTCD; coordination with other agencies	Consider in conjunction with signing for real-time work zone operation
Use of portable queue detectors	Real-time driver information	Accuracy of information; a system of this type was observed in the field	Consider a field test if equipment becomes available
Narrower lanes in work zones for autos only, with truck lane slightly wider for truck and auto use	Increased options for work zone traffic control plans	Consider safety issues and compliance with MUTCD	Consider field test in conjunction with truck lane assignment
Portable rumble-strip type devices used in lane closures	Potential positive impact on alerting drivers entering work zone	Does not currently conform to MUTCD	Not at this time

Meanwhile, other strategies are already being used in some instances in Texas work zones, and so do not necessarily require significant testing to validate their effectiveness. Lanes are commonly narrowed in work zones, for instance, without significant impacts on traffic capacity or speeds (15). Of course, the extent to which different lane widths could be provided as a means of encouraging trucks to avoid a lane has not been extensively evaluated.

Of the items identified through the European scanning tour, the potential application of differential narrowed lanes (narrow lane for automobiles, wider lane or two for trucks and automobiles) and portable queue length detection systems are perhaps the most relevant to Texas at this time. Issues regarding signing, actual lane widths, and other considerations would need to be resolved prior to testing. Portable queue detection systems are discussed later in this chapter.

Systems to Minimize Queue-Jumping

Researchers in Indiana, Illinois, and Nebraska have been experimenting with strategies designed to significantly reduce the problems associated with queue-jumping at work zones. One of these, the Indiana Lane Merge system, utilizes a series of “DO NOT PASS” signs placed periodically upstream of the work zone (Figure 3) (16). The system creates an enforceable no-passing zone upstream of the lane closure queue, the length of which will vary depending on the length of queue that has developed. As Figure 3 illustrates, queue detectors at one location activate the no-passing sign upstream.

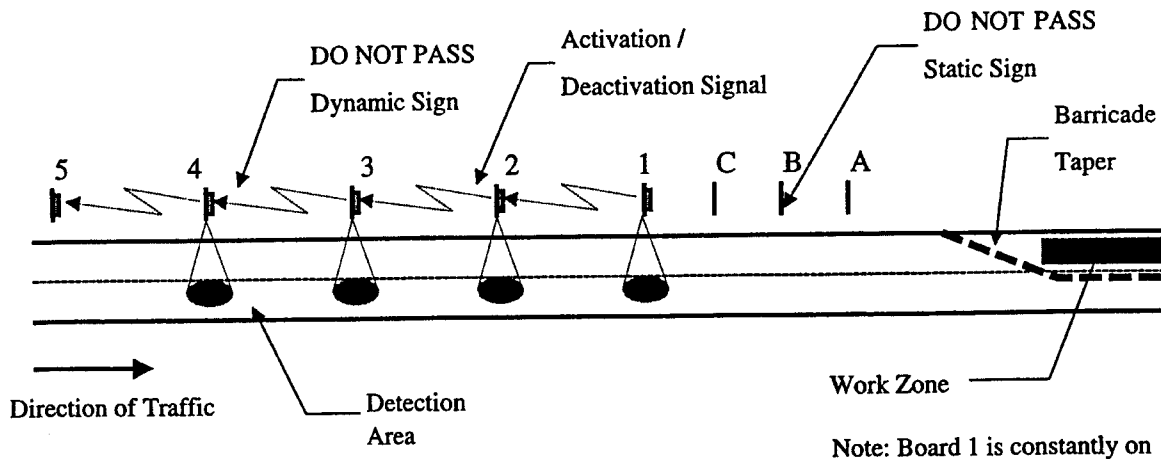


Figure 3. Illustration of the Indiana Lane Merge Concept (16).

The other approach that has been taken to alleviate queue-jumping at work zones has been to explicitly encourage motorists to delay when they move out of a closed lane prior to a work zone. This concept, termed Late Merge, incorporates static signing that asks drivers to remain in both lanes until they reach the merge point. At the merge point (i.e., the actual lane closure

location), a second static sign requires the motorist to take turns. This concept is illustrated in Figure 4 (17).

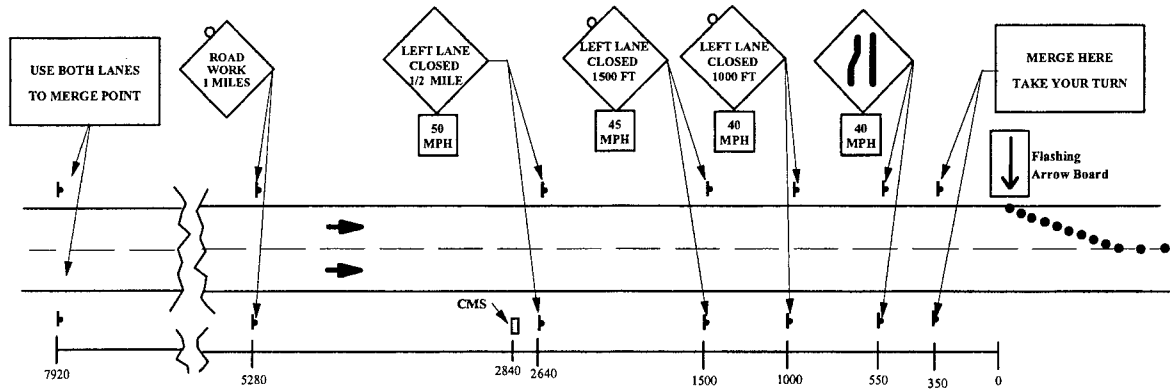


Figure 4. Example of the Late Merge Concept (17).

Both approaches have been shown to be effective in modifying driver behavior and reducing the frequency of queue jumping (17,18). However, both have only been evaluated in rural settings on four-lane divided roadways. In addition, significant limitations have been identified for each of these systems. For the Indiana lane merge, the most obvious limitation is the potential for longer queue lengths to develop upstream of the site, as all traffic merges into the open lane upstream of where the queue begins. This can require a significant number of “DO NOT PASS” signs and associated queue detection hardware/software. For the late merge concept, queue lengths tend to be shorter since both lanes are used for storage. Furthermore, researchers have found that the system can also significantly improve work zone discharge rates by filling in the large gaps that otherwise develop downstream of large trucks (18). While this approach works well as long as queues are present at the site, there are some concerns over motorist behavior under lower volume conditions without queues. Asking motorists to remain in the closed lane (at high speeds when no queues are present) may create undesirable conflicts and erratic maneuvers near the merge point (18).

When considering the potential applicability of these systems to work zones on high-volume, high-speed work zones in Texas, the biggest questions that arise are whether the systems can operate effectively on roadways greater than two lanes per direction. The Indiana merge concept would obviously require changes in signing to denote no passing in either the left or the right lane and could not address scenarios where the traffic-splitting technique was utilized in the middle of the roadway. Similarly, signing for the late merge strategy at the merge point may need to be modified slightly to ensure that lanes not requiring a merge would not be subject to the “take your turn” requirement.

Systems to Provide Individualized Feedback of Speeding Behavior at Work Zones

In addition to strategies and technologies discussed earlier in this chapter that are designed to assist enforcement personnel at work zones, there exists a body of technology that is intended to assist motorists in policing their own speed choice behavior. These systems rely on radar or other surveillance technology to detect the speed of approaching vehicles. The systems then take this information and display it back to the driver directly (as in the case of speed monitoring trailers) or present some type of advisory message (i.e., SLOW DOWN, YOU ARE SPEEDING, etc.) if the speed exceeds some preset threshold.

Studies of both the speed trailer and of speed-activated advisory messages have been shown to be effective in modifying vehicle speeds approaching a work zone (19-21). As in the case of the queue-jumping technology, these technologies have generally been limited to rural applications and two four-lane divided facilities (two lanes per direction). Questions remain concerning their ability to function effectively on a multi-lane, high-volume roadway or to significantly affect motorist speeds when a significant number of other vehicles are present in the traffic stream.

Another potential system for study is an offshoot of automated enforcement technology that has been used in Europe, where speeding vehicles are detected by radar or lidar and are identified with machine vision license-plate readers. The license plate is then immediately displayed on a downstream dynamic message sign along with a message "YOU ARE SPEEDING" (22). Although data are not available to review regarding the effectiveness of this technology, anecdotal information suggests that it does have a significant impact on speeds. Of course, automated speed enforcement technology is used quite extensively in Europe, and so license-plate detection may imply a much higher likelihood of citation in that context than in the U.S.

