Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-03/2137-3		

4. Title and Subtitle	5. Report Date
TRAFFIC MANAGEMENT AND ENFORCEMENT TOOLS TO IMPROVE WORK ZONE SAFETY	September 2002
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Gerald L. Ullman, Paul A. Barricklow, Rene Arredondo, Elisabeth R. Rose, and Michael D. Fontaine.	Report 2137-3
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	11. Contract or Grant No. Project No. 0-2137
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Texas Department of Transportation Research and Technology Implementation Office P. O. Box 5080 Austin, Texas 78763-5080	Research: September 1999-August 2002
	14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

Research Project Title: Improving Work Safety Through Better Work Zone Traffic Management and Enforcement

16. Abstract Project

This report presents the results of research to investigate the feasibility and effectiveness of the late-merge lane closure strategy and the CB Wizard technology at work zones in Texas. Previous research findings indicate that the late-merge strategy does offer the potential to improve vehicle throughput, queue lengths, and delays at work zone lane closures. Simulation analyses performed in this project suggest that the strategy may also be useful in managing queues at other types of major merge areas upstream or within work zones by modifying the relative service rates allocated to each approach or lane. Studies of the CB Wizard technology suggest that it can influence both the speed and lane choices of truck operators approaching work zones, but the extent of this influence is heavily dependent upon roadway and work zone site characteristics.

The report also provides implementation guidelines for incorporating enforcement pullout areas into long work zones where emergency shoulders have been eliminated.

17. Key Words	18. Distribution Statement
Work Zone, Work Zone Traffic Control, Work Zone Enforcement	No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	86	

Form DOT F 1700.7 **(8-72)** **Reproduction of completed page authorized**

TRAFFIC MANAGEMENT AND ENFORCEMENT TOOLS TO IMPROVE WORK ZONE SAFETY

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Report 2137-3
Project Number 0-2137
Research Project Title: Improving Work Safety Through
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Sponsored by the
Texas Department of Transportation
In cooperation with the
U.S. Department of Transportation
Federal Highway Administration

September 2002

TEXAS TRANSPORTATION INSTITUTE
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ACKNOWLEDGMENTS

This research was sponsored by the Texas Department of Transportation in cooperation with the Federal Highway Administration. The authors would like to thank Rick Collins, P.E., for his guidance in serving as the project director for this research. The authors would also like to thank the many people at the Waco, San Antonio, and Laredo District offices of TxDOT for their assistance and support during the various field studies that were conducted. The authors are also indebted to both Russell Henk and Poonam Wiles at Texas Transportation Institute who also provided expertise in the support of this project.

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1. INTRODUCTION

SIGNIFICANCE OF THE WORK ZONE SAFETY PROBLEM

According to data from the Fatal Accident Record System (FARS) (*1*), more travelers nationwide were killed in work zones during the 2001 calendar than ever before. Specifically, a total of 1079 lives were lost in 962 crashes, resulting in nearly three deaths each and every day of the year. Perhaps more frightening is the fact that these numbers have steadily increased over the past five years, and represent a dramatic 40 percent increase in the number of yearly work zone deaths since 1998.

Fortunately, the state of Texas has fared slightly better during this same time period. In 2001, work zone fatalities actually decreased from their 2000 levels. Whereas 140 fatalities occurred in 128 work zone crashes statewide during 2001, a total of 155 lives were lost in 133 fatal work zone crashes in 2000. Compared to 1998 data, work zone fatalities in Texas during 2001 are only 12 percent higher.

Although the increases in work zone fatalities statewide over the past several years are less than the national average, Texas has continued to lead the nation in the number of people killed in work zones throughout this time period. Certainly, the vast number of roadway miles within the state (and by extrapolation, a large number of work zone miles) is undoubtedly responsible for a large part of this unenviable rating. Even so, the disturbing trends in crash characteristics that have plagued Texas work zones (and those throughout the country) continued into 2001. As examples:

- *Work zone fatalities are over represented on high-speed, high-volume roadways* – whereas 22.1 percent of all fatal crashes on Texas roadways occurred on interstates and freeways (both urban and rural), these types of roadways comprised 36.7 percent of work zone fatalities statewide during 2001.
- *Large trucks are also over represented in fatal work zone crashes* – statewide, tractor-trailers and other large trucks were involved in approximately 12 percent of all fatal crashes, but 22 percent of the fatal crashes occurred in work zones.
- *Fatal crashes in work zones continue to involve rear-end collisions* – only 5.7 percent of fatal crashes in Texas during 2001 involved a rear-end collision between two or more vehicles. However, 10.9 percent of the fatal work zone crashes were the result of rear-end collisions. Although data on the exact nature of these collisions is not available from the accident database, it is likely most of these were the result of vehicles approaching at high speeds and running into the back of traffic queues at the work zone.

Clearly, improving upon these disturbing trends is an important goal of transportation researchers and practitioners. As one step towards addressing this goal, the TxDOT has sponsored a three-year study to examine ways that work zone safety can be enhanced through improved work zone traffic management and enforcement. Two reports have previously been published from this research (*2*, *3*).

CONTENTS OF THIS REPORT

This report covers the third and final year of research activities performed on this project. TTI researchers examined the feasibility and effectiveness of two specific traffic management technologies that have potential to address specific safety and operational problems that have been observed in work zones on high-volume, high-speed roadways. These two management technologies include:

- *the late-merge strategy* – a traffic management technique that employs static and/or changeable message signs to alert drivers to use all lanes until merge point and then take-your-turn and
- *the Citizens' Band Wizard Alert Radio (CB Wizard)* – an unmanned radio transmitter used as an advanced warning tool to alert truck drivers of hazards, work zones, and/or unusual conditions.

Researchers have also prepared guidelines for incorporating pullout areas into long work zones so as to support improved enforcement activities and thus better motorist compliance with posted traffic regulations. The documentation supporting the recommendations in those guidelines are included as part of this report. Meanwhile, the guidelines are provided as Appendix A.

2. EVALUATION OF THE LATE-MERGE LANE CLOSURE STRATEGY

Studies conducted during the first year of this research project identified driver queue-jumping behavior at temporary work zone lane closures as a significant safety issue (*2*). When stop-and-go congestion develops upstream of a lane closure, most motorists merge out of the lane identified in the advance warning signs as being closed, joining the traffic queue that exists in the open lane and proceeding gradually through the congestion. However, some drivers do not follow this procedure. Instead, these drivers remain in the closed lane and bypass the queued traffic in the open lane up to the point of the lane closure itself. At this location, these drivers then attempt to merge into the open lane in order to pass by the work area. This creates significant speed differentials between vehicles in adjacent lanes, and the situation becomes very unpredictable for motorists in both the congested open lanes and the higher speed closed lanes. Conflicts also arise at the point of the actual lane closure as the queue-jumping vehicles attempt to push their way back into the open lane while those motorists who have remained in the closed lane (often for a considerable distance) attempt to keep those vehicles from getting into the queued lane.

Driver frustration is reportedly quite high at these locations. In some instances, large trucks that have joined the queue attempt to restrict queue-jumping vehicles by straddling the lane lines between the open and closed lanes or by pairing up and traveling side by side in the closed and open lane slowly through the queue until the point of the lane closure. Although not necessarily unsafe maneuvers, these behaviors can lead to even more erratic behavior by queue-jumping vehicles (these drivers often use the emergency shoulder to bypass trucks that are blocking the closed lane). Furthermore, the poor acceleration characteristics of large trucks in stop-and-go conditions lead to large gaps between them and the vehicles in front, thereby reducing the overall traffic capacity past the work zone. One of the most promising traffic management techniques identified to potentially combat this concern was what is now referred to as the late-merge traffic control strategy. The late-merge concept was originally developed and implemented by the Pennsylvania Department of Transportation (PennDOT) to reduce road rage caused by queue jumping. Figure 2-1 shows an example of the original late-merge concept. In the PennDOT application, static signing is used to instruct drivers to remain in both lanes until they reach the merge point. At the merge point, a second static sign instructs motorists to take turns proceeding into the work zone activity area.

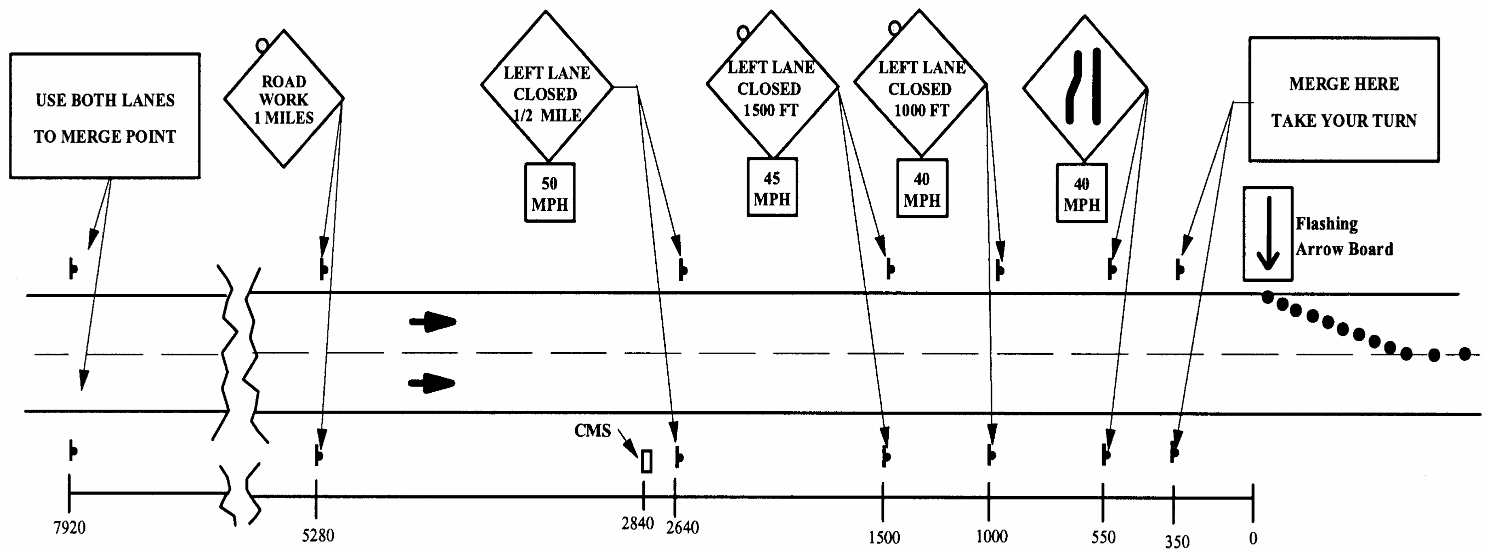

Figure 2-1. Example of Late Merge Application (*4*).

PREVIOUS LATE-MERGE EVALUATIONS

The University of Nebraska performed an evaluation of the late-merge concept on a four-lane rural interstate highway. Researchers found that the technique provided several benefits (*4*). First, the capacity of the late-merge was approximately 18 percent higher than when a traditional type of lane merge is used. Second, researchers reported that the late-merge strategy resulted in approximately 75 percent fewer merging conflicts as compared to the standard lane closure traffic control setup. Similarly, lane straddling was reduced approximately 30 percent when the late merge strategy was employed.

TTI researchers studied the late-merge concept at an urban freeway lane closure in Dallas as part of a project to reduce road rage (*5*). In this test, one of three travel lanes was closed for roadwork. Static signs similar to those shown in Figure 2-1 were used, with "USE BOTH LANES TO MERGE POINT" sign altered to read "USE ALL LANES TO MERGE POINT." The lane closure was placed out after the morning peak period and picked up prior to the evening peak period. This meant that congestion was sometimes, but not always, present upstream of the lane closure.

The evaluation of the late-merge strategy at this location was hampered by the unpredictability of both the duration of the lane closure each day and the presence of extent of traffic queuing that may or may not develop (depending on the extent to which traffic volumes fluctuated on a given day). However, the data that was able to be collected did suggest that the late-merge strategy led to slight improvements in traffic operations throughout the work zone. Researchers noted that the length of queue upstream of the lane closure was slightly less with the late-merge strategy deployed, and that the queue then dissipated slightly quicker than under the normal lane closure traffic control condition. Researchers also noted a slight increase in the volume moving through the work zone under congested conditions when the late-merge strategy was in place.

QUEUE MANAGEMENT POTENTIAL OF THE LATE MERGE STRATEGY

The results of the limited field testing in previous studies suggests that the late-merge lane closure strategy can provide some safety and operational benefits when congestion develops upstream of a lane closure. Certainly, filling all approach lanes with queued vehicles does eliminate the possibility of large speed differentials between adjacent lanes due to queue jumping. Furthermore, the strategy may help increase traffic flow rates throughout the work zone, which reduces delay and road-user costs due to the work zone.

Another interesting finding from the past projects is that the late-merge strategy may lead to fewer vehicle conflicts and smoother overall operations at the lane closure bottleneck. Intuitively, part of this smoother operation is reduced driver frustration because there no longer exists a perception that drivers in the closed lane at the merge point have cheated and cut in line to bypass the queue. However, part of this improved behavior may be the result of driver obedience to the special signing that directs them to "take your turn." If the directions on the sign are at least partially responsible for the improved merging behavior, it may be possible to employ this type of strategy at other congested merge points, such as entrance ramps, freeway-to-freeway merges upstream, or within a work zone.

Merge areas themselves tend to be capacity bottlenecks, the severity of which is dependent upon such factors as the roadway geometrics, length of available merging area, and relative demand from each of the merging freeways. In some situations, the freeway demands and roadway geometrics are not in balance and significant queuing can occur on one of the freeway approaches while the other approach operates fairly effectively. This situation could also occur at a high-volume entrance ramp where the work zone traffic queue on the freeway extends beyond the ramp merge area.

To test the potential benefit of this type of application in a controlled manner, researchers decided to examine the operational impact of the late-merge concept in this latter scenario using traffic simulation. Researchers tested the late merge using the VISSIM simulation model at the merge point of Interstate (I) 35E and I-35W traveling southbound, just north of Hillsboro. This site is located upstream of an actual work zone on I-35. The site features a reduction in the number of lanes from three to two, and a high volume of merging traffic during a few special occasions during the year. Specifically, TxDOT personnel indicated that the merge point of I-35E and I-35W traveling southbound experiences significant congestion during holiday weekends. Delays are particularly excessive on I-35W, with anecdotal evidence suggesting that delays exceed one hour for these drivers at certain times. TTI researchers hypothesized that the merge point at this situation restricts the flow rate on I-35W more significantly than on I-35E (I-35W is required to merge into the right hand I-35E lane), and so leads to much longer delays on I-35W. Attempts by TxDOT to remedy this situation through a static reassignment of capacity at the merge (by closing off one of the lanes on I-35E to create a free lane entrance for I-35W) during one of the holidays created such dramatic queues on I-35E and a negative perception by I-35E drivers that it was quickly abandoned.

Site Characteristics

Figure 2-2 shows a schematic of the merge point between I-35E and I-35W. The posted speed limit on both roads is 70 mph. Both approaches are two lanes upstream of the merge point. Approximately 0.5 miles upstream of the merge point, there is a lane drop on I-35W, reducing the road to one lane upstream of the merge point. The road is a three-lane section between the merge point and the exit ramp for US 77. The right lane of this section serves as a weaving area where traffic from I-35W attempts to merge with I-35E traffic, and I-35E traffic that wishes to exit at US 77 attempts to move over into the right lane. Following the US 77 exit ramp, I-35 is two lanes traveling southbound.

TxDOT personnel indicated that the merge point of I-35E and I-35W traveling southbound experiences significant congestion during holiday weekends. Delays are particularly excessive on I-35W, with anecdotal evidence that delays exceed one hour for these drivers on certain holiday weekends. TTI researchers have hypothesized that the developing congestion at the merge under this situation may restrict the flow rate more significantly on I-35W than on I-35E, leading to the much longer delays on I-35W. Attempts by TxDOT to reassign capacity at the merge by closing off one of the lanes on I-35E to create a free lane entrance for I-35W created large queues on I-35E to the extent that TxDOT chose to remove the lane closure and allow traffic flows to return to their natural state.

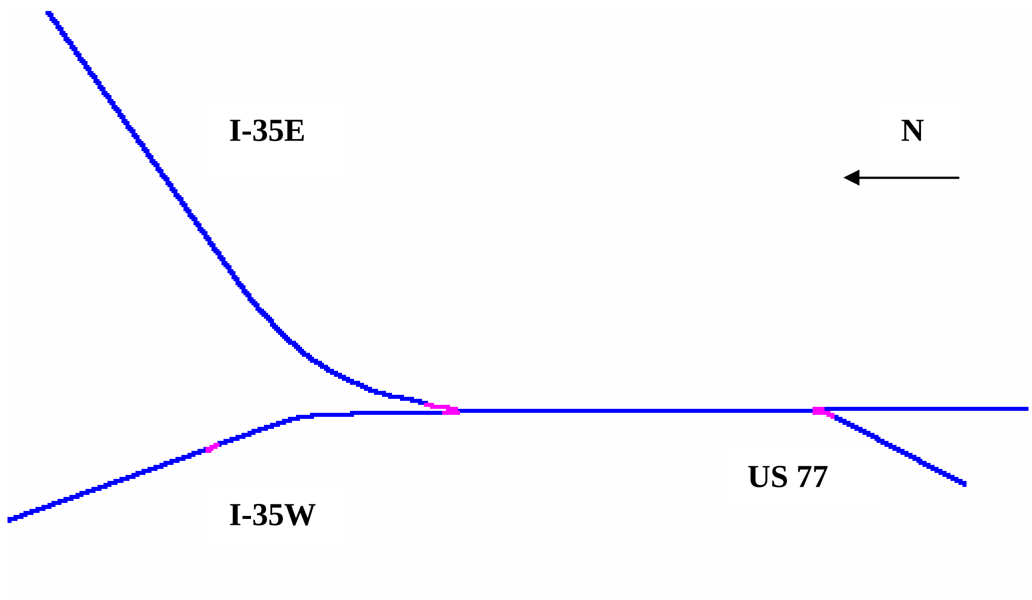

Figure 2-2. Schematic of I-35 Merge Point.

Objectives and Methodology

TTI researchers used this site to determine whether dynamic operational treatments could alleviate some of the delay that was being experienced on I-35W during high volume periods. In order to satisfy this goal, five potential scenarios were developed for the merge point:

- *Do nothing:* This served as the basis for comparing all treatments. Vehicles from I-35W merge into the I-35E traffic flow as acceptable gaps become available to them. As volumes on I-35E approach the capacity of the two freeway lanes downstream, the number of gaps available for I-35W traffic decreases.
- *Late-merge technique:* The late-merge strategy was applied to the I-35W ramp and the right lane of I-35E. This was expected to improve traffic flow on I-35W, although it would come at the expense of I-35E capacity in the right lane.

- *Close the right lane of I-35E to all traffic:* By closing the right lane of I-35E, traffic from I-35W would be able to continuously merge onto I-35. Capacity on I-35E would be reduced, however. This scenario was analyzed to compare to anecdotal experiences of TxDOT personnel during an attempt of this treatment in the field.
- *Close the left or right lane of I-35E to truck traffic:* It was hypothesized that by limiting truck traffic to either the right or left lane of I-35E, it may become easier for I-35W traffic to merge. This would be accomplished through upstream signing or CB radio message transmissions to the trucks.