Portable Traffic Management Systems to Enhance Motorist Decision Making Upstream and Within the Work Zone Traffic Queue

The final strategy discussed in this chapter is the potential use of portable traffic management systems. Several systems have been developed in recent years that may have the potential to address certain safety problems that exist at work zones on high-volume, high-speed roadways. The primary systems available at this time are the following:

- the Smart Workzone (SWZ), also termed the Advanced Portable Traffic Management System (APTMS), developed under partnership between the Minnesota DOT; ADDCO manufacturing, Incorporated; FHWA; and the University of Minnesota Center for Transportation Studies;
- the Adaptir™ system, developed by the Maryland State Highway Administration;
- the Computerized Highway Information Processing System (CHIPS), developed by ASTI Transportation Systems; and
- the Travel Time Prediction System (TIPS) for work zones, developed at the University of Cincinnati for the Ohio Department of Transportation and FHWA.

A brief discussion of each is provided below.

Smart Workzone

The Smart Workzone is designed to be a portable real-time traffic management system. It consists of video cameras, video detection cameras, and magnetic sensors. The video detection and magnetic sensors provide speed and volume data, whereas the video cameras provide visual surveillance capabilities as exists in a typical traffic management center in an urban area (23,24). The information collected is fed back via wireless communications to a central location (such as a construction trailer located in the work zone) where an operator can monitor conditions in real-time. This information can then be sent to other locations via wireline communications. The operator at the construction trailer or other remote site can then display messages about current conditions on portable dynamic message signs that are part of the system. Information about conditions and/or messages being displayed can be made available over the Internet.

Adaptir™

The Adaptir™ system is termed a condition-responsive system in that it has incorporated some basic autonomous functionality that allows it to operate unattended. The system relies on radar sensors located on a series of portable dynamic message signs located within and upstream of the work zone. These radar data are fed to a central system controller over wireless communications that evaluates the data and makes determinations regarding the display of speed or delay messages on the signs. The system uses a “time stamp” designed to indicate that the information being provided is current. The system reportedly also supports lane control signal (LCS) operations and traveler advisory radio. The algorithms used to make message decisions appear to be fairly simple and straightforward. In a recent study of the system, a speed message (REDUCED/ SPD AHD/ XX MPH) was displayed on a sign whenever more than a 10 mph reduction in average speed was detected between the current sign location and the next sign downstream. The speed displayed was rounded to the nearest 5 mph (25). According to the vendor literature, the system can also generate estimates of travel time delay.

Computerized Highway Information Processing System

Another version of a condition-responsive system with potential work zone applications is the CHIPS manufactured by ASTI Transportation Systems, Incorporated. This system utilizes infrared queue length detectors developed through the Strategic Highway Research Program (SHRP) to determine when traffic has slowed below a preset threshold or has stopped. The detection of stopped traffic automatically triggers the display of preset messages on dynamic message signs, sends updates about the possibility of a traffic stoppage to a traveler advisory radio system, to local police offices, and to an Internet site (26). The system also appears capable of activating a ramp metering system to reduce demand onto the freeway (if desired).

Travel Time Prediction System

TIPS is another version of a condition-responsive system designed to provide real-time traffic management capabilities in work zones (23). The system relies on side-fired microwave radar detectors positioned at select points along and upstream of the work zone. Information from these detectors is sent via wireless communications to a central processor. There, the system

computes a real-time prediction of the current travel time through the work zone from several predetermined locations and activates dynamic message signs that display the current travel time from that point through the work zone (i.e., 25 MIN TO END OF WORKZONE) (27).

System Comparability

As the above discussion suggests, these systems each differ slightly in terms of technology used, objectives, and capabilities. Table 4 provides a side-by-side comparison of the systems across several criteria.

Table 4. Comparison of Available Traffic Management Systems for Work Zones.

	SWZ	ADAPTIR	CHIPS	TIPS
Method of Traffic Surveillance	• Video • Video Image Processing • Magnetic sensors	• Radar	• Infrared queue detection	• Side-fire microwave detectors
Method of Control	• Manual	• Automated	• Automated	• Automated
Information Dissemination Methods	• DMS • Internet	• DMS • LCS • TAR	• DMS • TAR • Internet • Ramp metering	• DMS
Information to be Disseminated	• Incident locations • Speeds • Warning messages • Advisory messages	• Speed reductions ahead • Delays	• Traffic stopped • Location	• Travel time from predetermined locations through the work zone

DMS = Dynamic Message Signs

LCS = Lane Control Signals

TAR = Traveler Advisory Radio

Referring back to Chapter 2, the ability to accurately convey queue length location and/or expected travel time from a given point through the work zone would be best suited to address the erratic exit maneuvers that researchers observed at the beginning of the traffic queues. Information about queue presence and speed could also prove useful in addressing the hard-braking maneuvers that occurred (assuming some of those maneuvers were due to motorists not paying attention to the queue as they approached). Based on these needs, it appears that the SWZ would not have significant potential for purposes of this research project. The other systems all could provide some potential benefit, although the extent to which this occurs would likely depend on the robustness of the system (including the algorithms used) and site characteristics. Testing of one or more of these systems is recommended to assess these issues in greater detail.

4. STRATEGIES RECOMMENDED FOR FURTHER EVALUATION

Based on the information presented in Chapters 2 and 3, TTI researchers believe a fairly large number of strategies warrant evaluation within the context of this current research study. Unfortunately, the funding required to assess all of the potential strategies to a useful degree outstrip available project funding. Therefore, the following evaluation priorities are recommended:

1. *Demonstration of the Real-Time Remote Enforcement Concept (depending on further vendor development)* – Excessive speeds in work zones, particularly those in high-volume areas, represent one of the key concerns to DOT and contractor personnel. The concept has the ability to allow enforcement officers to safely work certain restricted width work zones. The potential impacts upon motorist speeding behavior in work zones are expected to be significant. However, it must be tested in a real work zone to determine its overall suitability. Methods of simulating enforcement (such as noting a driver's vehicle license number along with a SLOW DOWN or YOU ARE SPEEDING message) could also be examined as part of this effort.
2. *Comparison of Available Portable Traffic Management Systems (depending on vendor participation)* – Three different systems (SWZ, ADAPTIR, and TIPS) offer unique capabilities that could prove useful (particularly the displays of real-time delays, queue locations, and downstream speeds) in addressing one or more of the possible safety problems described in Chapter 2. Data are needed, however, to determine whether the automated messages displayed are accurate and whether Texas motorists respond appropriately. This question is particularly relevant since none of the previous studies have examined roadways wider than two lanes per direction.
3. *Evaluation of the Late Merge Control Strategy* – Studies suggest that the late merge control strategy can reduce queue jumping behavior and increase work zone discharge rates when a four-lane divided roadway is reduced to one lane in one direction. The applicability of this concept on wider roadways is not known and should be explored.

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APPENDIX A: RESULTS OF OBSERVATIONAL STUDIES AT HIGH-VOLUME, HIGH-SPEED WORK ZONES

OBJECTIVES

Researchers conducted a number of observational studies for this project in order to identify the types and magnitude of erratic maneuvers that can be potential safety problems at a work zone queue. It was believed that collection of data on erratic maneuvers could serve as a better measure than crashes of the unsafe conditions present due to work zone congestion, as they should be easier to observe in quantity. The erratic maneuvers to be studied included:

- driving through grass median to frontage road,
- forced merging,
- hard braking,
- moving into closed lane,
- queue jumping, and
- straddling two lanes.

SITE CHARACTERISTICS AND DATA COLLECTION METHODS

The project research team searched for work zones that would be suitable for data collection. For a work zone to be a good candidate, it needed to be in place for at least one day without moving the merge area, safe locations for the project team to observe traffic had to be present, and traffic levels needed to be high enough to provide the expectation that queuing would result. In addition, the congestion must have been expected at specific times, such as recurring peak hour congestion, in order for the data collection teams to maximize their effectiveness. Six work zones were visited for data collection for this project. The details of the projects are shown in Table A-1.

Table A-1. Data Collection Locations.

Study Site #	Site Location	City	Dates Visited	Direction
1	I-35	Austin	8/26-27/2000	• Southbound
2	I-35	Hillsboro	11/2/2000	• Northbound
3, 4	I-45	Houston	12/4-6/2000	• Southbound, Northbound
5, 6	US-59	Houston	1/9-10/2001	• Southbound, Northbound

Site 1 was a weekend project consisting of a full closure of Interstate 35 (I-35) at the interchange of I-35 and US-290 to allow for construction of a bridge overpass. Three normal lanes were reduced to two with traffic cones. All traffic on the two remaining lanes was shifted from the freeway to the frontage road to bypass the interchange. TxDOT used an enhanced traffic control plan in an attempt to minimize congestion. In addition to standard work zone traffic control, the traffic control plan consisted of extensive use of law enforcement to calm traffic, media announcements warning local motorists to avoid the area, and the closure of several nearby upstream on-ramps. Data collection consisted of videotaping the southbound approach to the work zone from a bridge overpass. In spite of the enhanced traffic control plan, researchers recorded 50 continuous minutes of congestion for analysis on the afternoon of August 26.

Site 2 was located on Interstate 35 near Hillsboro, TX. Construction work necessitated the complete closure of the interstate to demolish an overpass on November 2, 2000. Traffic in both directions was merged into one lane (from the normal two lanes per direction) and fed onto the frontage road, through the intersections with the crossing highway, and back onto the freeway. Regular advance signing was placed in both directions of travel, and portable dynamic message signs were placed farther upstream to warn that the freeway was blocked. The primary maneuver noted at this site was the frequent queue-jumping that occurred and the subsequent lane straddling by large trucks to block these queue jumpers.

Sites 3 and 4 were located at a major reconstruction project on Interstate 45 in downtown Houston, TX. The work zone consisted of a reduction of one of three lanes in the northbound direction, and motorists could remain in the other two lanes. In the southbound direction, the freeway was reduced from four lanes to two, and then all traffic was diverted around the activity area on the frontage road. This was a long-term project, remaining in place from October 2000 to January 2001. The research team collected data for multiple days at both peak and off-peak times using videotape from both portable video recorders and TxDOT closed circuit television (CCTV) cameras. Data was collected for the northbound traffic by the research team during peak hours, and all other data was collected by the use of the CCTV cameras.

In the field, the researchers documented the occurrence of erratic and aggressive maneuvers at the beginning of the lane closure taper and approximately 1500 ft upstream of the beginning of the taper. From the CCTV cameras researchers observed the freeway section where US-59S traffic exits I-45N to determine if drivers divert to US-59 when the queue from the work zone reaches the split area.

Sites 5 and 6 were on US-59 at FM 1960 north of Houston, TX. The work zone was a nighttime temporary closure to allow for an overlay on a bridge deck at FM 1960. Each direction of traffic was diverted from the freeway lanes onto the frontage roads to pass the work zone. Law enforcement was used to completely block the freeway for several minutes to allow for the contractor to place the work zone traffic control devices. This blockage created a queue in both directions, but due to relatively low evening volumes the queues quickly dissipated. The data collection team was able to videotape traffic conditions from a moving vehicle within the queue and was able to observe several erratic maneuvers.

Results and Conclusions

Results for each site are summarized below. Data was collected slightly differently at each site. Therefore, the format of the results differs slightly from one site to the next.

At Site 1, forced merges, hard braking, and driving through the grass median were recorded. These results can be found in Table A-2. In addition to motorists leaving the freeway through the grass median, it was unexpectedly observed that some motorists were also willing to cross in the opposite direction across the median to come onto the freeway. In addition, researchers observed that motorists were willing to drive through the median even with a law enforcement vehicle in the vicinity.

Table A-2. Erratic Maneuvers Observed at Site 1.

Count Start Time		1 Number of Cars	2 Number of Trucks	3 Forced Merges		4 Hard Braking		5 Freeway To Frontage Road Through Median		6 Frontage Road To Freeway Through Median	
hr:min:sec				# of VEHS.	# of Conflicts	# of VEHS.	# of Conflicts	# of VEHS.	# of Conflicts	# of VEHS.	# of Conflicts
1:03:30	1:08:30	150	11	6	7			7	27*	1	0
1:08:30	1:13:30	121	8	4	4	3	4	1	3	1	0
1:13:30	1:18:30	150	10	2	2						
1:18:30	1:23:30	139	7	1	2						
1:23:30	1:28:30	128	6					14	?		
1:28:30	1:33:30	131	8			2	2	1	1		
1:33:30	1:38:30	169	8	1	1						
1:38:30	1:43:30	137	13	1	12**						
1:43:30	1:48:30	162	8	2	2						
1:48:30	1:53:30	153	4			1	3				
		1440	83	17	30	6	9	23	31	2	0

* Number of conflicts here includes 13 conflicts on the frontage road as the cars entered the frontage road from the median and 14 conflicts on I-35 due to vehicles needing to brake sharply to avoid hitting the cars pulling onto the median.

** Number of conflicts here reflects the number of cars needing to brake to avoid hitting the car in front of them. One car attempted to change lanes, but drove down the middle of both instead, disrupting the flow of the rest of the platoon.

At Site 2, data on the number of trucks and the frequency of truck lane straddling maneuvers were noted. The northbound queue at this site developed up to about 1 mile in length and then stabilized. The majority of vehicles attempted to merge into the open lane as soon as the notification of a freeway blockage and merging activity was identified by the DMS and advance signing. However, an occasional passenger vehicle did move into the closed lane and travel down the entire length of queue. Researchers monitored the approximate 1500 feet upstream of the actual exit ramp where traffic was diverted onto the frontage road. It was noted that out of 121 trucks that were observed moving through the traffic queue over that distance, 26 (21.4 percent) straddled the lane line or matched up with an adjacent truck to block the open lane. During that time, one passenger vehicle was observed passing one of the trucks that was traveling in the open lane on the right shoulder.

At Sites 3 and 4, data was recorded in the field at two locations for the northbound approach and for one on the southbound approach. The northbound and southbound results are presented here separately.

The two locations for data collection in the northbound direction were (1) from the beginning of the taper to approximately 1000 ft upstream of the taper and (2) from approximately 1000 ft upstream of the taper to approximately 1500 ft upstream of the taper. Tables A-3 and A-4 show the types of maneuvers observed in both sections during a peak and non-peak period, respectively. The peak period study was conducted on Tuesday, December 5, 2000, from 6:50 am to 8:30 am. The non-peak period study was conducted from 9:30 am to 10:30 am on the same day.

Table A-3. Peak Period Maneuvers, Site 2 Northbound.

Maneuver	0 ft - 1000 ft ^a		1000 ft - 1500 ft	
	Passenger Vehicles	Trucks	Passenger Vehicles	Trucks
Hard Braking	13	0	0	0
Queue Jumping ^b	3	0	0	0
Forced Merging ^c	159	41 ^d	53	3 ^e
Moved into Closed Lane	1	0	0	0
Straddling Two Lanes	0	1	0	0

^a Observations from the beginning of the taper to 1000 ft upstream of the beginning of the taper

^b A vehicle that intentionally drove in the closed lane to pass other traffic

^c A vehicle that had to force their way into the open lane adjacent to the closed lane

^d Includes three school buses and one city bus

^e Includes two school buses

The researchers during the peak field studies noted the following observations:

- The majority of the vehicles in the closed lane merged into the adjacent open lane at the taper (i.e., the vehicle followed the taper into the open lane).
- The majority of the vehicles in the closed lane 1000 ft upstream of the beginning of the taper did not act like they wanted to exit the closed lane (no blinkers and traveling in the center of the closed lane).
- One near accident was observed approximately 1000 ft upstream of the beginning of the taper when an sport utility vehicle forcefully merged (cut off) a semi-truck.
- Based on a 15 minute count, the volume in the closed lane 1000 ft upstream of the beginning of the taper was 1056 vph (both passenger vehicles and trucks).

Table A-4. Non-Peak Period Maneuvers, Site 2.

Maneuver	0 ft - 1000 ft		1000 ft - 1500 ft	
	Passenger Vehicles	Trucks	Passenger Vehicles	Trucks
Hard Braking	23	2	3	0
Queue Jumper ^a	3	0	0	0
Forceful Merging ^b	91	10	1	0
Moved into Closed Lane	1	0	0	0
Straddling Two Lanes	0	0	0	0

^a A vehicle that intentionally drove in the closed lane to pass other traffic

^b A vehicle that had to force their way into the open lane adjacent to the closed lane

The researchers during the non-peak field studies noted the following observations:

- In general, traffic was free-flowing during the non-peak study.
- A passenger vehicle traveling in the open lane adjacent to the lane closure was behind a semi-truck. Very close to the beginning of the lane closure the car moved into the closed lane and slammed on its brakes after realizing the lane was closed. The vehicle moved immediately back into the open lane behind the semi-truck.
- The passenger vehicle and truck volumes in the closed lane 1000 ft upstream of the beginning of the taper were 468 vph and 4 vph, respectively (based a 15 minute count).