Field Data Collection

In an attempt to obtain a better perspective of the traffic behaviors occurring at this test site, TTI researchers collected traffic data over Memorial Day weekend in 2001. This data was to be used to develop and test the simulation for each traffic control strategy described above. Data were collected at the I-35E and I-35W merge point on May 27 and 28, 2001. Table 2-1 shows the peak hour volumes collected over this period.

Table 2-1. Memorial Day Traffic Counts at I-35 Merge Point.

Traffic Entering Network (vph[a])				**Traffic Leaving Network (vph)**			
I-35W (1 lane)		**I-35E (2 lanes)**		**US 77**		**I-35**	
Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks
902	64	1148	116	64	1	1986	179

[a]vph = vehicles per hour

Congestion never developed at this site over the two-day period, so the traffic volumes that cause the facility to reach stop-and-go breakdown conditions could not be determined based on the data collected. However, these data do illustrate that the relative traffic demands from I-35W and I-35E are fairly close (basically a 43/57 percent breakdown, respectively) during this time. Obviously, if this trend were to continue to higher traffic volumes (such as over the Thanksgiving weekend, for example), one would expect I-35W to experience operational problems much sooner than on I-35E. Conversely, simply reassigning one of the I-35E lanes at the merge point to I-35W traffic would simply move the problem over to I-35E. These data lend further support to the concept of a less dramatic management of merge point operations to help manage traffic demands from I-35W and I-35E.

Traffic Simulation of Merge Point Behavior

A series of traffic simulations were developed for each of the potential traffic control scenarios described in the objective section above. Traffic volumes between 1000 and 4000 vehicles per hour (vph) were then applied to both I-35E and I-35W in 1000 vph intervals in order to systematically assess how conditions might exist under various traffic demand scenarios. Two measures of effectiveness were selected for the simulations:

- traffic throughput and
- network travel time.

Researchers utilized the VISSIM microscopic traffic simulation model to investigate these measures (*6*). The primary reason for using VISSIM (over the more widely used CORSIM traffic simulation model developed by FHWA) was that it provided the researchers the ability to represent a take-your-turn merging behavior between I-35W and I-35E through manipulation of priority rules for yield control on a lane-by-lane basis (*7*). This type of control is not possible through the CORSIM model.

Representations of the existing do-nothing alternative, I-35E static lane closure alternative, and late-merge strategy alternatives help to visualize the situation. Figure 2-3 presents an illustration from the VISSIM output, showing the I-35 merge point using the simulated existing do-nothing traffic control. When volumes are high on the I-35E approach, substantial queuing occurs on I-35W. I-35E traffic maintains a relatively high speed, while I-35W traffic is forced to wait for gaps.

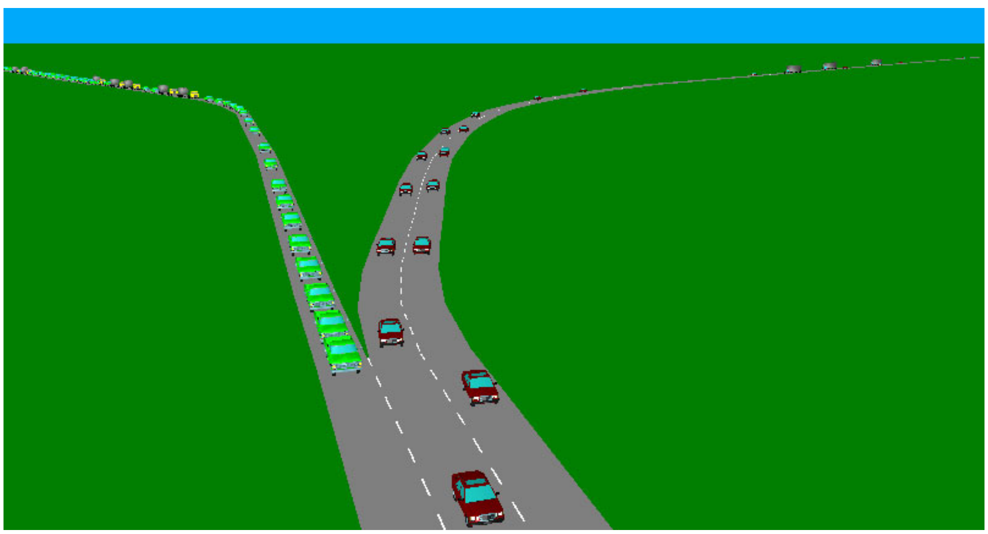

Figure 2-3. I-35 Merge Point with Existing Do-Nothing Control Alternative.

Conversely, Figure 2-4 shows the I-35 merge point when the right lane of I-35E is closed to traffic. Queuing on I-35E is significant in this scenario, as a lane normally assigned to that approach is eliminated, forcing traffic to queue up to use the single lane past the merge point.

Finally, Figure 2-5 shows the I-35 merge point when the late-merge strategy is used. Yield control rules for the I-35W and the right lane of I-35E are assigned at the merge point to replicate a take-your-turn behavior.

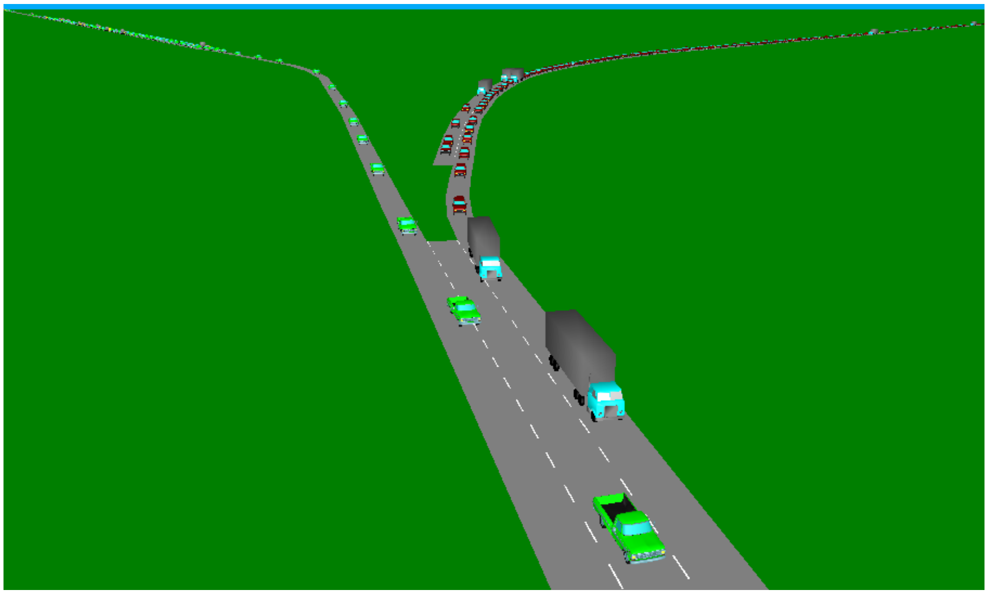

Figure 2-4. I-35 Merge Point with the Static Lane Closure Alternative.

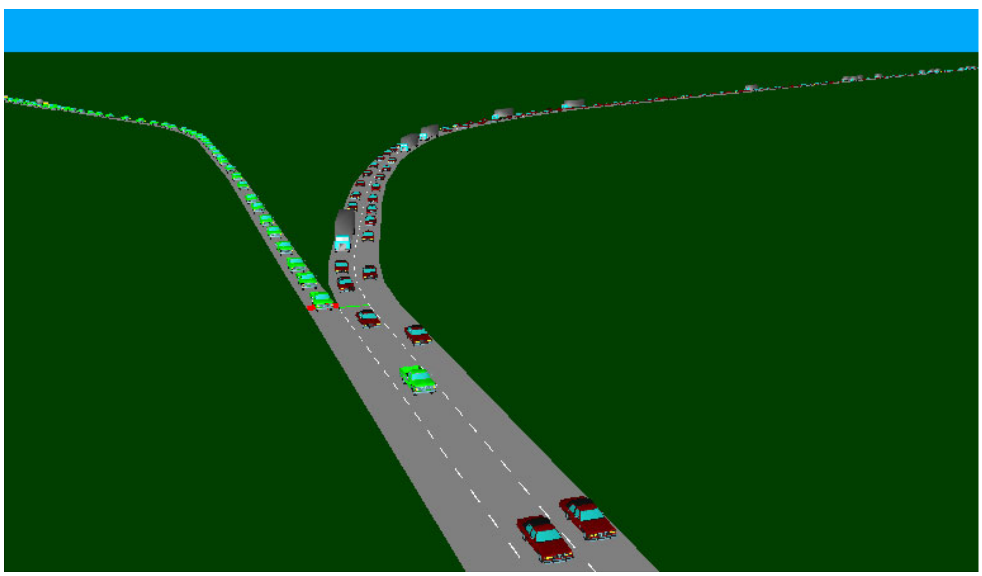

Figure 2-5. I-35 Merge Point with the Late-Merge Strategy Alternative.

Results

Throughput

Figure 2-6 shows the average I-35W throughput for each traffic control treatment. As would be expected, the traffic demand volume on I-35E had a direct impact on the simulated throughput of I-35W for all of the scenarios except the late-merge strategy and the I-35E static lane closure. The higher volumes on I-35E resulted in fewer acceptable gaps for I-35W traffic, thereby reducing throughput from the I-35W ramp.

Figure 2-6 also shows that closing the right lane of I-35E consistently produces the largest throughput on I-35W. This is to be expected, as the lane closure allows the traffic on I-35W to easily merge onto I-35 southbound in its separate lane. Of course, this comes at a significant expense to I-35E throughput and I-35E traffic travel times (see Figure 2-7). Truck restrictions do not significantly improve the throughput of I-35W beyond the normal throughput of the ramp.

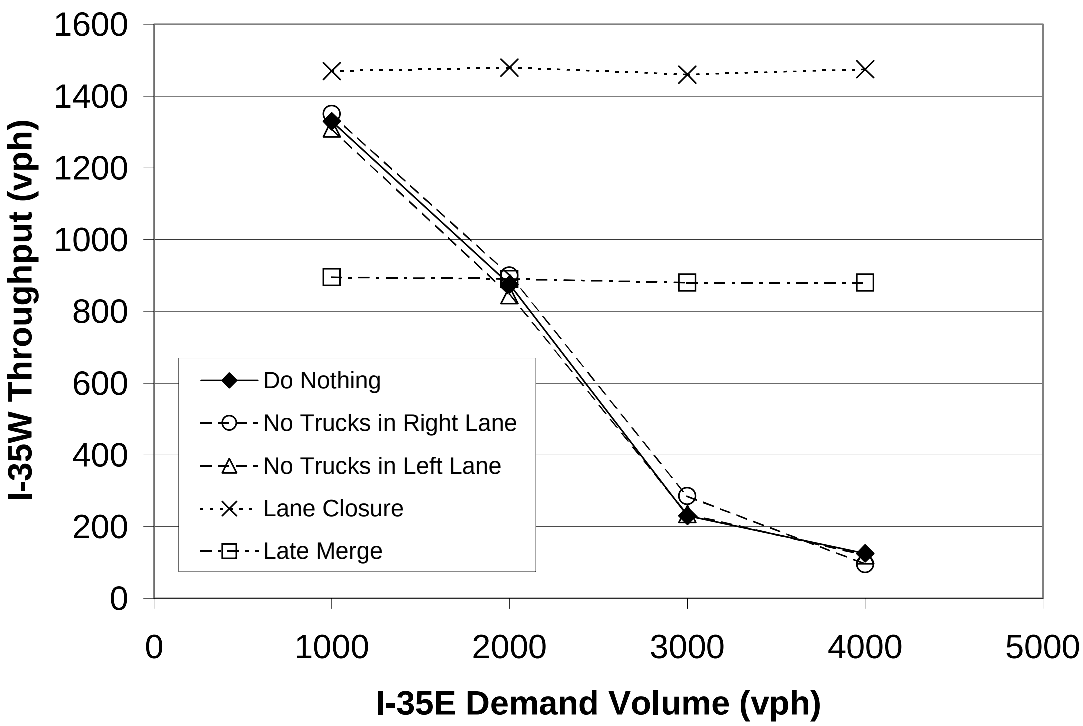

Figure 2-6. I-35W Throughput.

It is interesting to note that the late merge strategy does appear to improve the throughput from I-35W when volume levels are high on I-35E. In these cases, the late-merge creates additional opportunities for traffic on I-35W to merge that would not exist under traditional gap acceptance rules. However, the improvement is somewhat less than observed under the I-35E static lane closure scenario, indicative of the fact that some of the merge lane capacity is being utilized by I-35E traffic demand.

The results of Figure 2-6 are then compared to those shown in Figure 2-7, which presents the throughput on I-35E as a function of the demand volume on I-35E. Consistent with expectations, the late merge and I-35E static lane closure alternatives consistently produce the lowest throughputs on I-35E since they reduce the capacity of I-35E. One does get a sense of the capacity constraints that each alternative places on I-35E traffic. For the I-35E static lane closure alternative, I-35E throughput is capped at approximately 1700 vph, or the equivalent of one lane of traffic passing a temporary lane closure. Conversely, the flow rate for the late-merge strategy levels off at approximately 2400 vph. Again, the various truck restriction alternatives do not produce significantly different results from the existing conditions at the site.

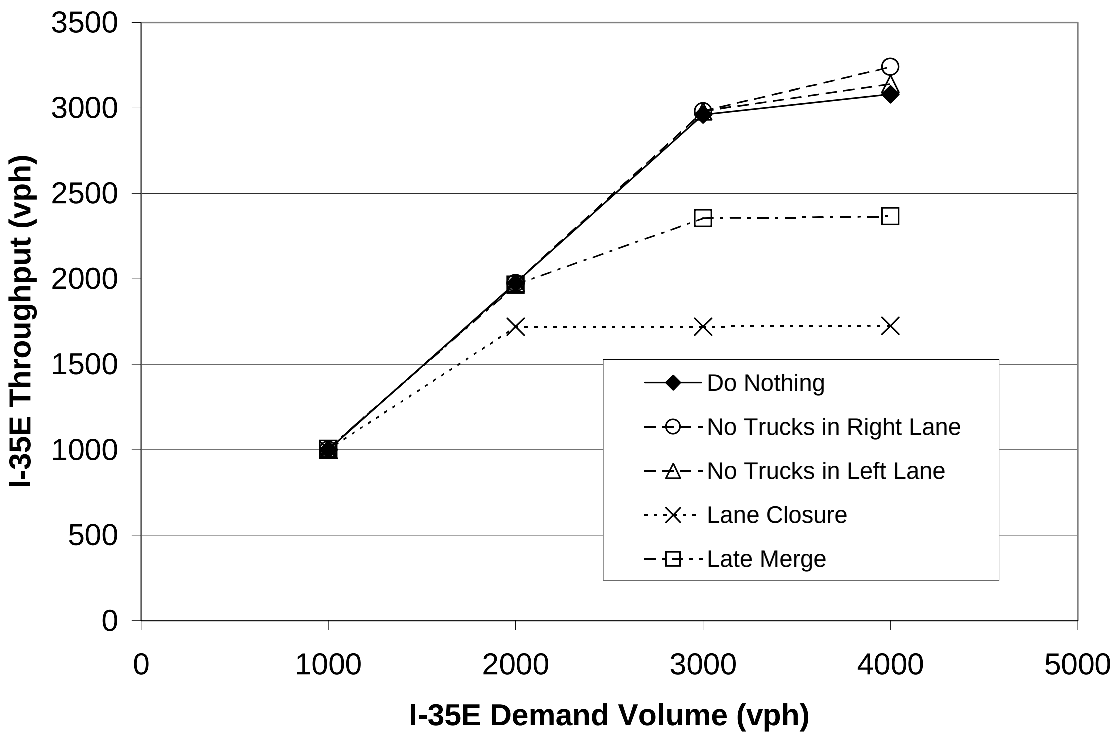

Figure 2-7. I-35E Throughput.

Travel Time

Whereas the assessment of the throughput from I-35W and I-35E helps to explain how the various alternatives utilize the available downstream capacity on I-35, the real question of interest in the analysis is the effect of the alternatives on travel time of vehicles on both approaches. As described earlier, one of the problems is the imbalance of congestion on I-35W relative to I-35E once the capacity of I-35 is reached south of the merge point. Travel times were measured from a point 1.5 miles upstream of the merge point to a point 0.5 miles downstream of the US 77 exit for traffic originating on both approaches. Researchers focused attention on the existing do-nothing alternative, the I-35E static lane closure, and the late-merge strategy. The alternatives involving truck restrictions on I-35E were not included in this discussion, as the previous section illustrated that these had negligible effects on either I-35E or I-35W outputs.

The simulations showed that the demand volume on I-35E had a major impact on travel times for both I-35E and I-35W. The demand volume on I-35W also impacted travel times on that approach, since increasing volumes created longer queues on I-35W. Specifically, whether the approach was over or under capacity impacted the magnitudes of the delay.

Since travel times were computed over a very confined area, the magnitude of these travel times should be used only for comparison purposes. They do not represent the entire time that was spent in the queue, since the queue frequently spilled back beyond the confines of the travel time estimates.

Figure 2-8 shows the travel times for I-35W when the lane drop on I-35W is under capacity. With existing conditions, I-35W traffic can experience very long travel times as the I-35E demand volume increases. In this case, fewer gaps are available for merging traffic, resulting in longer wait times (queuing) before traffic can merge onto I-35. The late merge produces lower travel times than the existing conditions once the demand volume on I-35E exceeds 2000 vph. The lane closure alternative consistently produces the lowest travel times for I-35W traffic because no traffic has to come to a stop or look for acceptable gaps in oncoming traffic when attempting to merge with I-35E.

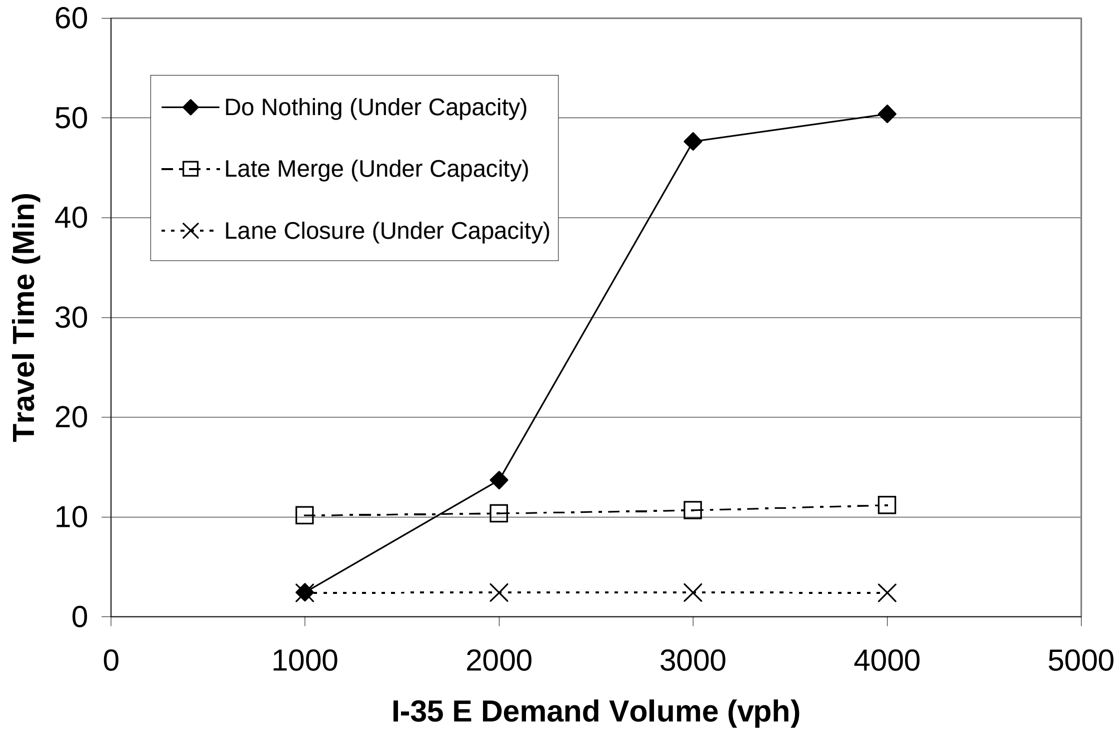

Figure 2-8. I-35W Travel Time (Under Capacity).