Using the CCTV cameras, researchers observed the freeway section where US-59S traffic exits I-45N. This location is upstream of the lane closure, but within the queue during peak periods. Traffic was observed during peak and non-peak conditions to determine if drivers divert to US-59 when the queue from the work zone reaches the split area.

Table A-5 contains the types of maneuvers observed at the US-59S/I-45N split. The morning peak period study was conducted on Wednesday, December 6, 2000, from 7:00 am to 8:00 am. The evening peak period and non-peak period studies were conducted on Tuesday, December 5, 2000, from 4:52 p.m. to 5:52 p.m. and from 3:00 p.m. to 4:00 p.m., respectively. The weather was cloudy with wet pavement for the morning peak observations. In contrast, the weather for the evening peak and non-peak studies was sunny and clear.

Table A-5. Maneuvers at the US-59/I-45 Split.

Maneuver	Morning Peak		Evening Peak		Non-Peak	
	Passenger Vehicles	Trucks	Passenger Vehicles	Trucks	Passenger Vehicles	Trucks
I-45 to I-59	1	0	8	0	3	0
I-59 to I-45	8	0	4	0	14	1
Hard Braking	25	5	0	0	3	0

The researchers during the peak CCTV studies noted the following observations:

- During the morning peak, the queue from the work zone periodically extended upstream of the US-59S/I-45N split outside of the field of view of the cameras. Traffic traveling onto US-59S also intermittently queued on the exit ramp back to I-45N.
- During the evening peak, the end of the work zone queue was generally located on I-45N immediately downstream of the US-59S/I-45N split.

Researchers collected data at the southbound traffic on I-45 during peak and non-peak conditions using CCTV cameras. The field of view of the camera used included the first lane closure; however, the entire closure could not be seen because of permanent obstructions (e.g., bridge piers and train tracks). Thus, researchers observed maneuvers in the middle of the first taper (between 350 ft and 600 ft downstream of the beginning of the taper) to the best of their ability.

Table A-6 contains the maneuvers observed within the first lane closure for southbound I-45. The morning peak period study was conducted on Wednesday, December 6, 2000, from 7:23 am to 8:23 am. The evening peak period and non-peak period studies were conducted on Tuesday, December 5, 2000, from 4:50 p.m. to 5:56 p.m. and from 3:00 p.m. to 4:00 p.m., respectively. The weather was cloudy with wet pavement for the morning peak observations. In contrast, the weather for the evening peak and non-peak studies was sunny and clear.

Table A-6. Maneuvers, Southbound Site 4.

Maneuvers	Morning Peak		Evening Peak ^b		Non-Peak	
	Passenger Vehicles	Trucks	Passenger Vehicles	Trucks	Passenger Vehicles	Trucks
Hard Braking	0	0	0	4	7	0
Forceful Merging ^a	43	3	36	5	22	3
Moved into Closed Lane	7	0	9	1	10	0

^a A vehicle that had to force their way into the open lane adjacent to the closed lane

^b Data was collected from 4:50 p.m. to 5:00 p.m. and from 5:23 p.m. to 5:56 p.m.. From 5:00 p.m. to 5:23 p.m. a train blocked the view of the CCTV camera.

The researchers during the morning peak noted the following observations for southbound I-45:

- The queue from the work zone extended upstream of the I-10 interchange, which is approximately 3000 ft (1/2 mile) upstream of the beginning of the lane closure taper.
- One passenger vehicle entered the work zone within the lane closure taper, stopped, and then re-entered the traffic stream.
- One of the semi-trucks that forcefully merged into the adjacent open lane almost collided with two passenger vehicles during the merging process.
- The passenger vehicle and truck volumes in the closed lane approximately 500 ft downstream of the beginning of the taper (i.e., within the taper) were 1028 vph and 8 vph, respectively (based on a 15 minute count).

The researchers during the evening peak noted the following observations for southbound I-45:

- The queue from the work zone extended to the I-10E entrance/exit ramp, which is approximately 1000 ft upstream of the beginning of the lane closure taper.

- One motorcycle entered the work zone immediately downstream of the beginning of the taper and then proceeded to travel in the work zone out of the field of view of the camera.
- The passenger vehicle and truck volumes in the closed lane approximately 500 ft downstream of the beginning of the taper (i.e., within the taper) were 1176 vph and 30 vph, respectively (based on a 15 minute count).

The researchers noted the following observations during the non-peak period for southbound 1-45:

- The queue from the work zone extended to the I-10E entrance/exit ramp, which is approximately 1000 ft upstream of the beginning of the lane closure taper.
- The passenger vehicle and truck volumes in the closed lane approximately 500 ft downstream of the beginning of the taper (i.e., within the taper) were 976 vph and 8 vph, respectively (based on a 15 minute count).

At Sites 5 and 6, the data collection team was moving in the traffic stream and was not able to observe all traffic in the queue. As a result total number of occurrence of erratic maneuvers was not obtained. Several erratic maneuvers were observed, however, including:

- queue jumping, and
- cutting across gore area to exit at upstream off-ramp.

The aggressive exiting of vehicles at the upstream off-ramp consisted of vehicles cutting across the gore area to exit upstream of the work zone. This maneuver was not previously considered for study, but clearly poses a safety concern.

APPENDIX B:
SURVEY OF LAW ENFORCEMENT PERSONNEL

INTRODUCTION

Work zone enforcement is critical for maintaining safety and obtaining motorist compliance with traffic control regulations. However, due to the restrictive nature of a work zone (narrow lane widths, reduced number of lanes, work activity, etc.), it is often difficult for an officer to be effective. This research examines how work zones can be improved to better support enforcement efforts.

This research project has two objectives. The first stated objective is the improvement of work zone enforcement areas and, therefore, enforcement presence within the work zone. The second is the identification of key traffic management and safety problems on high-speed, high-volume facilities. The work summarized here focuses on the first objective and was accomplished by contacting state law enforcement agencies around the United States to determine the state of the practice in work zone enforcement strategies.

INTERVIEW PROCEDURE

State law enforcement agencies from 20 states were contacted by telephone to determine how work zones are enforced in their respective states. Specifically, these agencies were contacted to gain insight on the law enforcement officer's perspective regarding the methods used in work zone enforcement. Typical contact persons included public relations officers, troop commanders, or troopers who actively patrol work zones. In a few cases, it was possible to speak directly with officers responsible for training other law enforcement officials in proper work zone enforcement.

Each officer was asked questions provided on the telephone survey created for this task. A copy of this survey is attached at the end of this document. Each call took approximately 45 minutes, but varied depending on the amount of information the specific officer was able to provide.

In addition to explaining how the officers operate in work zones, they were also asked several questions about the main reasons officers were most effective in their states, and also ways they could be even more effective. Answers varied, depending on the opinions and experiences of the officers interviewed and the specific policies of the officer's state. A summary of the comments is provided below.

The states contacted include:

- | | | |
|---------------|-----------------|----------------|
| • California | • Maryland | • Pennsylvania |
| • Colorado | • Massachusetts | • South Dakota |
| • Connecticut | • Michigan | • Utah |
| • Delaware | • Minnesota | • Wisconsin |
| • Florida | • Missouri | |
| • Illinois | • New Jersey | |
| • Iowa | • Ohio | |
| • Kansas | • Oregon | |

INTERVIEW RESULTS

This section summarizes the data obtained from the telephone interviews. Please note that some officers indicated multiple answers, indicating that more than one strategy or procedure is used in their state, and in some cases the officer was unsure of the answer. As a result, the sum of the responses for each question does not equal the sum of the total number of interviews.

How work zone enforcement is paid for:

- Eleven states require the construction contractor to hire the law enforcement as a subcontractor.
- Eight states indicate that their department of transportation hires them directly. In some cases this was for all work, and in some cases it was only to enforce DOT maintenance work zones.
- Eighteen states use off-duty officers either totally or at least to supplement work zone enforcement.
- Four states indicated that work zone enforcement activities are part of an officer's normal duty, so additional money was not an issue. In these cases, an officer might only be stationed at a work zone in 1-2 hour increments during the course of a shift.

Where officers are positioned in a work zone:

- Thirteen states indicated that officers used stationary enforcement techniques, positioning themselves at various points in the work zone, such as at the upstream end or the activity area.
- Nine states indicated that circulating patrols were used on a regular basis. In two states, it was indicated that circulating patrols were used exclusively, with no stationary enforcement.
- Five states (predominantly in the Northeast) reported the use of police acting as traffic controllers outside their patrol cars. In these cases, this was the predominant enforcement activity of officers.
- Four states also reported actively increasing the regularity of other officers in the area to gain an increased presence in the work zone area.
- One state indicated that work zone enforcement was conducted "at the edges of the work zone." Officers spend their time in an area up to 5 miles prior to the beginning of the work zone. By patrolling this area, it was believed that the officers are more effective because they have more room to maneuver and apprehend violators.

Typical comments from interviewed officers:

- The positive response most often stated by officers was that a highly visible enforcement officer and/or patrol car had the most positive impact on speed reduction. This was stated as a positive impact whether the officers were stationed outside of their vehicles as traffic controllers or if they were required to stay in their vehicles.
- Another desirable attribute often mentioned was good communication with their state department of transportation. In some cases, these officers have liaisons that work directly with the DOT. In others, they have little contact and hope to improve it.
- Media campaigns were generally thought to be very helpful in getting motorists to comply with work zone speed limits. Several different types of media outlets were mentioned, including television news stories, radio news stories, and paid commercial advertisements by

the highway patrols and department of transportation. These could be general warnings about the presence of work zones, public education about double fine laws, specifics about a work zone such as which ramps were open and which were closed, or the planned use of aerial enforcement.

- One officer reported that his state prints a construction map every year and distributes it at all rest areas and drivers license stations in the state.
- Several officers mentioned being provided with truck mounted attenuator vehicles to shield the patrol car from a collision. This was felt to be a positive move to increase the safety of the officers in the work zone. No mention was made of reducing the visibility of the officers to the public.
- Two states expressed interest in using a team of officers to enforce a single work zone. In one example, it was mentioned that it could be effective to have a radar operator at the beginning of the work zone and a second officer to pull violators over after the end of the work zone. In the second case, it was mentioned that the second officer could be used to move with the upstream end of the queue as a warning to approaching motorists.
- Several states mentioned that new technology is or has the potential to help with work zone enforcement. Specifically mentioned are automated speed enforcement cameras (South Dakota has purchased several sets, but cannot use them for enforcement unless the laws change) and lidar speed guns, which seem to be more effective in picking out individual cars from a platoon.
- One officer thought that equipping several DOT inspection pickups as squad cars might be a way to increase speed compliance. If these vehicles were heavily utilized and advertised in the media so the public was very aware of them, motorists would be more aware of regular DOT vehicles, and be more likely to comply with the reduced speeds. "They would start to think all DOT inspectors' trucks were police."

SPECIAL WORK ZONE PROGRAMS

In two states, special work zone enforcement programs were identified. The purpose of these special programs is to increase the effectiveness of work zone enforcement. Both of the special programs are briefly described.

South Dakota DOTCOP Speed Enforcement program

The DOTCOP program is a work zone speed enforcement program administered by the South Dakota Highway Patrol (SDHP). This is the mechanism that allows officers to be placed at a work zone in an overtime capacity. A DOTCOP wears a distinct uniform and drives a distinct patrol car, which designates it as a work zone enforcement vehicle (it says DOTCOP on the patrol car).

These officers only have jurisdiction in and around the work zone area. As a result, any arrest or other action, which might require the DOTCOP to leave the work zone, is beyond his/her powers. In such a case, another officer must be brought to the scene. This is useful because the DOTCOP is able to stay at the work zone.

SDHP introduced this program in 1997, and it showed some rather immediate results. The rate of interstate work zone accidents (normalized for any fluctuation in annual construction activities) decreased the first two years after implementing this program. Additionally, there were no fatal accidents within interstate work zones in 1999. The primary objective of the program was to improve work zone safety for the workers and the traveling public. It is generally felt by the SDHP that speeds have decreased in work zones due to this program and through public education. No data were available to verify this statement, however.

This program had one unique feature not utilized by another state: any sworn officer or retired officer with a current firearm certification can become a DOTCOP. As a result, local police and even retired troopers may take part in the program, increasing the pool of potential manpower.

New Jersey Division of State Police Construction Unit

The state of New Jersey maintains a unit of 35 state police officers who are dedicated to work zone enforcement. These officers work approximately nine months of the year enforcing work zones and supervising other officers manning a work zone on an overtime basis. All coordination for placing officers at work zones is done by this unit. In addition, these dedicated officers are certified Occupational Safety and Health Administration (OSHA) safety inspectors and are considered the main state safety inspector for a work zone.

During the winter months, this unit conducts training of other officers to prepare them for work zone enforcement duty. DOT engineers also receive training from this unit, to gain a better understanding of work zone enforcement duties. This unit also reviews traffic control plans and attends work zone planning meetings with the New Jersey DOT.

This program is easily the most comprehensive law enforcement program identified in this study. This unit maintains excellent communication with the DOT, and at the same time maximizes the enforcement potential through extensive officer training.

CONCLUSION AND RECOMMENDATIONS

Several interesting strategies were identified during this interview process that might be useful in improving work zone enforcement in Texas. These include alternative strategies that could increase the pool of law enforcement that is available to enforce work zones, undercover work zone strategies, and use of innovative enforcement technology. Any legal or jurisdictional issues that may impede the implementation of any of these strategies have not yet been addressed. These are merely strategies that are thought to be potentially useful in Texas.

Increase the Pool of Available Enforcement Manpower

One strategy that might be worthy of further analysis is the creation of a DOTCOP-like program, similar to that found in South Dakota. This would then allow local law enforcement agencies and possibly even retired officers the opportunity to be used in an overtime capacity to enforce work zones on state roadways. This might be useful to overcome any manpower shortages the Texas Department of Public Safety may have in staffing work zone enforcement shifts. The

South Dakota experience seems to indicate a positive safety benefit as well. This strategy could involve some legislative action in order to be legitimized.

Undercover Speed Enforcement Strategy

One officer mentioned that equipping several DOT pickups as squad cars could be a useful enforcement tool. If properly advertised, motorists would be aware of their presence and then might be inclined to think that every DOT pickup is an unmarked police vehicle. The potential result could be a speed reduction at all work zones, at relatively low cost.

Automated Speed Enforcement Equipment

Automated speed enforcement equipment was only mentioned by one officer: South Dakota purchased automated speed enforcement cameras, but are unable to use them due to legislative restrictions. Legal issues currently limit the application of truly automated enforcement in most states, including Texas.

APPENDIX C: FEASIBILITY OF REAL-TIME REMOTE SPEED ENFORCEMENT FOR WORK ZONES

Law enforcement officers can encounter a number of difficulties while performing work zone speed enforcement. The tight geometric constraints of work zones can limit the number of areas where officers can both set up to perform enforcement duties and also apprehend violators. The relatively fluid nature of work zones also requires that the officer constantly be aware of the current conditions at the site. All of these factors act as deterrents to the effective enforcement of work zone speed limits.

AUTOMATED SPEED ENFORCEMENT

Automated speed enforcement systems can provide work zone speed enforcement without many of the drawbacks of using police officers. These devices utilize a radar or lidar unit that is either aimed across a road or directly at oncoming traffic. Devices that utilize sensors placed in or embedded in the road are also available, but these units typically require more maintenance, particularly under high traffic volumes.

When a vehicle crosses through the radar/lidar beam of an ASE system while traveling above a preset speed threshold, a photograph is taken of the vehicle's license plate. Photos of the driver are also sometimes taken if needed for evidentiary reasons. Typically, these photographs are used to mail traffic citations to the registered owner of the vehicle. The ASE system offers the potential to act as a deterrent in much the same way as a law enforcement officer, but also offers a chance to improve safety within the work zone since officers will not have to attempt to pursue offenders within the high speed work zone.

Effectiveness

ASE has been used as a speed control and enforcement tool by over 40 countries around the world, with some systems having been in place for up to 30 years (28). Although no studies of the impact of ASE on work zone speeds could be located, numerous studies of the effectiveness of ASE units on residential roads and freeways indicate that automated enforcement could have a positive impact on speeds and safety.