The travel times for I-35W when the demand exceeds the capacity of the I-35W lane drop are shown in Figure 2-9. Although the magnitudes of the travel times increase substantially, the same basic relationships exist between the various traffic control strategies. Once traffic demands on I-35E reach approximately 2000 vph, opportunities for I-35W to merge onto I-35 begin to decrease and continue to decrease as I-35E volumes increase. Traffic on I-3W begins to queue behind the merge point, and travel times increase dramatically. Because both the I-35E static lane closure and the late merge maintain a constant merge capacity for I-35W traffic, travel times for those drivers are maintained at a fairly constant value independent of I-35E demand volumes.

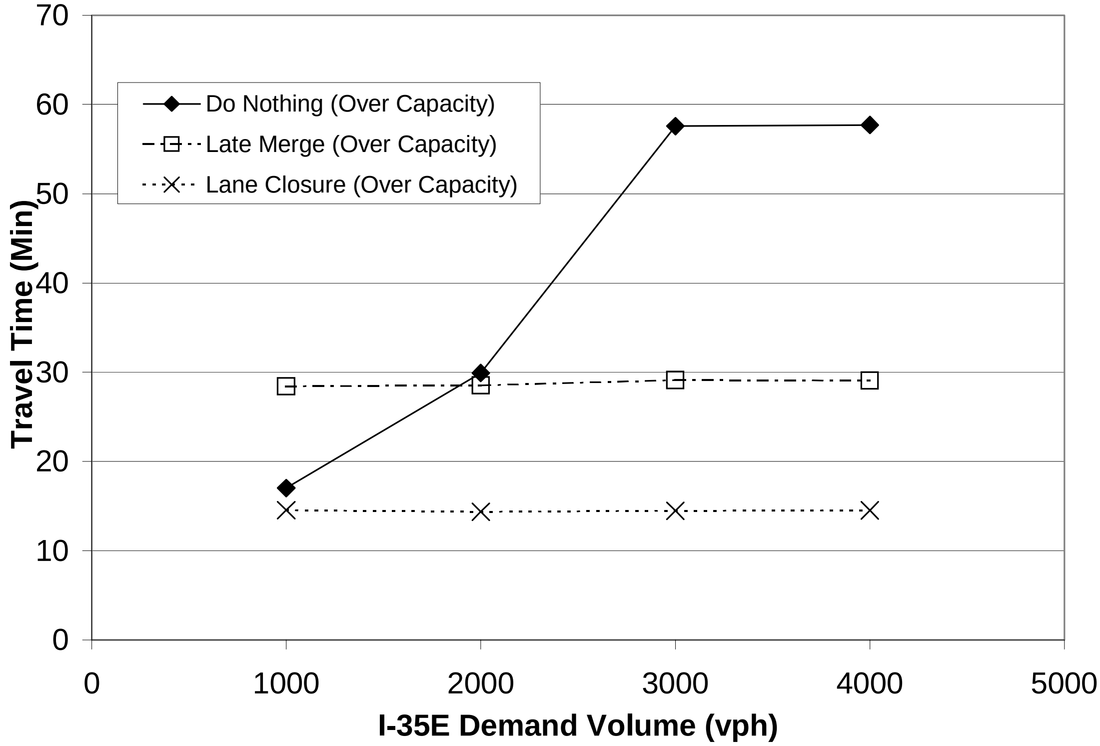

Figure 2-9. I-35W Travel Time (Over Capacity).

Figure 2-10 shows the travel times on I-35E. The existing do-nothing condition consistently produces the shortest travel times for I-35E. In all cases, the travel times were under five minutes with existing traffic control. This result is expected, as the existing condition provides the greatest allocation of roadway capacity to I-35E traffic approaching the merge.

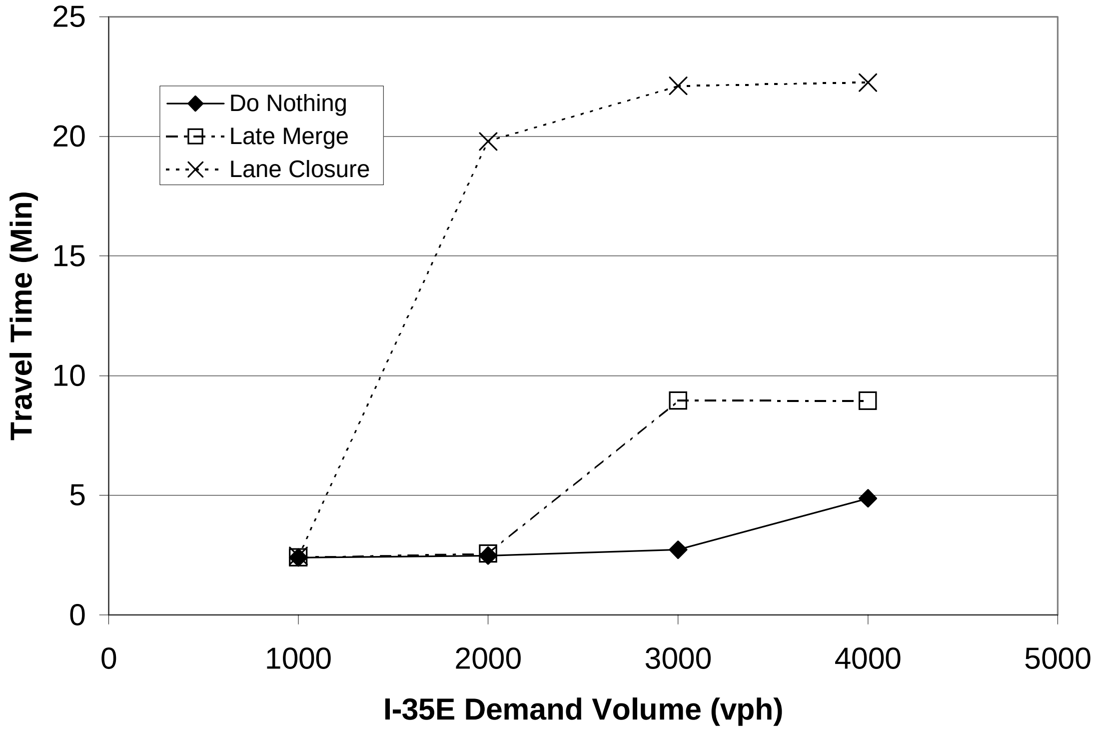

Figure 2-10. I-35E Travel Times.

Interpretation of Results

Table 2-2 summarizes the throughputs that were observed for each traffic control strategy. The existing conditions or various truck restriction scenarios produced the largest throughputs on I-35E when demand volumes were high. The lane closure option produced the largest throughputs on I-35W. The late merge significantly increased throughputs on I-35W when demand volumes on I-35E were greater than 3000 vph. Total throughputs were largest for the lane closure when the demand on I-35E was low, while the throughputs were comparable for all options when demand on I-35E was high.

Table 2-3 summarizes the travel time information obtained from the simulation. Existing conditions produced the shortest travel times on I-35E, while the lane closure produced the shortest travel times on I-35W. However, in both these alternatives, the travel time impact to the other approach is significant. The late-merge strategy, by comparison, provides a fairly substantial (although not the largest) benefit to I-35W travel times for a moderate increase in I-35E travel times.

Table 2-2. I-35 Merge Point Throughput Summary.

I-35E Demand Volume (vph)	Approach	Do Nothing	No Trucks Right Lane	No Trucks Left Lane	Lane Closure	Late Merge
1000	I-35W	1330	1350	1310	1470	895
	I-35E	1000	1000	1000	1000	1005
	Total	2300	2350	2310	2470	1900
2000	I-35W	875	900	845	1480	890
	I-35E	1975	1975	1975	1720	1965
	Total	2850	2875	2820	3200	2855
3000	I-35W	230	285	235	1460	880
	I-35E	2960	2980	2980	1720	2355
	Total	3190	3265	3215	3180	3235
4000	I-35W	125	95	120	1475	880
	I-35E	3080	3240	3140	1725	2365
	Total	3205	3335	3260	3200	3245

Table 2-3. I-35 Merge Point Travel Time Summary.

I-35E Demand Volume (vph)	Approach	Travel Time (Min)		
		Do Nothing	Lane Closure	Late Merge
1000	I-35W (Under Capacity)	2.5	2.4	10.2
	I-35W (Over Capacity)	17.0	14.6	28.4
	I-35E	2.4	2.5	2.4
2000	I-35W (Under Capacity)	13.7	2.4	10.4
	I-35W (Over Capacity)	29.9	14.4	28.5
	I-35E	2.5	19.8	2.6
3000	I-35W (Under Capacity)	47.7	2.4	10.7
	I-35W (Over Capacity)	57.6	14.5	29.1
	I-35E	2.7	22.1	9.0
4000	I-35W (Under Capacity)	50.4	2.4	11.2
	I-35W (Over Capacity)	57.7	14.5	29.1
	I-35E	4.9	22.3	9.0

Other Considerations

The results of the simulation analysis suggest that the late-merge strategy does offer the potential to help balance travel times at congested merge points where the demand volumes on the approaches to the merge are not in balance with the roadway geometrics and the normal merging behavior at the site. However, it should also be apparent from these results that the late-merge strategy is not necessarily appropriate for all traffic demand conditions. In the situation examined above, traffic demands on I-35E need to reach or exceed approximately 2000 vph before a late-merge strategy would be expected to provide any benefit. At lower volumes, the take-your-turn behavior is predicted to lead to slightly longer travel times, as drivers on both approaches have to wait on occasion for someone on the approach to take their turn. Although such behavior may not be truly realistic (drivers would most likely not wait for someone on the other approach to arrive), it does highlight a potential operational problem with the late-merge when there are not enough vehicles on both approaches to continuously support a take-your-turn strategy. Safety issues can arise as well. Approach speeds increase under lower volume conditions, reducing the amount of time drivers have to perceive and react in the prescribed cooperative manner.

Therefore, these results suggest that the implementation of the late-merge strategy in the type of situation described above should be done in a dynamic, traffic-responsive manner. Specifically, a take-your-turn message should only be displayed to drivers when demand volumes are high enough on both approaches to continually support this type of behavior and where the behavior itself helps to rebalance throughput on each approach to more closely match the relative distribution of the actual demand. There are several ways in which this can be accomplished. Various portable traffic management systems (some of which were reviewed in previous research (*1*)) exist which can provide both remote surveillance and portable changeable message sign (PCMS) control. This would allow an operator monitoring conditions at the site to determine when demand volumes were imbalanced and when enough traffic was present to support a take-your-turn merging strategy. Simple messages can be displayed on a PCMS located at the merge point (i.e., MERGE/HERE, TAKE/YOUR/TURN) when the operator deems it appropriate, and then removed when conditions no longer warrant. This approach maximizes credibility and accuracy of the system, but requires staff or contractor time to monitor and so increases labor costs.

Another alternative is to implement the strategy as an automated portable system. In this approach, traffic speed sensors are used to detect when conditions on both approaches have reached congestion, at which time a PCMS message is activated. When the sensors detect that congestion no longer exists, the message is removed. This approach does not require continuous monitoring by an operator, but will likely not be as responsive to changing traffic conditions. Furthermore, assessments of traffic demand or travel time imbalances on each approach would require extensive surveillance equipment far upstream on each approach.

TTI researchers provided TxDOT personnel with the results of the simulation analysis, and suggested that a field test of the late-merge strategy might be beneficial. However, due to the lack of real-world data available to calibrate the model under congested conditions (remember that data from Table 2-1 did not exceed capacity at this site) and the fact that the simulation results indicated that a traffic-responsive strategy would likely be needed, TxDOT personnel decided not to attempt a field test at this location.

ATTEMPTS TO EVALUATE THE LATE-MERGE STRATEGY IN TEXAS

Although there was no interest in testing the late-merge strategy for queue management purposes, researchers did attempt to conduct a field test of the late-merge strategy in a manner that simulated traffic-responsive operations at a standard work zone lane closure. One could argue that a traffic-responsive late-merge strategy is more appropriate for use at standard work zone lane closures than the static signs that have been used in past tests. In fact, requesting drivers to use all lanes to the merge point under non-congested traffic conditions can be argued as inconsistent with the traditional goal of encouraging high-speed traffic to move out of the closed travel lane as far upstream as possible. Earlier lane changes out of a closed lane at high speeds maximizes the amount of time that drivers have to find an acceptable gap in the adjacent lane and make the lane change maneuver prior to reaching the lane-closure taper itself. Consequently, the static instruction to use all lanes to the merge point may lead to reduced credibility and effectiveness of the strategy over time, and could possibly lead to driving behaviors that are less safe than traditional traffic control methods for temporary lane closures. Therefore, TTI researchers attempted to determine whether a dynamic late-merge application where messages were displayed on portable changeable message signs, only when congestion was present, would yield operational benefits under actual field conditions in Texas.

TTI researchers tried throughout fiscal year 2002 to identify suitable candidate sites where the late-merge strategy could be effectively tested. TxDOT personnel in both the Houston and Dallas districts expressed interest in the concept, and helped to identify potential project sites where testing could possibly occur. The results of those efforts are summarized below.

Houston

Three locations were identified in Houston. The first site was located on US 59 (the Eastex Freeway) north and east of downtown. Ongoing construction work required a long-term closure of three northbound travel lanes (from five down to two lanes). TxDOT personnel indicated that this site experienced significant congestion and queue jumping in the closed lanes during peak periods. At the same time, a similar long-term closure of two out of four travel lanes existed on I-45 north of downtown Houston. TTI researchers conducted site visits to both locations and determined that the US 59 site was most suitable for purposes of evaluating the late-merge strategy. However, since the potential site was part of an ongoing construction project, cooperation and approvals needed to be obtained from the contractor responsible for the work.

TxDOT staff then initiated contact with the contractor about conducting an evaluation of the late-merge strategy. After multiple conversations with TxDOT and receipt of descriptive information about the late-merge concept and the potential project procedures, the contractor declined to participate in the project unless TxDOT changed the current contract language that makes the contractor liable for the traffic control located on the site. This was not a realistic request from TxDOT's perspective, so TTI researchers abandoned attempts to use this site and searched for another Houston location.

After a short delay, TxDOT personnel again identified a suitable candidate site in Houston. This site was located on US 59 south and west of downtown. At this location the contractor had upcoming night work on an overpass that would require the closure of one of the two outbound travel lanes. This work would occur on multiple nights over a couple of weekends. TTI researchers traveled to Houston to inspect the site and met with both TxDOT and contractor personnel at the job site to discuss details of the late-merge concept, its potential benefits, and the specific project procedures that would be utilized. Initially, the contractor was agreeable to participating in the project, so long as a signed and sealed traffic control plan was submitted, approved by TxDOT, and also approved by their corporate office. TTI researchers agreed to provide such a plan. The researchers returned to headquarters, prepared and sealed a traffic control plan for use in the studies and sent them to TxDOT and the contractor for approval. This plan is illustrated in Figure 2-11. After a few weeks, researchers began contacting the contractor about the status of the proposed work and the corporate approval. After several weeks and multiple contacts, researchers received news that the contractor's corporate office officials had once again declined to participate in the project.

Dallas

With this latest setback, researchers decided to focus efforts on identifying work zone lane closures that were being done by TxDOT maintenance forces on high-volume freeways, and so avoid the difficulties previously encountered in obtaining private contractor cooperation. Unfortunately, researchers determined that the Houston district does not do a significant amount of work itself on freeways, let alone work that involves lane closures. Rather, this type of work is generally contracted out as well.

Researchers then contacted TxDOT personnel in the Dallas district, who had been supportive of previous testing of the late-merge strategy (*5*). Researchers anticipated that responses from contractors in Dallas would be similar to those in Houston. Therefore, efforts focused on identifying possible TxDOT work zone lane closure activities. However, despite several promising leads over a several-week period, a suitable project site could not be found for testing purposes. Efforts to find a site and conduct an evaluation were finally abandoned in late-summer 2002.

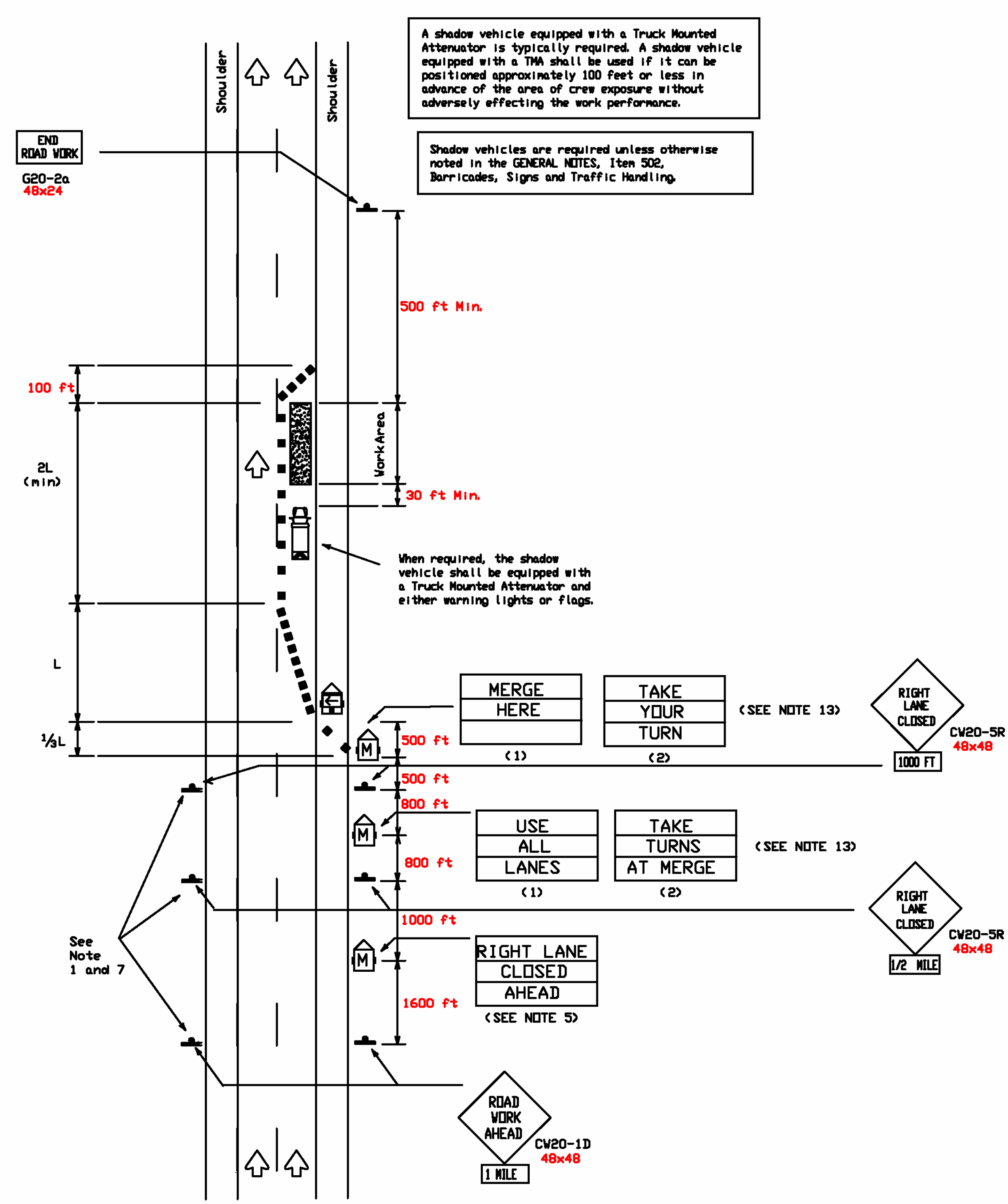

Figure 2-11. Example of a Dynamic Late Merge Strategy Traffic Control Plan.