ASE has been used extensively in Europe for a number of years. In 1978, ASE units were installed on a high-accident portion of the German autobahn (29). Prior to the installation of the photo radar, the 85th percentile speed was 93 mph in a 62 mph zone. The 85th percentile speed dropped to 65 mph after ASE was put in place. The yearly number of accidents also was reduced dramatically after the system was installed (28). A study in the Netherlands evaluated the effects of ASE when combined with variable message sign warnings (30). Researchers conducted the study on two-lane rural roads with 50 mph speed limits. This study found that average speeds were reduced by 3 mph and the 85th percentile speeds were reduced by 5 mph. The percent of vehicles speeding dropped from 38 percent to 11 percent after the system was installed.

Norway began using ASE in 1988 and now has units on 209 mi of road (31). The ASE units are usually set to take pictures when vehicles are traveling more than 6 mph over the speed limit. A study found that the number of injury accidents on the portions of road with the ASE systems

had declined an average of 20 percent, and the total number of accidents on these sections had declined between 5 and 26 percent.

Canada and Australia have both used ASE in order to address speeding concerns (29). In Ontario, a one-year ASE pilot program reduced the number of vehicles exceeding the speed limit by 50 percent. The number of vehicles traveling at 87 mph or more in a 62 mph zone was reduced by 74 percent. In the Australian state of Victoria, the percent of traffic exceeding the speed threshold for enforcement fell from 10.8 percent to only 2.4 percent after the ASE system was implemented.

ASE systems are not used as widely in the United States. In 1998, there were only four states that utilized ASE: Arizona, California, Colorado, and Oregon (32). The primary application of ASE in the United States has been at the local level. This is primarily due to the increased flexibility that local governments have at creating a legal framework that allows the use of ASE systems. Two of the cities where photo radar is being used extensively are Paradise Valley, Arizona, and Riverside, California. Pasadena, California used to operate an extremely active ASE program, but the program has been discontinued, in part due to adverse public reaction to the system (32). In all locations where ASE has been implemented in the U.S., citations carry the same weight as parking tickets and are not considered moving violations. Legal provisions exist whereby if the owner is not the driver of the vehicle when it is photographed, the owner can choose to identify the driver and avoid the fine.

Paradise Valley uses a mobile ASE unit that is positioned in an attended, marked police vehicle. Signs warning of the presence of photo radar are placed at the entrances of neighborhoods and just upstream of the current position of the photo radar (28). The citation rate is approximately 19 times that of mobile police patrols. The photo radar program has become a revenue generator for the city since the income far exceeds the cost. City officials say the speeds on most roads have decreased, and the ASE has freed officers to address other issues. No speed data was found to substantiate these claims.

Riverside, California, has used ASE since mid-1991 and recently performed a study to determine the impact of the system on speeds adjacent to and downstream of the ASE unit (33). The effectiveness of photo radar was evaluated on several collector roads with a posted speed limit of 25 mph and a traffic volume no greater than 10,000 vehicles per day. Photographs were taken when vehicles were detected traveling over 10 mph. The photo radar was mounted in a van marked with the local law enforcement agency insignia. The photo-radar van produced average speed reductions of 5.1 mph alongside the van and 4.1 mph about 1000 feet downstream of the site. The photo-radar reduced the percentage of vehicles traveling more than 10 mph over the 25 mph limit from 52.1 percent to 21.9 percent when the van was in place. This 30 percent reduction in the percentage of vehicles traveling more than 10 mph over the speed limit was still present 1000 feet downstream of the installation.

While most American applications have occurred on relatively low-speed urban roads, a study conducted by Lynn, et al. evaluated the effectiveness of photo radar for use on high speed, high-volume facilities (34). Photo radar equipment from five manufacturers was tested for two weeks on I-64, I-81, I-295, I-95, and I-495 in Virginia and I-95 in Maryland. The most efficient model

detected and adequately photographed 2.4 percent of vehicles exceeding the speed limit, and the least efficient detected and adequately photographed 1.7 percent of vehicles exceeding the speed limit. This translates into 65 citations/hour for the most efficient model and 9 citations/hour for the least efficient model. The less efficient model still outperforms a traffic officer's capabilities.

Applicability to Texas

Several potential legal barriers must be overcome before ASE units can be used in Texas. Under current Texas law, registered owners cannot be presumed to be responsible for the unlawful operation of their vehicle by another driver. Thus, the identity of the driver must be known so that they can be charged with the offense. In order for ASE systems to be usable in Texas, legislation must be passed in order to allow the registered owner of the vehicle to be charged with the offense. Enabling legislation passed in other states is set up similar to laws that assume the registered owner is responsible for parking tickets. In these cases, the ASE tickets are punishable by a simple fine but do not result in points on the license. In August 1990, the TxDOT General Council noted that the only possible recourse to force an owner to identify the driver in an ASE photograph would be contempt of court (7). The 5th Amendment to the U.S. Constitution could also be used to challenge citations under the due process clause if the owner is assumed to be liable for violations. Finally, in Texas spouses cannot be forced to testify against their husband or wife, which may make it difficult to enforce the program (7). The lack of enabling legislation and the potential for frequent legal challenges make it unlikely that an ASE system could be implemented on the state system anytime soon.

REMOTE ENFORCEMENT CONCEPT

A prototype remote enforcement system that can allow an officer to enforce work zone speed limits safely and efficiently was developed as part of this project. The proposed system combines the advantages of ASE systems with actual enforcement at the scene by a law enforcement officer. Vehicles that are exceeding the posted speed limit approaching or within the work zone are photographed by the system. The picture of the violator is transmitted to an officer stationed at a location downstream that permits safe enforcement of violations. The distance between the officer and the speed detection and imaging station must be sufficient to allow for data transmission, but should not be so long as to interfere with the officer accurately identifying the offender. ASE systems currently available do not provide data transmission capabilities. Thus, it is hoped that by transmitting images in real time, the officer will be able to set up in a safe location outside of the work zone and enforce the speed limits within the confines of the existing Texas law.

The remote speed enforcement unit will consist of the following four major components:

- speed detection system,
- vehicle imaging system,
- wireless communications system, and
- downstream viewing system.

Implementation of remote enforcement systems on a widespread basis could also create additional opportunities to improve safety in work zones. Automated speed enforcement is regularly used on some European facilities. On these roads, signs warning of the use of automated speed enforcement systems are in place continually, but the actual devices are only used sporadically. These signs result in lower speeds on these facilities even when the cameras are not in use. The remote system could also generate widespread reductions in vehicle speeds if signs and dummy installations are used at locations where no officer is present.

Prototype System Description

A prototype system was constructed using off-the-shelf technology. Kustom Signal/Lasercraft provided an automated speed enforcement system to detect and photograph violators. Nova Engineering, Inc. provided high-speed wireless routers for data transmission. The Texas Transportation Institute then developed software to facilitate communications between the upstream camera installation and the downstream observers.

Speed Detection and Vehicle Imaging System

The Kustom Signal/Lasercraft Traffic Monitoring System (TMS) provided the basic technology to capture images of speeding vehicles. The TMS is intended to be a stand-alone system used for automated speed enforcement. It consists of a Prolaser III lidar gun mounted on top of a high resolution 300 mm lens. Figure C-1 shows the lidar and camera provided. By using a lidar gun, the TMS can accurately determine the speed of an individual vehicle from within a group of vehicles.

This system is connected to an industrial computer that runs a data acquisition program and stores digital images of violators. Figure C-2 shows the computer along with the DC power supply. Two proprietary programs were provided by the manufacturer:

- a data capture program that allowed the user to set parameters such as image brightness and the range during which images should be taken, and
- a viewer program that allows images to be viewed with speed and location information superimposed on the picture.

The data capture program shows real-time video of the vehicles passing through the camera's view, while the viewer program only shows the still image files that were captured by the system. The images collected by the TMS can be stored as either JPEG or bitmap files. All photos were in black and white. Figure C-3 shows the image file as displayed by the viewer program. The entire system was powered by a 12VDC power supply.



Figure C-1. Traffic Management System Lidar and Camera.



Figure C-2. Traffic Management System Computer.

Wireless Communications System

Nova Engineering provided NovaRoam 900 wireless routers to provide communication between the camera and the downstream data collection station. The NovaRoam 900 is a spread spectrum wireless Ethernet router with an embedded TCP/IP stack. It uses an Ethernet connection to wirelessly transmit data using the TCP/IP protocol. The wireless routers were connected to the computers at the upstream camera position and the downstream observation site. Magnetic mount antennas were used to facilitate communications between the two NovaRoam units. The stated maximum range of the routers was approximately 2 miles.