Lessons Learned

Although TTI researchers were not successful in conducting an actual field test of the late-merge strategy, it became clear that the reason for the lack of success was not necessarily with the strategy itself. Rather, the difficulties appear to stem from the fact that contractors have now been explicitly assigned legal responsibility for the implementation and maintenance of work zone traffic control devices in the construction contract (something that had previously been assigned to TxDOT). This has significantly altered perceptions of liability by the contractor and has made them much more resistant to any deviations from traffic control plans that have been approved and implemented in a project. The resistance may stem from a perception that risk is no longer being shared equitably and therefore there is no incentive to innovate or test new ideas unless liability risk can be reassigned.

Whatever the reasons, it is important to recognize that despite the potential benefits of a late-merge strategy, implementation of the strategy at future work zone lane closure sites will likely not occur unless explicitly required in the traffic control documents for a particular work zone configuration. Although experiences with the strategy are not substantial enough yet to warrant TxDOT adopting a special standard late-merge traffic control plan at this time, there does seem to be enough positive potential in the strategy to encourage traffic control plan designers to consider specifically calling for its use when conditions warrant (i.e., when the lane closure is expected to generate significant traffic queuing upstream of the work zone). If the lane closures are short-term and will generate queues during the entire time they are present, a traffic control plan similar to that shown in Figure 2-11 could be specified and implemented using standard a PCMS. Conversely, if the project will involve lane closures that will only occasionally result in congestion, a more sophisticated implementation scheme may be required. This implementation scheme may include the purchase of portable work zone Intelligent Transportation Systems (ITS) or technologies configured to identify congestion and automatically post appropriate messages on PCMS's that are integrated into the system and linked by wireless communication technologies.

3. EVALUATION OF THE CB WIZARD TECHNOLOGY

Passage of the North American Free Trade Agreement (NAFTA) has significantly increased large commercial truck traffic volumes on many roads in Texas. Given the increase of large commercial truck traffic volumes using Texas freeways, it may be beneficial in some situations to communicate information specifically to this segment of freeway traffic.

One situation where additional communication with drivers of large trucks may be beneficial is the approach to certain types of work zones. Accident data presented in Chapter 1 illustrates that trucks appear to be over represented in work zone fatal crashes when compared to their involvement rates in non-work zone fatal crashes. Large trucks do not have the same acceleration, deceleration, turning, visual, and other characteristics of passenger cars. As a result, large speed differentials at the upstream end of work zone queues and increased lane changing activity by motorists, as they approach a work zone, can create significant difficulties for drivers of large trucks. One traffic management technology recently introduced into the market place that has the potential to directly communicate with drivers of large trucks is the CB Wizard. This chapter documents the ability of the CB Wizard transmitter to convey information about work zone conditions to truck drivers as they progress through a work zone. The effect of this information on driver behavior was assessed at work zones along I-35 in Hillsboro, Texas, I-410 in San Antonio, Texas, I-35 in Cotulla, Texas, and Loop 20 in Laredo, Texas.

The purpose of this evaluation was to determine truck driver compliance of CB Wizard transmissions with regard to work zone information. The specific objectives of the project were to:

- determine if advanced warning notifications via the CB Wizard provided safer transition and weaving maneuvers upstream of the construction work zone;
- determine if audible speed reduction notifications via the CB Wizard provided lower (and safer) speed profiles throughout the entire construction work zone; and
- determine if information provided in Spanish regarding construction work zones via the CB Wizard were effective in areas of predominantly Spanish speaking commercial truck drivers, specifically the U.S./Mexico border areas.

CB WIZARD DESCRIPTION

The CB Wizard is an unmanned CB radio transmitter that is manufactured by Highway Technologies, Inc. The CB Wizard can be used to provide pre-recorded information regarding highway or work zone conditions, much like a highway advisory radio (HAR). The benefit of the CB Wizard is that truck operators are typically tuned to a CB radio frequency so no further action is required to listen to the advanced warning. The CB Wizard unit is shown in Figure 3-1.

Figure 3-1. CB Wizard Advanced Warning Unit.

The CB Wizard is capable of storing three different pre-recorded messages for transmission. The maximum length of a pre-recorded message is 18 seconds. The user must manually select one of the three messages to be transmitted by the CB Wizard. Messages can be played at 30, 60, or 90 second intervals. The maximum range of the CB Wizard is approximately 4 miles, but remains dependent on the capabilities of the receiving CB radio, prevailing roadway geometry, and topography. Figure 3-2 illustrates a deployment of the CB Wizard within a data collection trailer at one of the test sites. Messages can be played on any band, but channel 19 is typically the most widely used CB channel by truck drivers for communication purposes.

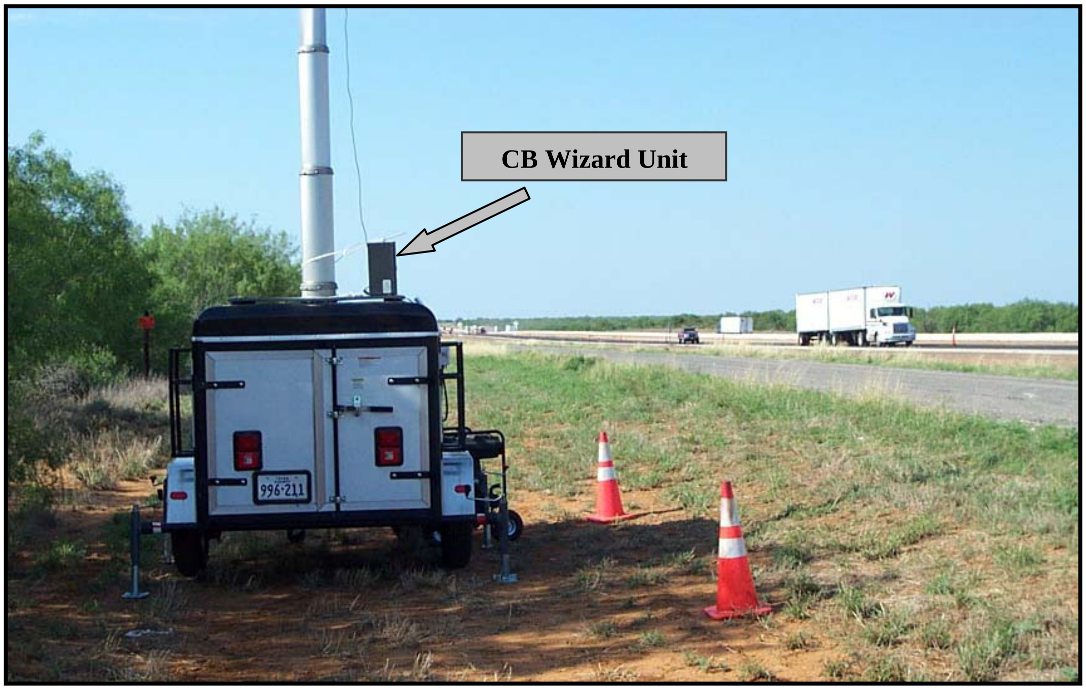

Figure 3-2. Typical CB Wizard Unit Evaluation Set-Up (I-35, South of Cotulla, Texas).

PRIOR CB WIZARD EVALUATION EXPERIENCES

In 1999, the states of Iowa, Kansas, Missouri, and Nebraska created the Midwest States Smart Work Zone Deployment Initiative (MwSWZDI). MwSWZDI is a pooled-fund project to develop better ways of controlling traffic through work zones, which would ultimately improve the safety and efficiency of traffic operations and highway work. During the first two years of the MwSWZDI, a total of 23 technologies were deployed and evaluated in the four states.

One of the technologies deployed for evaluation during the MwSWZDI study was the CB Wizard Alert System. The CB Wizard Alert System may be either vehicle-mounted or self-contained as a trailer-mounted unit. The MwSWZDI evaluated the vehicle-mounted version.

The MwSWZDI conducted a speed survey within the work zone on US 50, and administered a survey at a truck stop downstream of the work zone. Survey results indicated truck drivers were receptive to the idea and that the system would serve as an effective manner of conveying work zone information.

The MwSWZDI evaluation of the CB Wizard concluded that although no significant difference in speeds was expected or observed during the project, it was highly recommended as a versatile and effective tool for disseminating information related to work zones in areas where truck traffic is heavy (*8*).

TESTING OF THE CB WIZARD IN TEXAS

As part of this current research project, researchers evaluated the CB Wizard at four work zones (test sites) within Texas. Each of the four test sites was chosen for specific roadway characteristics (i.e., lane closures, reduced speed limits, etc.) that allowed the researchers to focus on different measures of effectiveness. The performance measures used for the CB Wizard evaluation included lane changes and merging behaviors upstream of a work zone, and speed profiles upstream and within the work zone.

Another question the researchers attempted to answer during these evaluations was the potential applicability of the CB Wizard technology in addressing work zone information needs of truck drivers having little or no English comprehension skills. It is known that many of the truck drivers near the Mexico border cannot easily read or speak English. This can be a significant problem, especially in work zones where the advance warning signs consist primarily of English text. Although posting dual English-Spanish work zone signs is neither practical nor desirable due to the visual clutter and potential information overload problems such a practice could create, it was hypothesized that information about a work zone could be recorded on the CB Wizard in both English and Spanish. Consequently, researchers utilized additional performance measures to explore the feasibility of this approach more directly at a test site near Laredo, Texas.

Site 1: I-35 (Hillsboro, Texas)

Site Description

Site 1 was located along I-35 near Hillsboro, Texas. TxDOT had determined that there were potential soil stability problems under the right lane of the freeway, and were conducting tests to determine an appropriate corrective measure. Until a solution was developed, TxDOT wanted to remove the heavy vehicles from the right lane. The work zone tested was approximately 6.5 miles long. Figure 3-3 illustrates the site layout for I-35 near Hillsboro, Texas.

This site had several characteristics that made the use of the CB Wizard appropriate. First, trucks compose a very large portion (> 20 percent) of the traffic stream. Most truck drivers have a CB radio, so the CB Wizard messages could potentially be heard by a large number of vehicles. Second, the purpose of the truck restriction was not apparent to drivers, and this information cannot be conveyed to drivers traveling at highway speeds by using static signs or PCMS's. The CB Wizard offers the opportunity to explain the purpose of the lane restriction to truck drivers, potentially increasing compliance. There was also a perception that speed limit compliance at this site is low. The CB Wizard can be used to increase awareness of the 55 mph speed limit.

The evaluation occurred over three days. Data on truck lane usage and speeds were collected from 7:00 AM to 9:00 AM, 11:00 AM to 1:00 PM, and 4:00 PM to 6:00 PM all three days. Truck volume data were collected 0.5, 3.5, and 6.5 miles after the start of the work zone, and truck speed data were collected 0.5 miles and 3.5 miles after the start of the work zone.

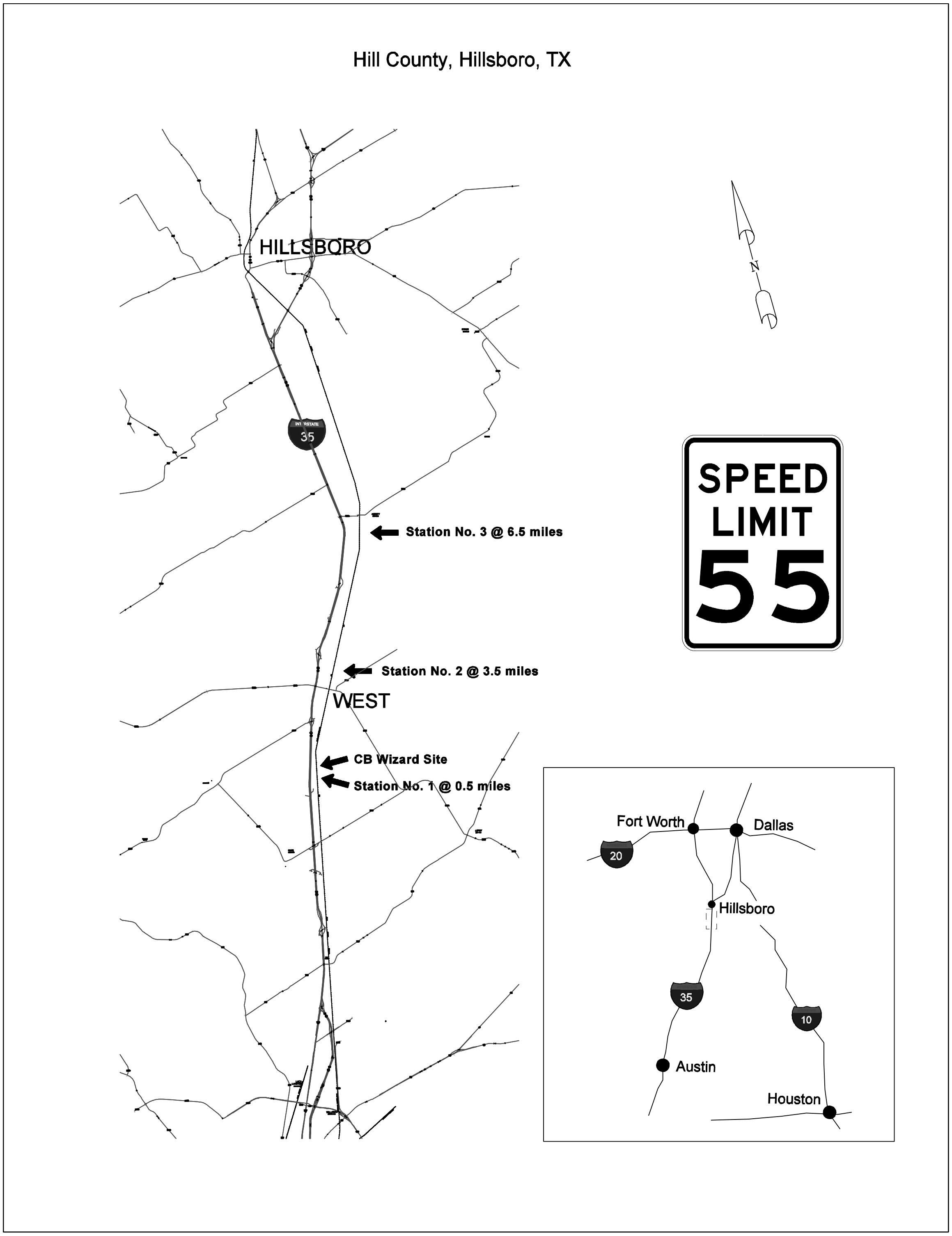

Figure 3-3. Site 1 Layout (I-35, Hillsboro, Texas).

The CB Wizard was not used on the first day of data collection in order to determine normal truck lane usage and speed limit compliance with existing traffic control. On subsequent days, the CB Wizard was activated and placed 0.5 miles from the start of the work zone. The observed maximum range of the CB Wizard transmissions at the site was 2 miles. Different messages were evaluated on the second and third day of testing. The CB Wizard was tested with the following two messages:

Site 1, Message 1: (Base)	*This is the Texas Department of Transportation.* *All Northbound trucks on Interstate 35 should use the left lane through the next work zone.* *The speed limit through the work zone is 45 miles per hour.* *Thank you.*
Site 1, Message 2: (Explanatory)	*This is the Texas Department of Transportation.* *All Northbound trucks on Interstate 35 should use the left lane through the next work zone.* *We are performing an analysis of the soil strength below the right lane.* *The speed limit through the work zone is 45 miles per hour.* *Thank you.*

Effect of Wizard on Lane Choice

The impact of the CB Wizard on the lane choice of trucks was examined first. Table 3-1 shows the percentage of trucks that utilized the left lane for each type of message. The results showed that the CB Wizard significantly increased the percentage of trucks that were in the left lane when they entered the work zone. The CB Wizard allowed truck drivers to receive advance warning of the lane restriction before static signing or PCMS messages became visible, so these results are not surprising.

Message 2 also significantly increased the percentage of trucks that utilized the left lane at the data collection station 3.5 miles from the start of the work zone. It is possible that the explanation added greater weight to the message, encouraging compliance with the lane restriction. There was no difference in the percentage of trucks using the left lane at the end of the work zone.

Table 3-1. Percent of Heavy Vehicles in the Left Lane at Each Data Collection Station.

Message	**Distance from Upstream Start of Work Zone (Miles)[a]**		
	0.5	**3.5**	**6.5**
No Message	55.1	85.2	42.3
Message 1	77.9	87.6	44.4
Message 2	79.2	89.6	43.1

[a] Shaded cells are significantly different from "No Message" condition at $\alpha = 0.05$.

Effect of Wizard on Speed Compliance

Researcher's assessed the impact of the CB Wizard on truck travel speeds. Table 3-2 summarizes the speed data that was collected for each message. The mean speeds at the start of the work zone were higher when the CB Wizard was used versus when it was not used. The CB Wizard did not create speeds 3.5 miles into the work zone that were significantly lower than the speeds observed when the Wizard was not used.

Speeds observed during testing of messages 1 and 2 were not significantly lower than the speeds during the "No Message" condition. However, speeds were reduced by a statistically significant amount between the start and the middle of the work zone when the CB Wizard was active, which did not occur during the "No Message" condition. Truck speeds were found to be between two and three mph lower in the middle of the work zone than at the beginning of the work zone when the CB Wizard was transmitting a message. The number of vehicles that were traveling more than 10 mph over the speed limit was also reduced when the CB Wizard was used.

Table 3-2. Speed Characteristics, Site 1.

Statistic	**Message**					
	No Message		**Message 1**		**Message 2**	
	0.5 Miles	**3.5 Miles**	**0.5 Miles**	**3.5 Miles**	**0.5 Miles**	**3.5 Miles**
Mean Speed[a]	62.8	62.4	64.9	61.9	63.7	61.5
Standard Deviation	4.9	4.3	4.1	4.6	5.0	4.6
85th Percentile Speed	68	67	69	67	69	67
% Over 55 mph	94.1	93.6	99.2	94.9	95.5	88.0
% Over 65 mph	30.9	22.8	46.1	21.5	37.3	24.8

[a] Speeds in shaded cells are lower than initial work zone speeds at α=0.05.

Although statistically significant speed reductions were observed between the start and the middle of the work zone, the magnitude may not represent practically significant changes in truck driver speed choice as a result of the messages on the CB Wizard. For both the base and explanatory message, speeds 3.5 miles into the work zone were within 1 mph of the speeds observed without using the CB Wizard.

Site 2: I-410 (San Antonio, Texas)

Site Description

Site 2 was located along I-410 between I-10 and I-37 in southeast San Antonio, Texas. This section of roadway is a four lane divided interstate highway with frontage roads and a grassy median. Figures 3-4 through 3-6 show the typical roadway characteristics. The roadway project for this evaluation was an asphalt overlay of the main highway lanes in both directions, approximately 7.0 miles total. The project was divided into four sections (two in each direction). Figure 3-7 illustrates the site layout for I-410 in San Antonio, Texas, and a general Traffic Control Plan (TCP) is provided in Figure B-1 in Appendix B.

Figure 3-4. Site 2 – Photo of I-410 at Station 1 (San Antonio, Texas).

Figure 3-5. Photo of Typical Counter Setup for Site 2.

Figure 3-6. Site 2 – Photo of Roadway View between Station 5 and Station 6.

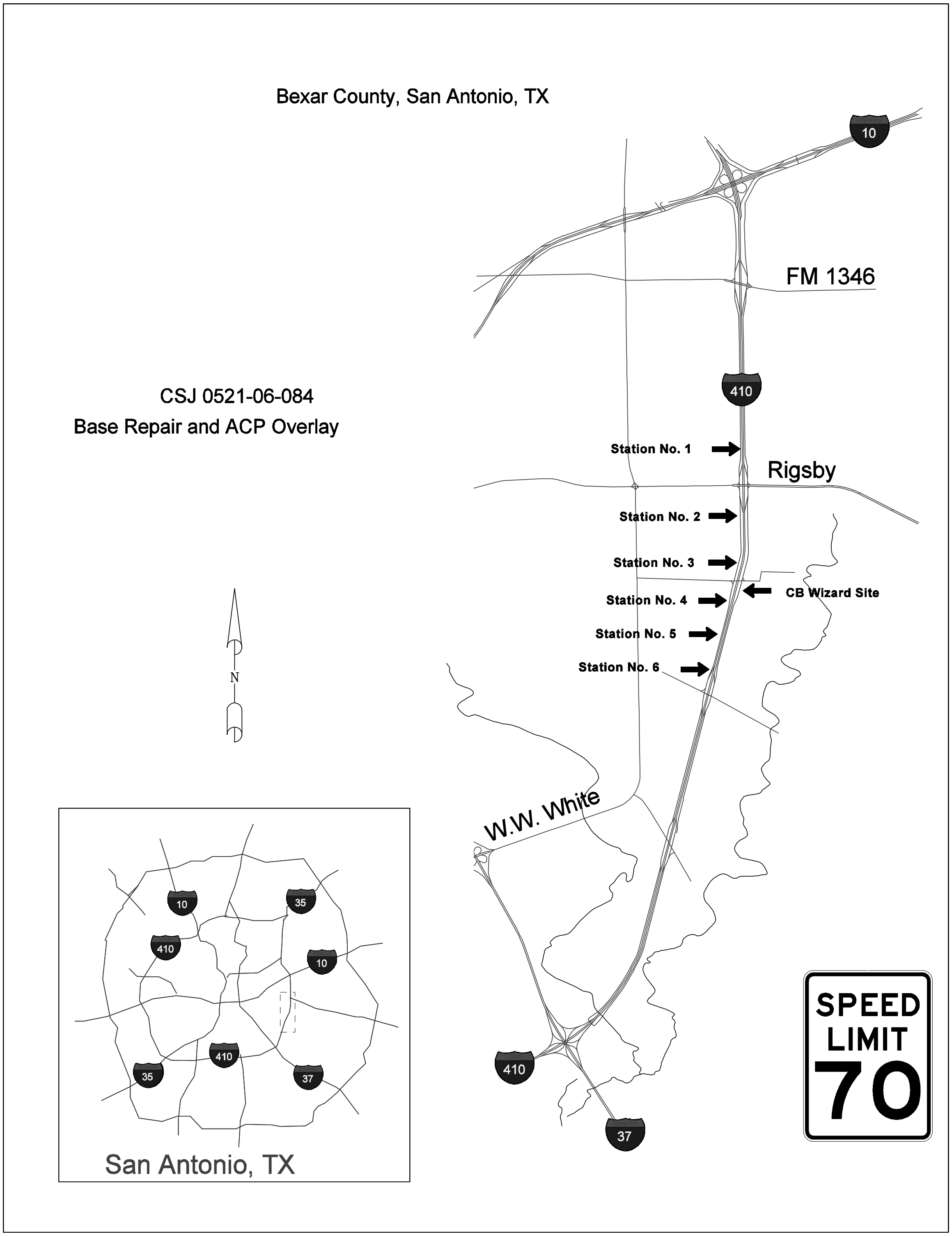

Figure 3-7. Site 2 Layout (I-410, San Antonio, Texas).

The posted speed limit is 70 miles per hour with no advisory speed limit recommended within the work zone. Site 2 was examined for lane change effectiveness of the CB Wizard warning system and for speed compliance. The following message was used for Site 2 testing:

(Site 2 Message) *This is the Texas Department of Transportation. Southbound Interstate 410 traffic is entering a work zone. All vehicles must use the left lane. Thank you.*

Six tube counter stations were placed in the roadway spaced 0.5 miles apart. Two days of speed data were collected on April 16-17, 2002, prior to the work zone being in place. The control speed and lane choice data were collected on Friday April 19, 2002, with the tube counters and three video cameras, from 9:00 AM to 12:00 PM. The CB Wizard message was broadcast and data were collected immediately following the control, from 12 PM to 3:00 PM

The CB Wizard was located between Stations 3 and 4 with a confirmed broadcast radius of one mile. The study site also had an entrance ramp between Stations 1 and 2 and an exit ramp at station 6 (see Figure 3-7).

Effect of CB Wizard on Lane Choice

Researchers examined the impact of the CB Wizard on the lane choice of trucks first. Figure 3-8 shows the percentage of trucks that utilized the left lane for the "control" and the CB Wizard Tests. Station 2 was not visible by the video cameras, so data were not able to be collected. The results for the other five counters showed the CB Wizard to have little effect in the lane choice decisions at this site. Station 1 and 3 showed a slight increase in the percentage of trucks in the left lane; however, Stations 4, 5, and 6 showed a decline in the left lane percentage from the "control" condition. These slight variances in the data can most likely be attributed to entrance and exit ramp maneuvers as well as general traffic friction associated with lane changes (i.e., normal weaving activity). However, it is encouraging to note that the trends suggest a slight shift of truck traffic to the open lane upstream of the work zone where the CB Wizard message is first encountered by truckers. Then, as truck drivers get closer to the work zone and the ramp effects begin to take on a more significant role in driver decisions and lane choices, the influence of the Wizard appears to diminish.

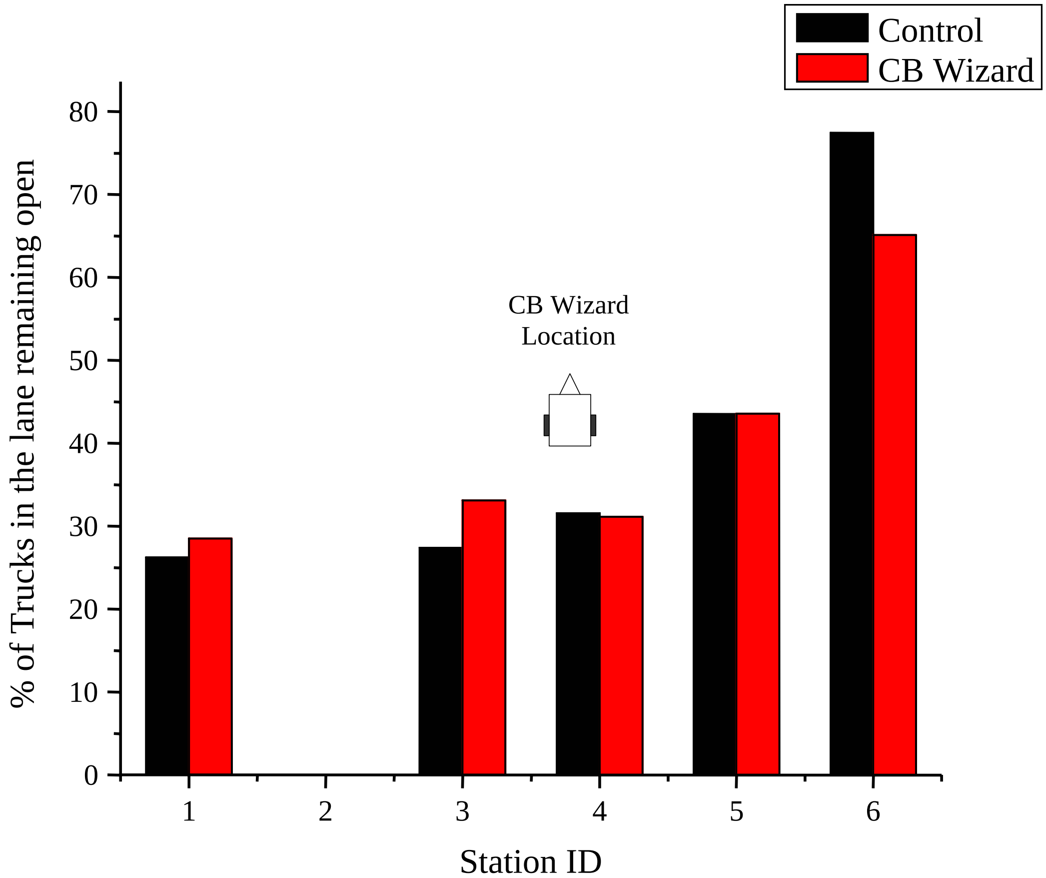

Figure 3-8. Lane Choice for Heavy Vehicles at Site 2 (I-410, San Antonio, Texas).

Effect of CB Wizard on Speed Compliance

The impact of the CB Wizard on truck travel speeds was also assessed for Site 2. Figure 3-9 shows the speed profile for the site on a day prior to the work zone being put in place. Figure 3-10 then shows the speed profiles for the "control" case and the CB Wizard test case. The data do not show a clear impact of the CB Wizard on speeds. Examining Figure 3-10, Station 1 shows a slight decrease in speed; however, it was determined not to be significant. Station 2 shows a significant difference between the control and the CB Wizard test. However, this difference was also seen between the AM and PM data collected before the work zone was in place (Figure 3-9). Based on these data, it is not possible to conclude that the CB Wizard had a substantial speed-reducing effect. As an additional measure of performance at this site, Figure 3-11 shows the percent of the truck traffic stream exceeding the 70 mph speed limit. Stations 1, 2, and 3 had a reduction in violations while stations 4, 5, and 6 experienced an increase in percent violations. Again, this trend is interesting in that the stations farther upstream of the work zone where the CB Wizard can be heard do experience some positive effects in speeding behavior, but this is lost once the trucks are closer to the work zone and are being affected by ramp traffic. For this site, researchers could not positively conclude that the CB Wizard had a consistent speed-reducing effect upon large trucks in the work zone.

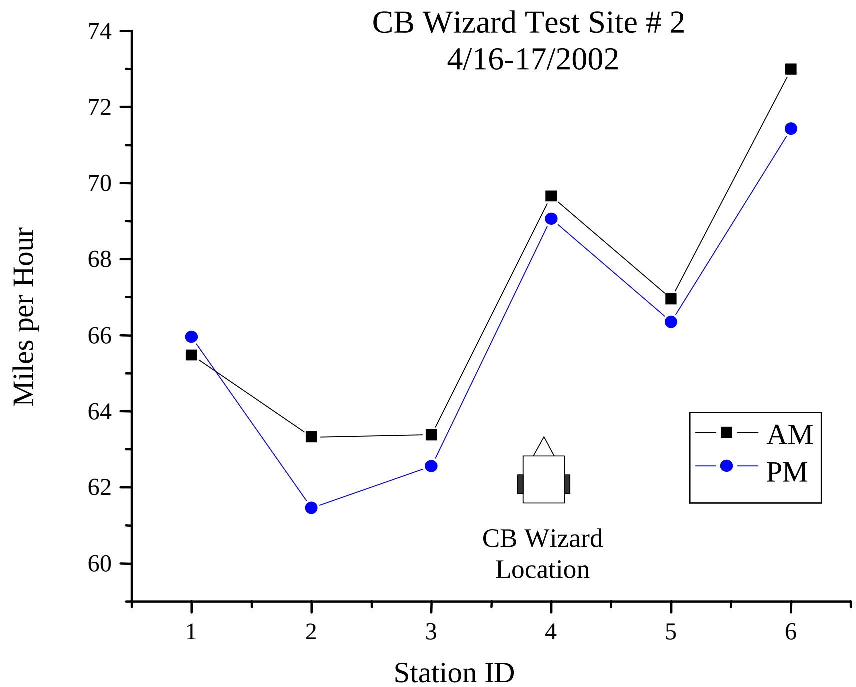

Figure 3-9. Speed Profile for Heavy Vehicles at Site 2 – Before Condition.

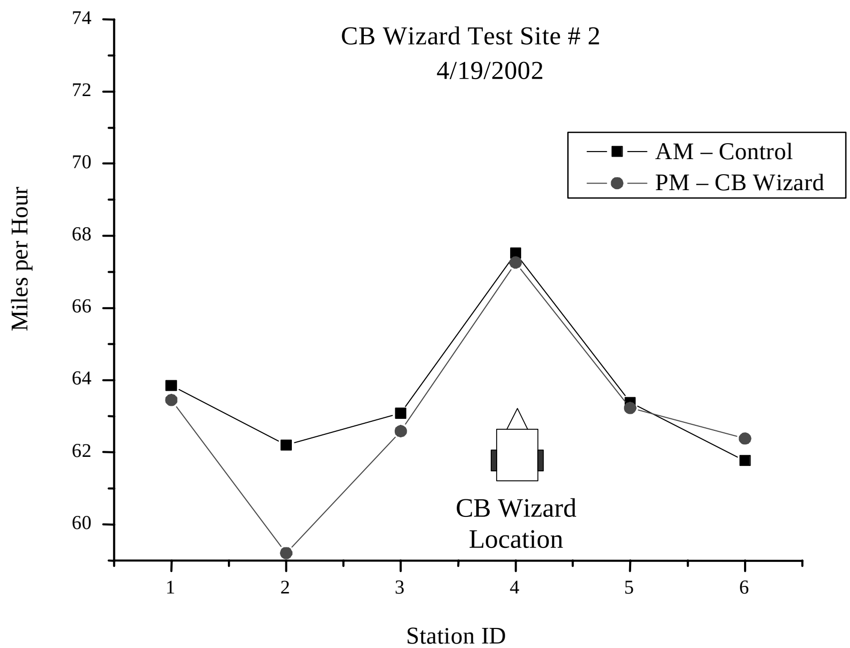

Figure 3-10. Speed Profile for Heavy Vehicles at Site 2 – During Condition.

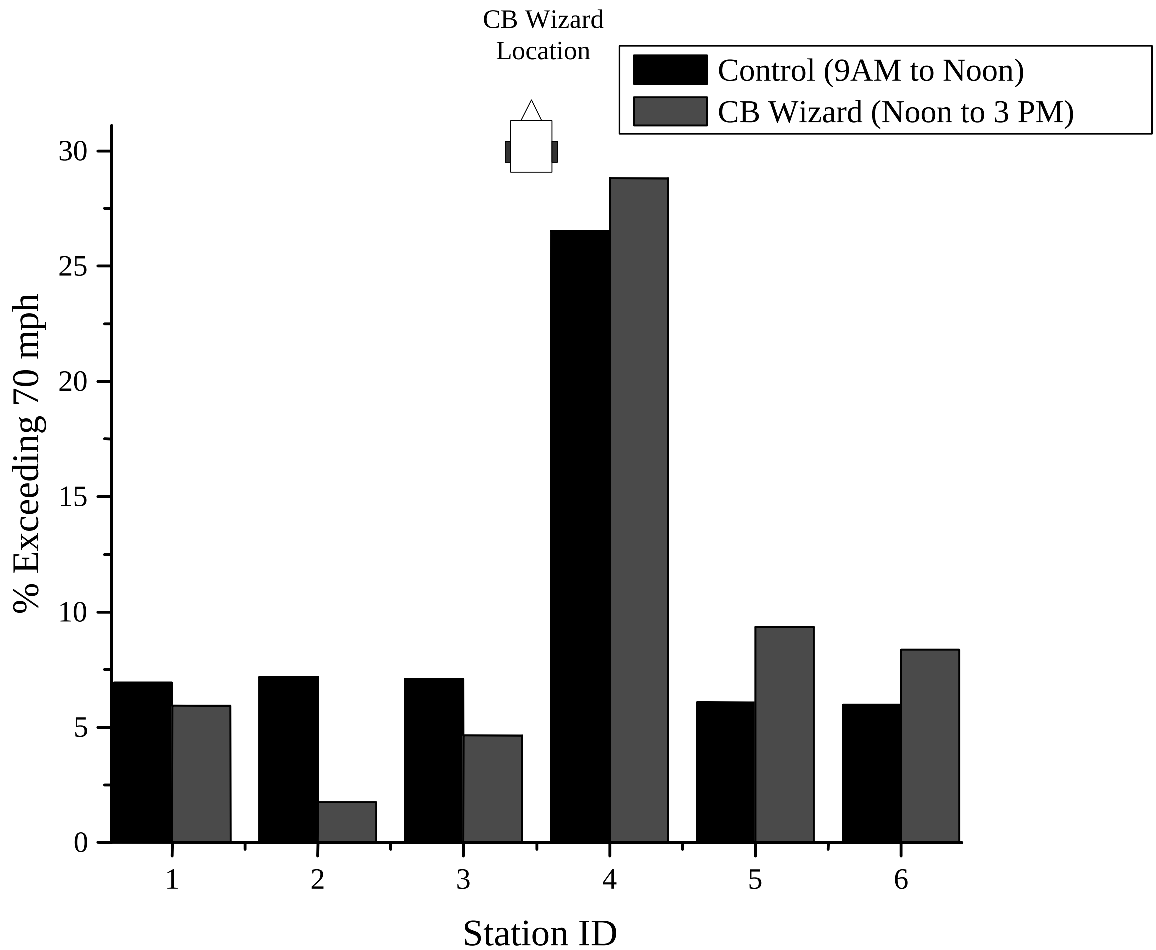

Figure 3-11. Percent of Heavy Vehicle Traffic Exceeding 70 mph at Site 2.

Site 3: I-35 (Cotulla, Texas)

Site Description

Site 3 was located along I-35, south of Cotulla, Texas. Similar to Site 2, the roadway is a four-lane divided interstate highway with a grassy median. The TxDOT construction project considered for this evaluation was a complete reconstruction of the main highway lanes (i.e., lime treatment, subgrade, base, and surface) in both directions, approximately 7.4 miles total. The project was divided into 2 mile sections (four sections in each direction) during the roadway reconstruction. Photos of the roadway are included as Figure 3-12 and 3-13. Figure 3-14 illustrates the site layout for I-35 south of Cotulla, Texas, and a general TCP is provided in Figure B-2 in Appendix B.

Figure 3-12. Site 3 Photo of Merge Area.

Figure 3-13. Site 3 Photo of Construction Zone.

The posted speed limit is 70 miles per hour with an advisory speed limit of 55 miles per hour through the work zone. The work zone was free of influences until the on ramp just before station 5.