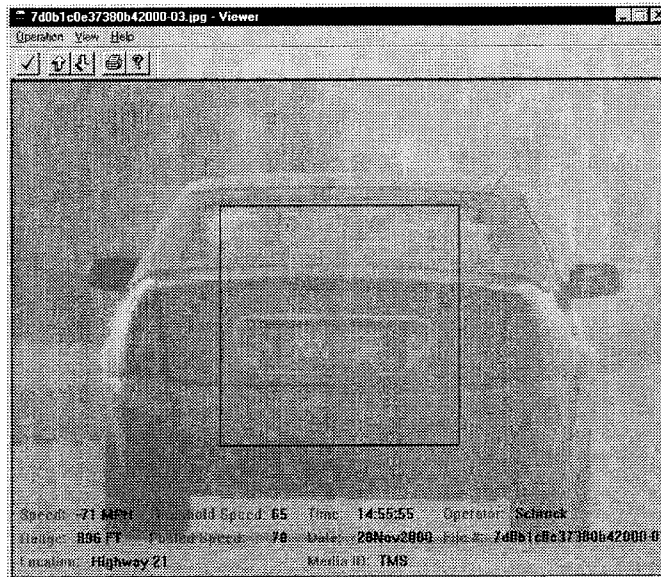


Figure C-3. Sample Picture Produced by TMS.

Downstream Viewing System

The downstream viewing system consisted of a commercial laptop and a NovaRoam 900 router. The Texas Transportation Institute developed two pieces of software to allow the laptop computer to communicate with the upstream camera system. First, a data transfer program was developed for use on the camera's computer. This program checked a directory every 3 seconds to see if new images were present. If a new image was located, it was transmitted, and then moved into a different directory.

A data reception program was also developed for use on the downstream laptop. This program provided an audio signal when a new image was present. An inverted image was also shown to the observer. The image was not correctly presented because the image is encoded by the manufacturer's software and can only be properly viewed through the use of the viewing software. When a new image arrives, the user presses the "Launch Viewer" button to start the developer's proprietary software, which allows the user to see an image similar to Figure C-3. Figure C-4 shows the viewing window that was initially presented to the downstream observer.

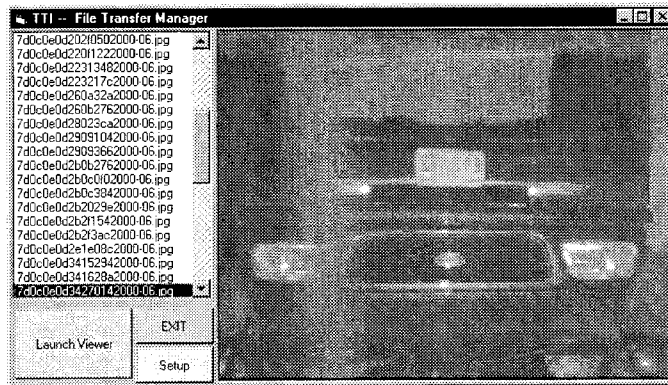


Figure C-4. Downstream Viewer Window.

DATA COLLECTION

Data on the performance of the speed enforcement system was collected in two phases. First, the system was tested in the field to determine some of its basic operating capabilities. Second, two demonstrations were performed for law enforcement personnel to determine prevailing opinions on the use of the device.

Field Data Collection

The purpose of the field data collection was to determine whether implementation of the system in the field was practical. Limited testing was performed in order to identify potential operational limitations and determine areas where the system could be improved. The specific goals of the field evaluation were to determine:

- maximum effective data transmission range,
- ability of observers to correctly match images to passing vehicles,
- impact of speed threshold and traffic volume and data transmission, and
- factors impacting identification of vehicles.

The system was field tested at four sites in Brazos County, Texas. All sites were four-lane divided highways with a 70 mph speed limit. Table C-1 summarizes the characteristics of the sites.

Table C-1. Site Characteristics.

Site	Date	Speed Limit	Vehicles Per Hour	
			Right Lane	Total
SH 47 SB	11/10/00	70	211	284
SH 47 SB	11/14/00	70	92	112
SH 21 WB	11/21/00	70	566	1067
SH 21 WB	11/28/00	70	232	350

The system was set up on the right shoulder at each site. All sites were relatively flat. Data were collected on sunny, dry days. The camera was typically aimed between 600 to 800 feet downstream of the TMS installation. Figure C-5 shows a typical TMS installation.

Data collection personnel were located at two positions. One member of the data collection team was stationed at the TMS to ensure that the equipment was operating properly. This person also counted vehicles that passed the data collection station. Two other members of the data collection team drove downstream of the camera setup. The first member of the team was designated as the observer. This person had the responsibility of attempting to correctly match passing vehicles to the images that were transmitted to the laptop. The second member of the data collection team determined whether the observer correctly identified the vehicle as it drove past.



Figure C-5. Typical TMS Setup.

Range of System

The effective transmission range of the remote enforcement system is critical to the successful use of the device. Many work zones are several miles long, necessitating that the system be able to consistently transmit long distances. The range of the system was a function of the communication system used and exhibited a great deal of variability depending on topographical and meteorological factors. The maximum observed range of the communication systems was approximately 1.5 miles, although the range was as little as 0.5 mile at one site. This range is too short for many long term construction and maintenance zones, but it could be extended through the use of a repeater.

Lane of Traffic

Researchers also examined whether the system was more effective at photographing vehicles in the right or left lane. The system was able to consistently capture violators in the right lane when the system was aimed properly. Capturing vehicles in the left lane proved to be problematic and could never be sustained for prolonged periods of time. Vehicles in the right lane interfered with the capture of vehicles in the left lane, particularly on higher volume facilities. Also, the lidar had some difficulty in capturing speeds. The lidar was most effective when it could target a flat plane, such as a license plate. When the lidar was aimed at the left lane, the surfaces were angled away from the laser beam, creating some difficulty in acquiring vehicles.

Data Transmission

Next, researchers investigated the data transmission between the camera and the downstream laptop. At each site, fewer pictures were successfully transmitted to the downstream computer than were taken by the camera. Table C-2 shows the percentage of pictures that were successfully transmitted from the camera to the downstream laptop.

Table C-2. Data Transmission Results.

Site	Images Taken per Hour	Images Received per Hour	% Successfully Transmitted
SH 47 SB	226	139	61.5%
SH 47 SB	147	102	69.4%
SH 21 WB	550	65	11.8%
SH 21 WB	134	95	70.9%

Figure C-6 shows the relationship between the number of pictures taken per hour and the percentage of images that were successfully transmitted. This figure seems to indicate that a relatively linear relationship exists between the number of pictures taken and the percentage that are successfully transmitted downstream.

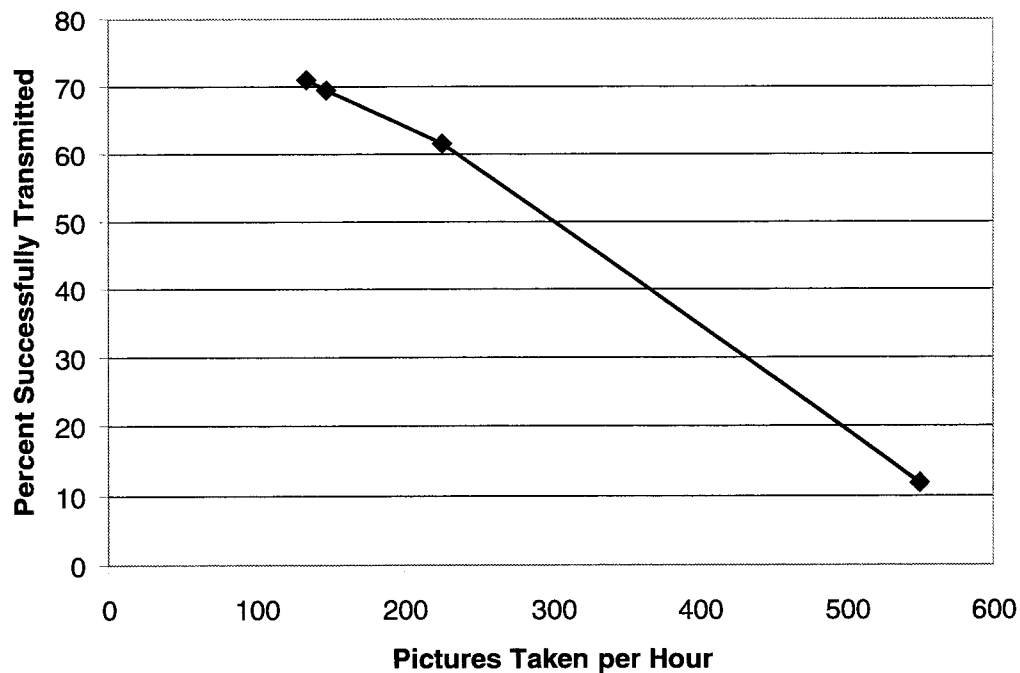


Figure C-6. Transmission Rate vs. Pictures Taken.

Figure C-6 implies that setting a proper speed threshold is critical to the successful operation of this system. When large numbers of photos are taken every hour, a relatively small number of images are successfully transmitted to the downstream laptop. Based on these data, a regression equation was developed in order to predict the percentage of vehicles that would be transmitted successfully:

$$\% \text{ of Pictures Successfully Transmitted} = 0.914 - 0.0014 (\text{Number of Pictures Taken})$$

The R^2 value of this equation is 0.996, indicating that it provides a good fit for the data. However, it should be noted that this equation is based on only four data points and could change as more data becomes available. As shown in Table C-3, the number of pictures that are transmitted to the downstream laptop can decline dramatically as the system attempts to transmit large numbers of images. The equation may serve to help personnel involved in work zone enforcement to select a speed threshold that will result in a high percentage of violators being transmitted to the downstream laptop without overloading the communications system.

Table C-3 summarized the number of pictures that were successfully transmitted to the downstream laptop. In many cases multiple images were captured of the same vehicle. In these situations, only a single image of a vehicle may need to be transmitted to the downstream laptop for a violator to be identified. Table C-3 summarizes the percentage of vehicles that had at least one image successfully transmitted to the downstream laptop. The percentage of vehicles successfully transmitted is higher than the percentage of pictures successfully transmitted. This is due to the fact that multiple images are captured for some vehicles, but in many cases only a single image is transmitted downstream. However, this data still shows a decline in the transmission percentage as the number of vehicles photographed increases.

Table C-3. Vehicle Transmission Rate.

Site	Vehicles Photographed Per Hour	Vehicles Received per Hour	% Successfully Transmitted
SH 47 SB	164	110	67.1%
SH 47 SB	76	61	80.2%
SH 21 WB	310	46	14.8%
SH 21 WB	100	75	75.0%

Vehicle Identification

The researchers investigated the ability of a downstream observer to successfully match images to passing vehicles. Table C-4 summarizes the percentage of vehicles that were successfully identified by the downstream observer. At all four sites, between 84 and 88 percent of the vehicles transmitted were identified. The distance between the camera and the downstream observer did not appear to have a significant impact on the identification of the vehicles.

Vehicles were photographed from the front at the first three sites and from the rear at the last site. Identification rates did not appear to be impacted by whether a vehicle was photographed from the front or the rear. Longer distances between the observer and the camera and the presence of intermediate access points could all serve to lower the percentage of vehicles successfully identified.

Table C-4. Vehicle Identification Rate.

Site	Distance Downstream from Camera	% Successfully Identified
SH 47 SB	1 mile	88.0%
SH 47 SB	1.5 miles	84.0%
SH 21 WB	0.5 miles	86.7%
SH 21 WB	1 mile	88.0%

SYSTEM LIMITATIONS

The field testing revealed several limitations of the prototype system related to both the hardware and software of the unit. First, the set-up time for the system was lengthy. It often took in excess of 45 minutes before the system was functional. If the system were to be used on a widespread basis, set-up time would need to be reduced. Ideally, the system would only require that the user attach a few cables, and limited troubleshooting would be required.

TTI researchers identified several limitations with the current TMS system in this application. First, the computer provided frequently rebooted during the initial setup without any warning. This required that the operators reconfigure the system each time the system restarted. Several

problems were identified with the imaging system, as well. The knob provided to focus the camera did not seem to be well calibrated, causing the time to focus the camera to be excessive. The lidar gun provides a precise estimate of the distance to the vehicle, but when the focussing knob is set to this distance, the image was rarely clear. It was also noted that when the temperatures dropped below 50 °F, the camera would only produce a solid black image. When the unit was brought indoors and allowed to warm up, it again produced a clear image.

The communications system also had some limitations. The range of the unit varied significantly from site to site. At one site, images were received 1.5 miles from the camera, and at another site, images could not be received more than 0.5 miles from the camera. In all cases, the range of the communications equipment did not appear to be adequate for use for work zone enforcement. There is the potential that the range of the routers could be increased by increasing the height of the antennas. A communications system which will produce a longer range without the aid of repeaters should be developed.

Researchers also identified several potential areas where the software could be improved, particularly in the data transfer software at the downstream laptop. First, the image presented to the observer should be oriented correctly. The vehicle's speed should also be visible in the preview image so that officers can determine if they want to pursue the vehicle. Images of vehicles should also be presented in a tiled manner so that multiple pictures can be viewed simultaneously. The software developed by TTI also did not manage memory efficiently. This required the laptop to be restarted approximately every 30 minutes. Finally, pictures should be available in color to aid in the positive identification of vehicles. While this did not seem to cause a significant problem during the evaluation, it would improve the ability of the observer to identify passing vehicles.

OFFICER COMMENTS

After the field testing was completed, the remote enforcement system was demonstrated to representatives of several law enforcement organizations. These representatives provided insight into how actual enforcement agencies would utilize the remote enforcement system. Potential legal issues with implementation of the system were also discussed. The following organizations provided their opinions on the remote enforcement system:

- Harris County Sheriff's Department and
- Texas Department of Public Safety.

Opinions on the system showed some variation between organizations. The comments provided by each agency are discussed separately.

Harris County

Overall, the officers' impressions of the technology were favorable. They noted that the approach had potential merit not only in work zones, but anywhere where the roadway cross-section was restricted (such as on long bridges). The attempts made to identify vehicles whose

images were transmitted downstream were generally successful. It was noted that the black-and-white display image made vehicle identification slightly more difficult, but not extremely so.

One of the officers mentioned that he envisioned the application of this technology in conjunction with a dedicated task force consisting of several officers. One officer would monitor the downstream equipment and identify approaching vehicles that the additional officers positioned next to him would pull over and issue citations. He felt that the technology would allow more violators to be identified and processed with this technology than could be achieved with the traditional multiple-officer enforcement teams.

One of the officers also mentioned that having the digital image of the vehicle could be useful during the issuance of violations if the driver disagreed with the officer about violating the law. The officers also felt that the distance between the camera and where the officer was stationed should not exceed one mile. They felt that motorists would be less accepting of the system if distances were long. This could potentially limit work zone applications of the remote enforcement system.

One of the key issues raised by the officers during their visit was the ability to monitor the actual video in real-time from the downstream laptop location. They were concerned that they would not be able to establish visual verification that a violator did indeed appear to be exceeding the speed limit. According to their comments, it would be necessary for the officer to establish probable cause (which the technology could then verify with the video image and imprinted speed data) upon which to stop the violator and issue the citation. TTI researchers asked whether continuous video tracking would be necessary for this purpose from the point of detecting a violation until the vehicle was pulled over. According to these officers, that was not a critical issue. Rather, it was only necessary to have several seconds of real-time video feed that the officer could see and make a determination that the vehicle did appear to be exceeding the speed limit. It was felt that with proper training, an officer could eventually learn how vehicles traveling at various speeds (especially those traveling at excessive speeds) would look on the downstream monitor.

Texas Department of Public Safety

The representatives from the Texas Department of Public Safety (DPS) had a more cautious view of the system than Harris County. The DPS representatives had concerns that they would not have a continuous visual tracking history from the time the vehicle is detected exceeding the speed limit until the officer apprehends the motorist. The DPS officers indicated that they could not be absolutely sure that they were ticketing the proper driver, even if the gap in visual tracking history was only 1 minute. They felt that continuous, real-time video was the only way to ensure a visual tracking history that could not be challenged in the courts.

The DPS representatives interviewed indicated that they felt that remote enforcement had limited applications in Texas. The officers stated that automated speed enforcement would be the best method to reduce their workload and improve safety. They felt that the most immediate application of this technology would come as a result of the passage of enabling legislation at the state level.