Site 3 had six stations measuring truck speed at 0.5 mile spacings throughout the work zone. Data were collected for the control from 9 AM to 3 PM on Wednesday, May 29, 2002. The CB Wizard test case data were collected the following day during the same time periods. The CB Wizard was located 0.5 miles upstream of the first counter station 1. The message used in the testing broadcast was:

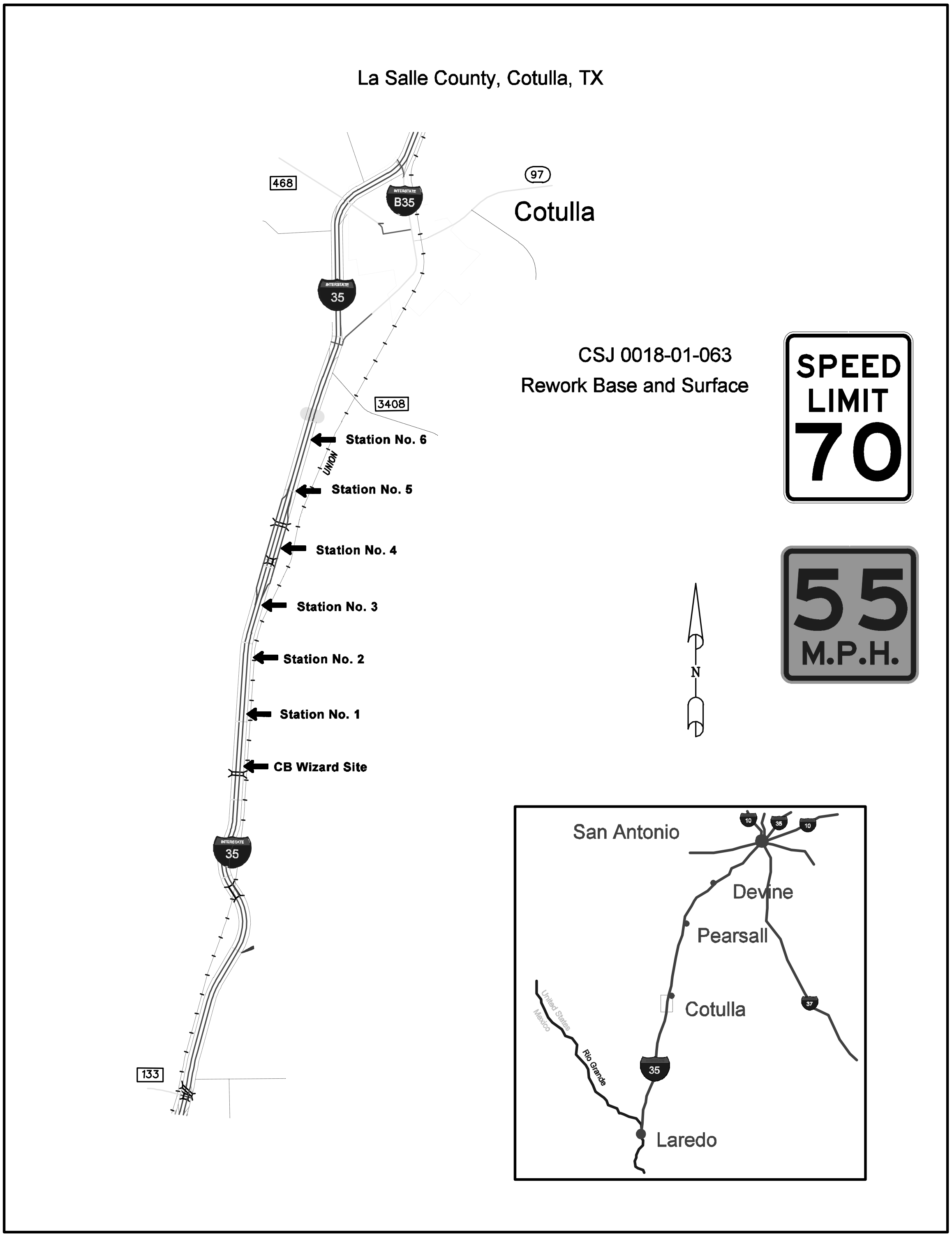

Figure 3-14. Site 3 Layout (I-35, Cotulla, Texas).

Site 3 Message: *This is the Texas Department of Transportation. All northbound traffic on Interstate Highway 35 should use the right lane through the next work zone. The advisory speed limit through the work zone is 55 miles per hour. Thank you.*

Effect of the CB Wizard on Speed Compliance

The impact of the CB Wizard on truck travel speeds is present in Table 3-3. Figure 3-15 illustrates the speed profiles during the "control" and the CB Wizard tests. The count reported by station 2 was low compared to all of the other stations. However, the available data from station 2 were reviewed and found to be of a quality comparable to the other stations.

Table 3-3. Summary of Speed Profile for Site 3 (I-35, Cotulla, Texas).

Station	Condition	Count[a]	Mean Speed[a]	Standard Deviation	Significant Difference (α=0.05)
1	Control	760	61.3	6.4	Yes
	CB Wizard	788	59.4	6.3	
2[b]	Control	400	56.9	5.3	Yes
	CB Wizard	439	54.8	5.2	
3	Control	791	58.5	4.5	Yes
	CB Wizard	837	56.8	4.5	
4	Control	770	61.5	4.9	Yes
	CB Wizard	790	59.7	4.8	
5	Control	770	60.7	7.3	No
	CB Wizard	595	61.1	6.9	
6	Control	688	66.3	5.0	No
	CB Wizard	697	66.2	4.5	

[a] The Timemark System was used to analyze the tube hits into vehicle classes and speeds.
[b] The Timemark System found anomalies in the data and disregarded the data that it could not process into vehicles and speeds.

The data from Stations 1, 2, 3, and 4 showed a significant difference between "control" and the CB Wizard test conditions. Station 5 was possibly influenced by the entering traffic from an access road. Station 6 experienced an increase in speed on both days, possibly due to the visual confirmation of the end of the work zone and the end of the advisory speed. Figure 3-16 shows the percent of trucks traveling faster than the posted 70 mph speed limit. Taken together, the data from this site strongly suggests that the CB Wizard decreased speeds and speeding violations throughout the work zone, and that the reduced speeds were maintained throughout the length of the work zone.

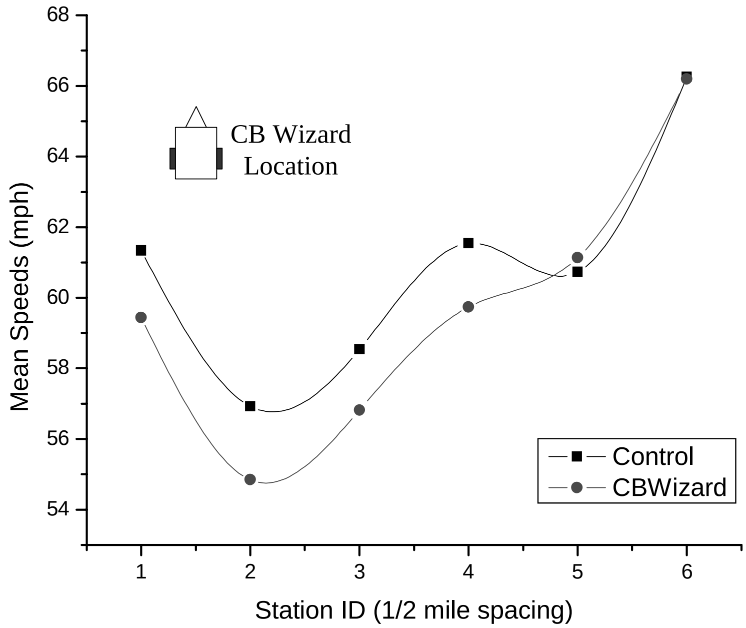

Figure 3-15. Speed Profile for Heavy Vehicles at Site 3.

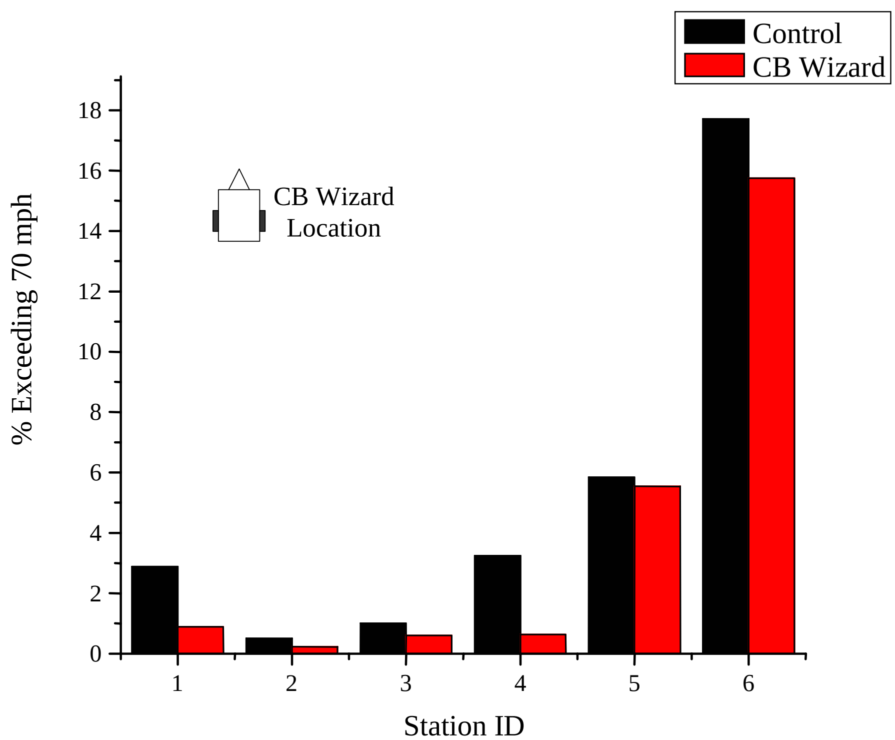

Figure 3-16. Percent of Heavy Vehicle Traffic Exceeding 70 mph at Site 3.

Site 4: Loop 20 (Laredo, Texas)

Site Description

Site 4 was located along Loop 20 (Bob Bullock Loop) between Del Mar Boulevard and McPherson Road in Laredo, Texas. Loop 20 is a two lane arterial presently under construction for widening to a five-lane roadway, two-lanes in each direction with a two-way left-turn lane (TWLTL). The work zone was one lane in each direction with a short two-lane passing section. The construction project extends south of Del Mar Boulevard; however, due to cross street traffic from Del Mar Boulevard, the project site was limited to that intersection. The intersection of Del Mar Boulevard and Loop 20 is signalized. Figures 3-17 through 3-19 show the work zone characteristics. Figure 3-20 illustrates the work zone layout for Loop 20 in Laredo, Texas, and a general TCP is provided in Figure B-3 in Appendix B.

Figure 3-17. Loop 20 at Station 1.

Figure 3-18. Loop 20 'S' Curve in the Work Zone.

Figure 3-19. Loop 20 Work Zone Approaching Del Mar Boulevard.

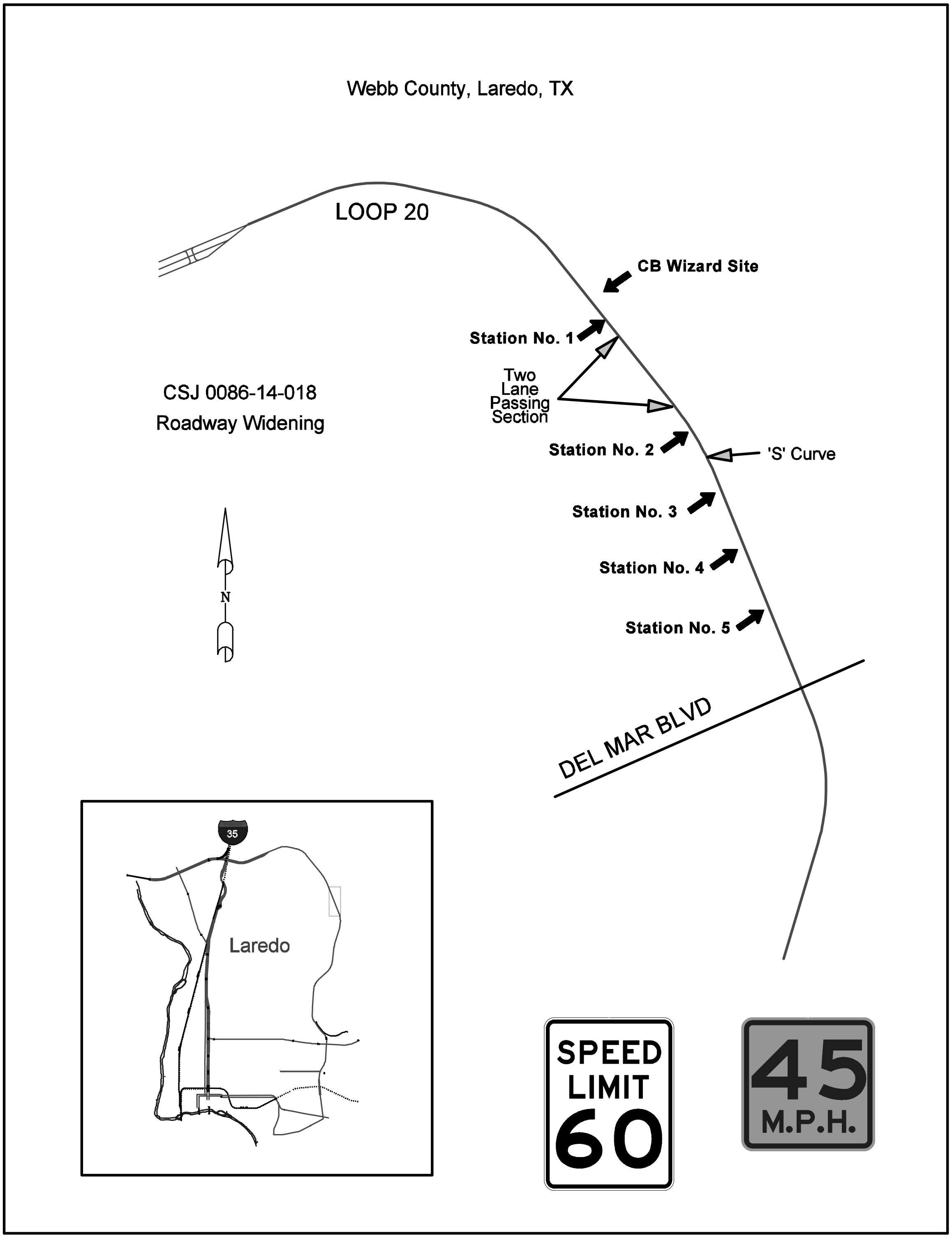

Figure 3-20. Site 4 Layout (Loop 20, Laredo, Texas).

The posted speed limit is 60 miles per hour with an advisory speed limit of 45 miles per hour through the work zone. Site 4 was tested for speed reduction effectiveness of the CB Wizard warning system in a bilingual mode (i.e., Spanish and English) and supplemented by a survey of truck drivers preferences conducted at the intersection of Loop 20 and US 59.

Five stations were set up to collect speeds throughout the Loop 20 work zone. Each station was approximately 0.5 miles apart. The CB Wizard was located just upstream of station 1. The site was free from ramps and driveways.

The project was conducted over a three-week period, only using Tuesdays, Wednesdays, and Thursdays to collect data. The first-week data were collected in the work zone without the influence of the CB Wizard (control). The second week the CB Wizard was used broadcasting in Spanish, while the third week was broadcast in English. The messages broadcast during the CB Wizard tests were:

Site 4, Message 1: (English)	*This is the Texas Department of Transportation.* *Southbound traffic on Loop 20 is approaching a construction work zone.* *Construction in progress, please use caution.* *The advisory speed limit is 45 miles per hour. Thank you.*
Site 4, Message 2: (Spanish)	*Este es el Departamento de Transporte de Tejas.* *El trafico de sur salta en Loop 20 se acercan una zona del trabajo de construccion.* *Construccion es en progreso, por favor de usar cuidado.* *Velocidad maxima es 45 millas por hora. Gracias.*

Effect of CB Wizard on Speed Compliance

Figure 3-21 shows the truck speed profiles for each week tested. Generally speaking, speeds during the presentation of the Spanish message were almost identical to those recorded during the control (no CB Wizard) condition. The exception to this occurred at Station 2. At this location, average speeds when the Spanish message was presented were significantly lower than the control condition at a 0.05 confidence level. Strangely, the speeds observed during the English message presentation did not resemble the speed profiles for either the Spanish message condition or the control condition. The mean speed during the English message presentation at Station 2 was lower than observed during the control conditions. However, the mean speed at the other data collection locations exceeded those during the control condition. TTI researchers could not identify any plausible causes for the different speed profile (i.e., change in traffic control scheme, new businesses opening or closing, etc.). Nevertheless, it is again encouraging to note that the CB Wizard did reduce speeds at Station 2 under both the English and Spanish message conditions. Prior to the introduction of the Wizard, trucks were accelerating substantially during the initial section of the work zone. With the CB Wizard in place, the amount of speed increases did diminish. Given that operating speeds at the downstream stations were largely controlled by the geometrics of the site (refer back to Figures 3-18 and 3-20), a reduction in speeds at Station 2 can be viewed as particularly positive.

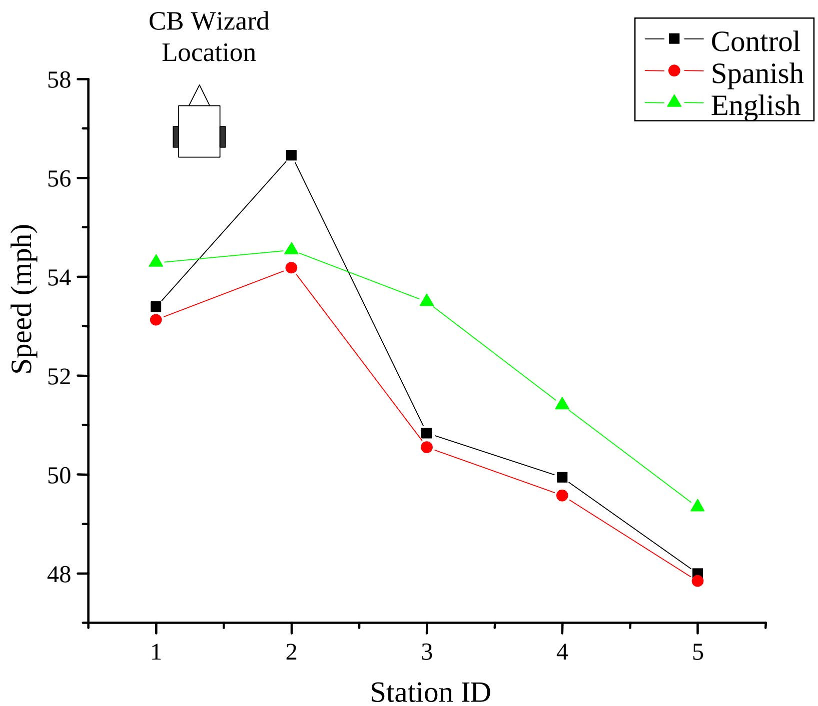

Figure 3-21. Speed Profile for Heavy Vehicles at Site 4.

Figure 3-22 shows the percent of trucks exceeding the posted 60 mph speed limit at each of the data collection stations for each of the test conditions. Interestingly, a significant reduction in speed violations can be seen at stations 1 and 2 for both messages on the CB Wizard. Although speed violators were up under both CB Wizard message conditions at stations 3 and 4, these stations are beyond the critical geometric feature of the work zone (i.e., the S-curve). Furthermore, the approximate 15 percent of speed violations during the English message presentation, while an increase over the control condition, is not excessive. It should be noted that the 85th percentile speed of traffic, which means that there are 15 percent of vehicles with higher speeds, is commonly used to define appropriate speed limits on public roadways.

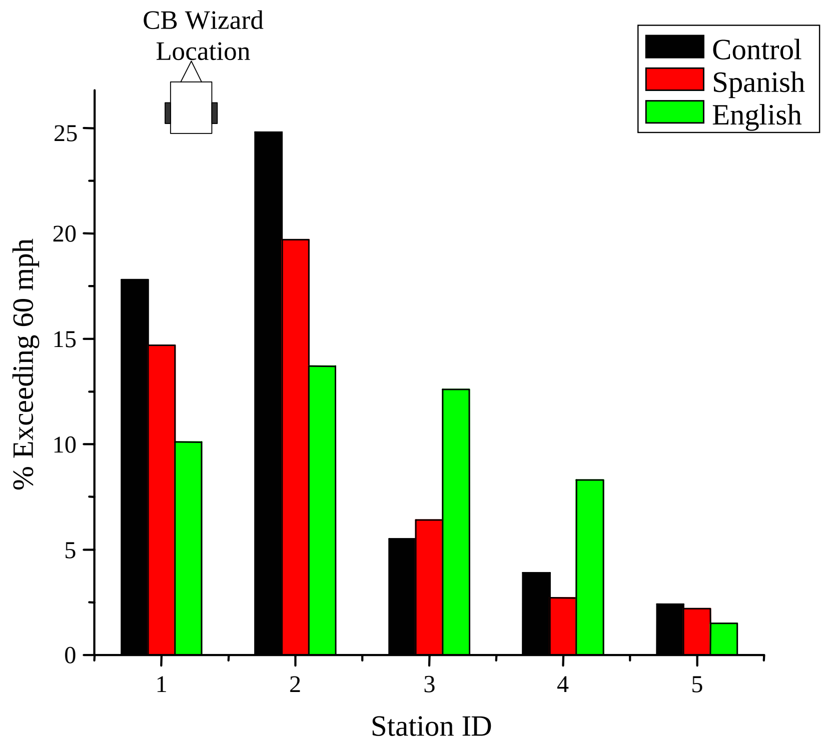

Figure 3-22. Percent of Heavy Vehicle Traffic Exceeding 60 mph at Site 4.

Truck Driver Survey Findings

To further explore the potential of bilingual messages presented via the CB Wizard, data collectors interviewed more than 80 truck operators during the weeks that the Wizard was activated. The operations were queried on Southbound Loop 20 at US 59 at the signalized intersection approach.

The operators were asked three basic questions:

1. Did you hear the message in the Loop 20 work zone?
2. What channel are you listening to?
3. In what language do you prefer to receive traffic information?

Generally speaking, all of the truck operators surveyed acknowledged driving through the work zone, but many did not hear the CB Wizard message. Many drivers actually had to turn their radio on or up when the researcher asked if they had heard the message.

Figure 3-23 reports the language preference of the operators interviewed. In the Laredo region, most truck operators (69 percent) are bilingual or speak predominantly Spanish. Figure 3-24 is a summary of the channel preference as expressed by the surveyed operators. Although operators cited channel 19 as their preferred channel most often, there were substantial numbers of several other channel preferences and a significant number of operators without CB radios at all. These results were somewhat surprising, so researchers performed more detailed analyses of these data. When channel preference is categorized according to the CB language preference, a distinct trend emerges. As depicted in Figures 3-25 through 3-27, operator preference for CB channel 19 is highly dependent upon the language preferences of the operator. Whereas English-preferred operators overwhelmingly prefer CB channel 19 (85 percent of operators who prefer English), only 50 percent of bilingual operators and just 3 percent of operators preferring Spanish actually prefer channel 19. In fact, most of the operators who prefer Spanish do not even have a CB radio in their cab. This finding indicates that the CB Wizard may not be the appropriate mechanism for presenting bilingual traffic information to truck operators, since only a few operators who could benefit from having the information will have the hardware means necessary to actually receive the information.

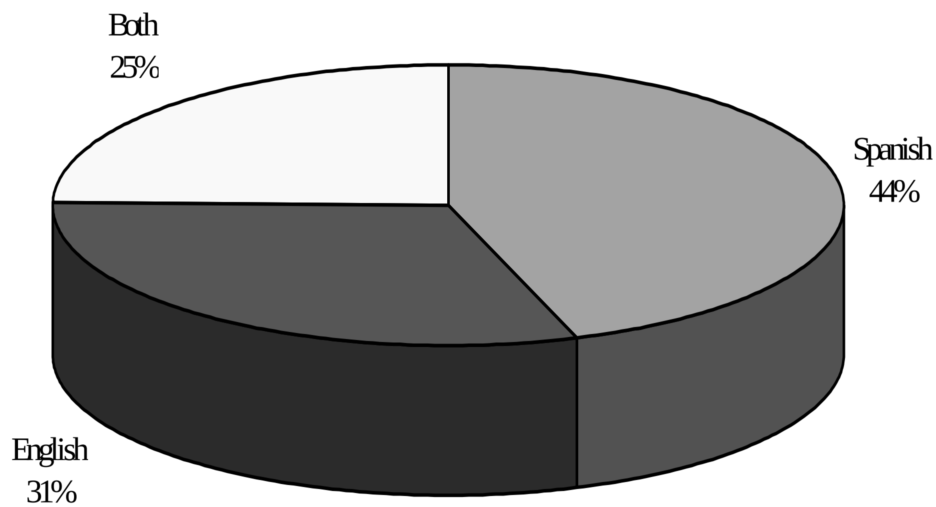

Figure 3-23. CB Radio Language Preference in Laredo, Texas.

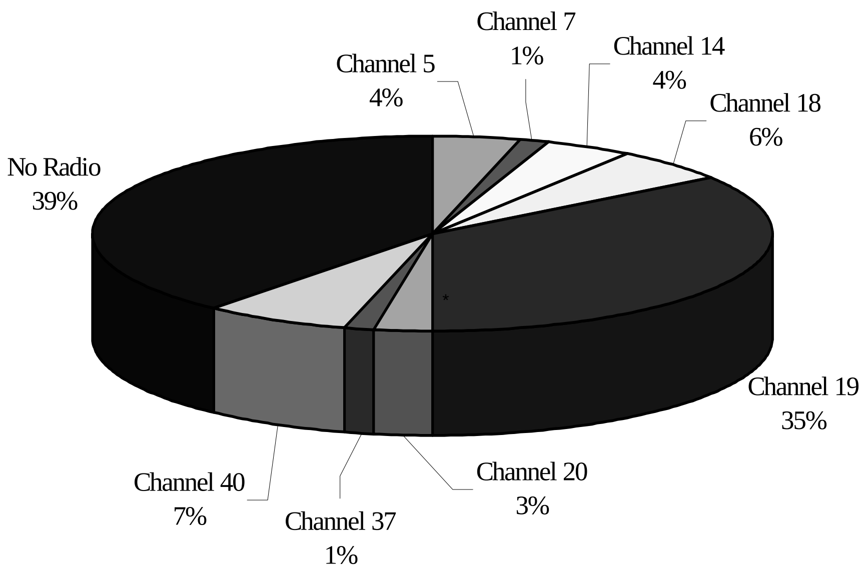

Figure 3-24. CB Radio Channel Preference in Laredo, Texas.

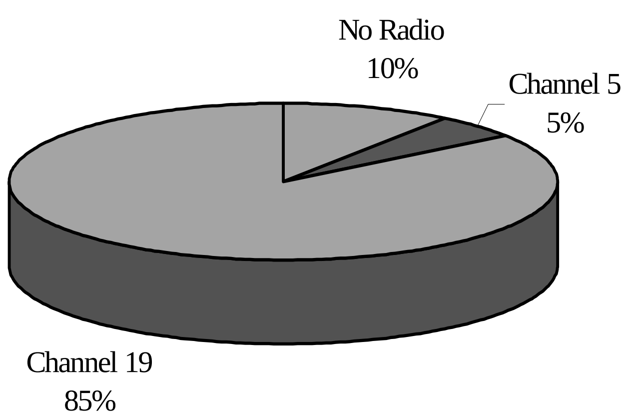

Figure 3-25. CB Radio Channel Preference of English-Speaking Operators.

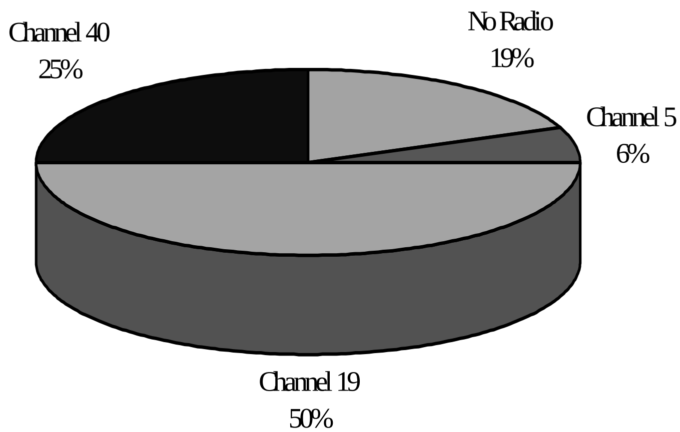

Figure 3-26. CB Radio Channel Preference of Bilingual Operators.

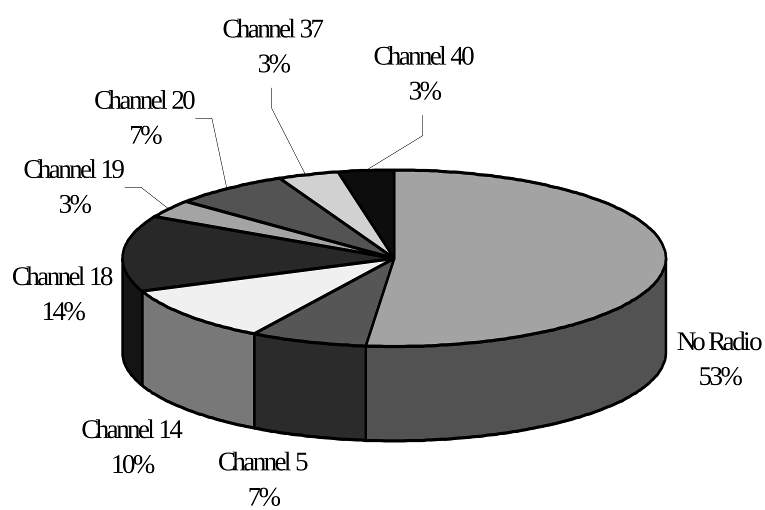

Figure 3-27. CB Radio Channel Preference of Spanish-Speaking Operators.

Other Observations Affecting CB Wizard Effectiveness

In addition to the results presented in previous sections, TTI researchers recorded a number of other practical observations that appeared to directly or indirectly influence the effectiveness of the CB Wizard. These observations are summarized below. Additional comments are summarized in Table 3-4.

Study Site 2: (San Antonio, Texas)

- Topography and roadway curvature limited the CB Wizard transmission range.
- Freeway characteristics, primarily ramp locations and operations, may have affected the analysis as well.

Study Site 3: (Cotulla, Texas)

- Topography and roadway curvature limited the CB Wizard transmission range.

Study Site 4: (Laredo, Texas)

- Topography and roadway curvature limited the CB Wizard transmission range.
- Commercial vehicle operations (i.e., drayage, long-haul, and local delivery) are multi-purpose and relied on other communication options (e.g., mobile phone).
- CB Radio multi-channel usage / no usage were prevalent in the Laredo area.
- Roadway characteristics such as passing lanes and horizontal curves at the test site may have affected the results.

Table 3-4. Site Summary.

Site	MOE	CB Wizard Impact	Other Observations
1 – I-35 near Hillsboro	Lane Preference	Statistically Significant	CB Wizard was effectively used to provide additional information specifically to commercial traffic
	Speed	Marginal Change	-
2 – I-410 in San Antonio	Lane Preference	No Change	CB Wizard was not able to prove itself effective at this site, possibly due to high percentage of local traffic
	Speed	No Change	CB Wizard was not able to prove itself effective at this site, possibly due to high percentage of local traffic
3 – I-35 near Cotulla	Speed	Statistically Significant	CB Wizard proved effective in the rural, high truck percentage location
4 – Loop 20 in Laredo	Speed	Marginal Change	Speeds upstream of a reduced speed curve were positively affected
	Bilingual Applications	No Change	Survey showed CB Wizard had difficulties reaching a Spanish speaking audience

IMPLEMENTATION RECOMMENDATIONS

- Static operation of the CB Wizard could be most effective when used in work zones in rural projects (minimal local commercial traffic) where there is a high percentage of commercial-through traffic.
- Mobile operation of the CB Wizard (i.e., included in a work convoy that moves intermittently or continuously), although not evaluated in this project, may be valuable where a high percentage of the traffic stream consists of commercial vehicles.
- The topography of the area adjacent to the work zone should be considered during set-up of the CB Wizard System as vertical curves in hilly environments affect transmission range of the CB transmitter. The CB Wizard System operates at optimum range when positioned at the upstream crest of a vertical curve within a work zone.
- Set-up of the portable CB Wizard System requires a 12-volt DC power source (i.e., a vehicle cigarette lighter). The device can also be run from a generator through an AC-DC converter. Since the device will typically be set up on the roadside, steps should be taken to ensure power will be supplied throughout the implementation and to secure the device to avoid tampering. This may require the purchase of a larger, more powerful trailer-mounted unit (currently available from the vendor), or co-locating the CB Wizard with a piece of equipment such as an arrow panel.
- Channel selection for the CB Wizard System may be customized to a specific area or an intended audience.
- At the present time, the CB Wizard should not be considered a feasible method of conveying traffic information in both English and Spanish formats in border areas. The majority of the audience for which the Spanish information would be intended will not receive this information due to a lack of CB radio market penetration in the vehicles.
- The CB Wizard message should be recorded away from the roadway or indoors to minimize background noise. The message should contain a brief user identification statement, and short message containing only pertinent information about the work zone, and a “thank you” or other closing comment. Female voices are preferred due to their higher frequencies.
- Modifications and enhancements to the existing CB Wizard that appear to warrant further consideration include:
    - longer message capacity,
    - less restrictive repetition times, and
    - capability of broadcasting on several channels at once.

4. DEVELOPMENT OF IMPLEMENTATION GUIDELINES FOR ENFORCEMENT PULLOUT AREAS IN WORK ZONES

BACKGROUND

Research conducted during the second year of this project examined the potential of incorporating periodic enforcement pullout areas, similar to those recommended for high-occupancy vehicle (HOV) lane operations, into long work zones as appropriate (*2*). The results of that research provided recommended spacing and length requirements for pullout areas that were acceptable to both the enforcement personnel who must use the areas, and the contractors who must ultimately incorporate the areas into the overall construction sequencing and phasing. Specifically, the research suggested that enforcement pullout areas need to be approximately 0.25 mile long to safely accommodate the access and egress maneuvers. The enforcement areas should be spaced approximately every 3 miles to adequately support efforts by law enforcement. Interestingly, these values are very close to those recommended (based on trial-and-error and practical experience) for HOV lanes (*9*).

Obviously, there are additional issues relative to the design and implementation of enforcement pullout areas into a proposed construction project. Issues such as consensus-building between local enforcement and TxDOT personnel about the need for enforcement pullout areas in a particular project, basic design considerations such as width and placement within the confines of a project, advance signing, and implementation alternatives all come into play when considering how to best include pullout areas in work zones. During the third year of the project, TTI researchers consolidated many of these concerns into a single set of implementation guidelines. These guidelines are included in this report as Appendix A.

Of the many issues that were considered in the creation of the guidelines, sight distance was determined to be the one most critical to safety and most difficult to address. Sight distance needs for a pullout area depend on two key maneuvers. First, traffic approaching on the main travel lanes must have enough sight distance to detect, perceive, and if necessary, stop prior to reaching a vehicle that chooses to pull out of the area and into the travel lane. Second, sight distance must be large enough to allow a vehicle in the pullout area to see traffic approaching in the adjacent travel lanes and correctly identify a gap large enough to allow them to pull into the travel lane. These two distances involve consideration of both stopping sight distance and critical gap acceptance criteria. The remainder of this chapter describes the engineering analyses utilized to determine acceptable sight distance requirements for work zone pullout areas. The larger of these two values will represent a *minimum* sight distance requirement. Whenever feasible, decision sight distance should be provided. Decision sight distance is addressed in *Policy on Geometric Design of Streets and Highways (11)* from the American Association of State Highway and Transportation Officials (AASHTO).

SIGHT DISTANCE CALCULATIONS FOR PULLOUT AREAS

As stated above, two types of analysis are required to determine an adequate sight distance for a driver that has pulled off the road into a work zone enforcement pullout zone: critical gap analysis (CG) and stopping sight distance (SSD).

The former condition is described via procedures included in the 2000 edition of the *Highway Capacity Manual* (HCM) (*10*) whereas the second condition is addressed in *Policy on Geometric Design of Streets and Highways* (*11*) from AASHTO.

Perhaps the biggest limitation to applying the HCM criteria to a pullout area is that the maneuver itself is not explicitly addressed in the manual. Rather, HCM analyses address vehicles making left and right turns from roadways onto crossing roadways. TTI researchers were unable to identify any available literature or data relating more directly to the condition of interest here (i.e., a vehicle on the shoulder facing the same direction of traffic and accelerating into the available gap). Therefore, researchers opted to adopt a conservative approach and calculate required sight distance to allow a vehicle to make a right turn into the right lane of a multilane roadway.

The AASHTO SSD formulae define the distance at which a driver would need to see a small object in the roadway to be able to safely stop before impact with the object. Given that a vehicle entering the roadway from a pullout area is significantly higher than the small (0.5 ft) object, adoption of this criteria for pullout areas is also somewhat conservative.

The following variables affect the distance required for each method.

- Critical gap:
  - grade,
  - percent heavy vehicle traffic on main road,
  - number of lanes on major road, and
  - geometry of the site.

- Stopping sight distance:
  - grade,
  - coefficient of friction,
  - reaction time, and
  - operating speed on the main road.

Grade affects each method differently. For the CG analysis, a positive grade creates the need for a longer sight distance because the key maneuver is a vehicle pulling out into the travel lanes. The equation used to determine the critical gap is based on field studies, so it estimates what length of gap the driver in the pullout will need to *feel comfortable* pulling out onto the road. In that most drivers perform these maneuvers daily without adverse consequences, it is assumed that drivers behave in a reasonably prudent and safe manner. Conversely, a negative grade will increase sight distance requirements for the

SSD analysis because the maneuver of interest is the vehicle in the travel lanes attempting to stop. As will be shown in the following section, stopping sight distance is much more sensitive to grade than the critical gap distance.

Critical Gap Analysis

The critical gap analysis is based on the procedure given in HCM 2000, 17-5 through 17-7 (*9*). For this analysis, the following assumption is made: a car stopped in a construction pullout zone will need a gap distance no greater than the distance that a car making a right turn from a minor road onto a two-, four-, or six-lane major road at a two-way stop controlled (TWSC) intersection would need.

The following equation from the HCM determines the critical gap in seconds:

$$t_{c,x} = t_{c,base} + t_{c,HV} P_{HV} + t_{c,G} G - t_{c,T} - t_{3,LT}$$

where:

$t_{c,x}$	=	critical gap for movement x (sec).
$t_{c,base}$	=	base critical gap (6.2 sec for two-lane roads; 6.9 sec for four- or six-lane major roads) (sec).
$t_{c,HV}$	=	adjustment factor for heavy vehicles (2.0 for major four lane streets) (sec).
P_{HV}	=	proportion of heavy vehicles for *Minor Movement* (i.e. pullout zone).
$t_{c,G}$	=	adjustment factor for grade (0.1 for movements 9 and 12 – right turns from minor road) (sec).
G	=	percent grade divided by 100.
$t_{c,T}$	=	adjustment factor for each part of a two-stage gap acceptance process (1.0 for the first or second stage; 0.0 if only one stage) (sec).
$t_{3,LT}$	=	adjustment factor for intersection geometry (0.7 for minor turn left-turn movement at three legged intersection, 0.0 otherwise) (sec).

Several of the variables in this equation can be assumed to be constant due to the nature of the analysis and initial assumptions. The percent heavy vehicle, P_{HV}, represents the heavy vehicle traffic on the minor road only. Since pullout design is not intended to be long enough for heavy vehicle use, this variable is assumed to be equal to zero. The adjustment factor for each part of a two-stage gap acceptance process, $t_{c,T}$, can also be considered a constant equal to zero, since the vehicle in the pullout would only need a gap in one lane of traffic to be able to merge onto the main roadway. The adjustment factor for intersection geometry is zero unless the movement is a left turn at a three-legged intersection. The equation is thus reduced to:

$$t_{c,x} = t_{c,base} + t_{c,G} G$$

Once the critical gap is determined, it can be easily converted to an equivalent distance at various operating speeds. In this situation, grade also then has a small effect. For illustrative purposes, Figure 4-1 shows the affects of varying grade on critical gap distances for a base critical acceptable gap of 6.9 seconds. The lines practically overlap each other.

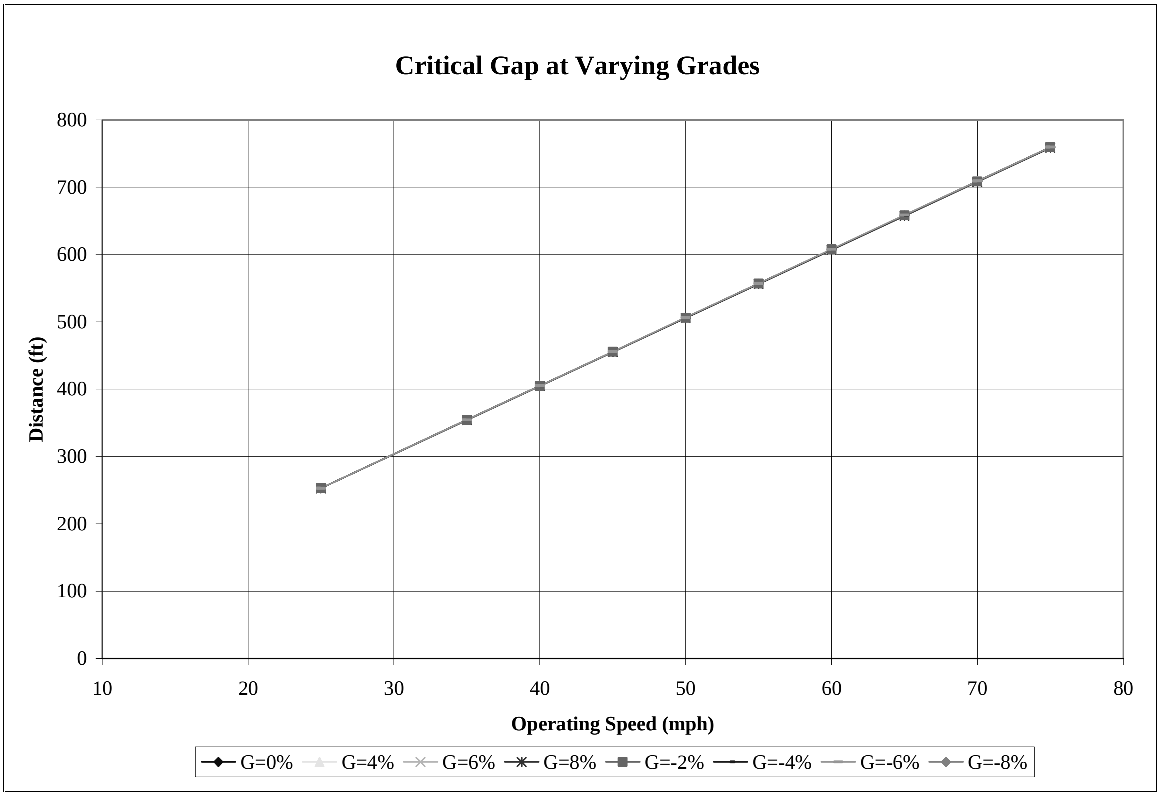

Figure 4-1. Effect of Grade on Critical Gap Distance.

Whereas grade does not have a significant effect on critical gap distance, the number of approach lanes on the major roadway does. The HCM justifies an increased base critical gap time for four- or six-lane roads to account for uneven lane distributions that typically exist on multilane roadways. Figure 4-2 shows the difference between the critical gap distances required for various operating speeds on two-lane roads (6.2 seconds) versus 4 four- or six-lane roads (6.9 seconds).

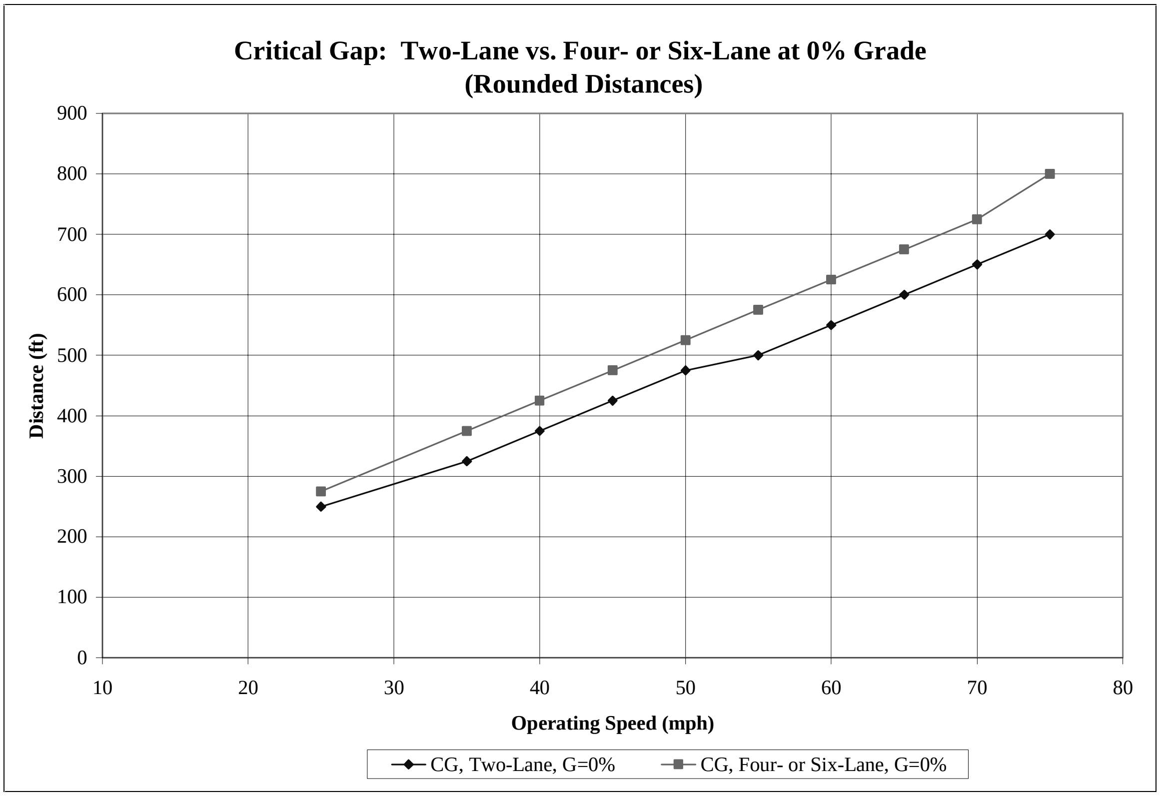

Figure 4-2. Effect of Number of Lanes on Critical Gap Distance.

Values in Figure 4.2 are used to generate Tables 4-1 and 4-2, which show calculated and recommended sight distance requirements for design based on these critical gap values.

Table 4-1. Sight Distances to Satisfy Critical Gap Needs: Two-Lane Roadway.

Approach Speed (mph)	CG Distance (ft)	Rounded Value (ft)
25	227	250
35	318	325
40	364	375
45	409	425
50	455	455
55	500	500
60	546	550
65	591	600
70	637	650
75	682	700

Table 4-2. Sight Distances to Satisfy Critical Gap Needs: Four- and Six-Lane Roadways.

Approach Speed (mph)	CG Distance (ft)	Rounded Value (ft)
25	253	275
35	354	375
40	405	425
45	455	475
50	506	525
55	557	575
60	607	625
65	658	675
70	708	725
75	759	800

Stopping Sight Distance Analysis

The stopping sight distance differs from the critical gap distance in that it is from the perspective of the upstream driver instead of the driver in the pullout area. This analysis, as previously mentioned, represents a conservative estimate for the required minimum sight distance value since it assumes that the driver in the pullout stops once it is on the major road instead of accelerating. The stopping sight distance is determined using the formula (*11*):

$$SSD = 1.47\ V_o t_r + V_o^2 / (30(\ (a/32.2) \pm G))$$

where:

SSD	=	Stopping sight distance (ft).
V_o	=	Operating speed of the upstream driver (mph).
t_r	=	Reaction time (s) (Assumed to be 2.5 s).
a	=	Deceleration rate (ft/s^2) (Assumed to be 11.2 ft/s^2).
G	=	percent grade divided by 100.

Stopping sight distance is sensitive to grade and speed changes. Table 4-3 illustrates the stopping sight distances at various grades and speeds.

Table 4-3. Stopping Sight Distance at Varying Grades and Speeds.

Grade: Speed, Vo (mph)	G = -6% Distance (ft)	G = -4% Distance (ft)	G = -2% Distance (ft)	G = 0% Distance (ft)	G = 2% Distance (ft)	G = 4% Distance (ft)	G = 6% Distance (ft)
25	165	160	156	152	149	146	143
30	215	208	202	197	192	188	184
35	271	262	254	247	240	234	229
40	333	321	310	301	292	285	278
45	400	385	372	360	349	340	331
50	474	455	438	424	411	399	389
55	553	530	510	493	477	463	450
60	638	611	587	566	547	530	515
65	729	697	669	644	622	603	585
70	825	788	756	727	702	679	658
75	928	885	848	815	786	760	736

Final Sight Distance Requirement Calculations for Pullout Areas

With the information generated in the previous sections, the final step in the analysis process is to determine which sight distance requirement (stopping sight distance or critical acceptance gap sight distance) governs the design. To determine this, results for both analyses are plotted together as a function of operating speed on the travel lanes, as shown in Figure 4-3 and Figure 4-4. The two figures show that the critical gap distance is longer SSD at lower speeds, but on two-lane roads SSD can exceed the CG distance at speeds as low as 50 mph depending on grade and heavy vehicle shorter than the critical gap distance at low speeds and longer than the critical gap distance at higher speeds.

The graph indicates that on flat terrain, the stopping sight distance becomes the critical distance for design purposes at speeds of 55 mph and higher on 2 lane roadways, and at speeds of 60 mph and higher on 4 to 6 lane roadways. Significant positive or negative grades will move the value of this critical speed up or down as much as 10 mph, however.

For summary purposes, Table 4-4 summarizes the sight distance values that govern pullout area sight distance design considerations. These values represent flat terrain.

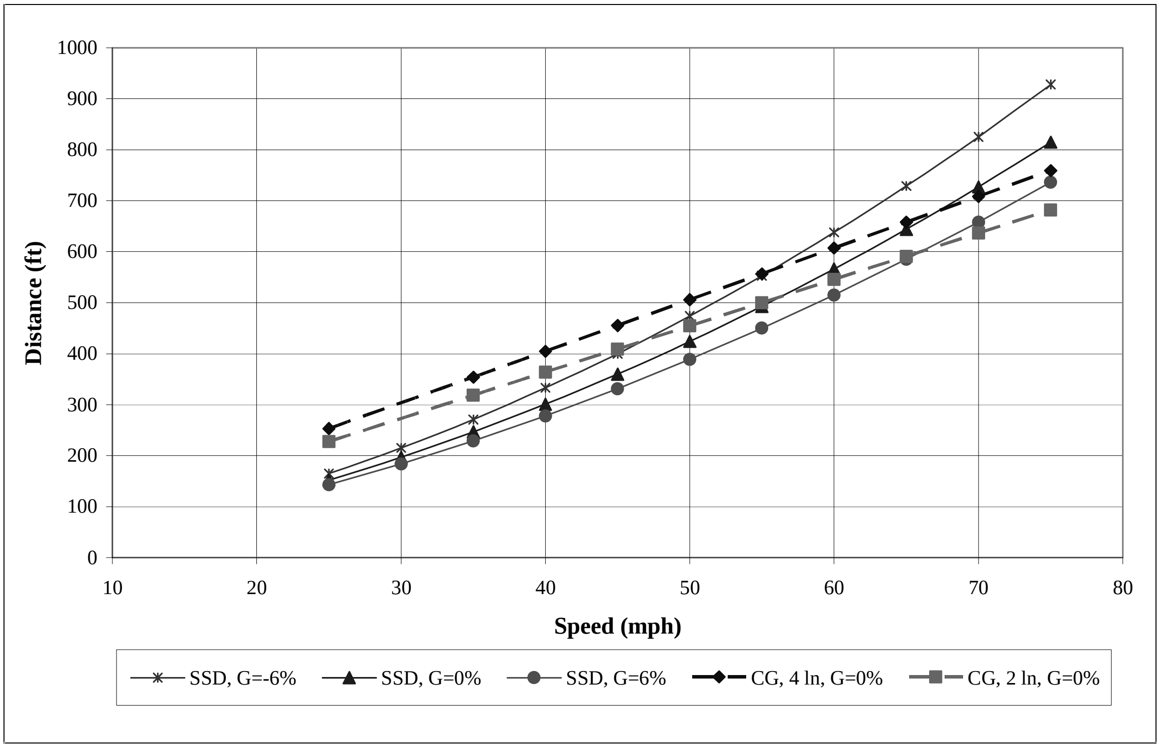

Figure 4-3. Comparison of Sight Distance Requirements, SSD versus CG.

Table 4-4. Enforcement Pullout Area Sight Distance Requirements at 0% Grade.

Required Sight Distance at 0% Grade						
		Two-Lanes			Four- or Six-Lanes	
Speed[1] (mph)	Analysis Method	Required Distance (ft)	Rounded Distance (ft)	Analysis Method	Required Distance (ft)	Rounded Distance (ft)
35	Critical Gap	318	325	Critical Gap	355	375
45	Critical Gap	409	425	Critical Gap	456	475
55	Critical Gap	501	525	Critical Gap	557	575
60	SSD	566	575	Critical Gap	607	625
65	SSD	644	650	Critical Gap	658	675
70	SSD	727	750	SSD	727	750
75	SSD	815	850	SSD	815	850

[1] Speed refers to the operating speed of the vehicles already traveling on the road. Speed of the vehicle pulling out into traffic is assumed to be 0 initially.

5. SUMMARY AND RECOMMENDATIONS

SUMMARY

Efforts during this third year of research have focused on two traffic management techniques (the late-merge strategy and the CB Wizard technology) that offered potential for addressing some of the traffic safety problems that have been observed at work zones on high-volume, high-speed roadways. Efforts have also focused on the development of implementation guidelines for incorporating enforcement pullout areas into long work zones when normal emergency shoulders are not available for use by enforcement personnel. Research findings from these efforts are summarized in the following sections.

Late-Merge Strategy

- Previous studies of the late-merge strategy indicate moderate improvements in throughput, queue length, and delays upstream of work-zone lane closures where traffic demands exceed the reduced work-zone capacity.
- Simulation analyses suggest that the take-your-turn designation used in the late-merge strategy may offer potential queue management benefits at congested merge points where approach demands on the two approaches are not in balance with naturally-occurring merging practices.
- Despite the potential benefits of the strategy, contractors appear to be somewhat hesitant to employ the technique on projects where the traffic control plan has already been prepared and approved. It will be necessary to specifically integrate the strategy into the traffic control plan documents of future projects if TxDOT wishes to move forward with implementation.
- The strategy is designed to improve vehicle operations in the traffic queue upstream of a work zone lane closure. Consequently, the strategy is most appropriate for temporary short-term lane closures where traffic demands are expected to exceed the capacity of the work-zone over the entire duration of the work activity, or where advanced traffic management technologies are being contemplated to employ the strategy in a dynamic, traffic-responsive manner.

CB Wizard

- Results of field studies conducted at several work zones in Texas indicate that the CB Wizard can be an effective method of providing truck operators with advance information about work zones they may be approaching. Researchers demonstrated an ability to influence both lane choice and speeds of trucks approaching work zones.
- The extent to which the CB Wizard can influence truck operations is heavily dependent upon site-specific characteristics. Based on the results of this research, the CB Wizard looks to have the greatest potential influence at work zones on rural roadways with high commercial truck volumes.

- The CB Wizard does not appear capable of reaching a significant portion of the Spanish-speaking truck operators in border areas. Consequently, it should not be used to provide advance warning information in bilingual formats to truck operators in these border areas.

Enforcement Pullout Area Implementation

- Pullout area placements need to consider the sight distance needs of vehicles on the main travel lanes approaching a pullout area as well as vehicles already in the pullout area trying to reenter the travel lanes.
- For roadways with free-flow operating speeds below 55 mph, sight distance requirements for vehicles in the pullout area trying to reenter the traffic stream will govern. At higher speeds, the sight distance requirements of vehicles in the travel lanes approaching the pullout area will govern.
- Advisory signs alerting drivers of the location of the pullout area should be placed at least decision sight distance away.

RECOMMENDATIONS

- TxDOT should consider implementation of the late-merge strategy at temporary lane closures where traffic demands are expected to exceed the work-zone capacity over the duration of work activity.
- TxDOT should consider the potential of using portable ITS technologies for implementing the late-merge strategy in a traffic-responsive mode at long-term lane closures where traffic queues are expected to occur during peak travel periods.
- The late-merge take-your-turn strategy should be considered as a queue management option at congested merge points where traffic demands on the two approaches are not in proportion to their relative service rates in the merge area.
- Static operation of the CB Wizard could be most effective when used in work zones in rural projects (minimal local commercial traffic) where there is a high percentage of commercial-through traffic. Topography and roadway geometrics will influence the transmission range of the CB Wizard and should be taken into consideration when determining placement of the radio.
- TxDOT should take steps to incorporate the implementation guidelines for enforcement pullout areas into its work zone planning process.

6. REFERENCES

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APPENDIX A:

GUIDELINES FOR
ENFORCEMENT PULLOUT AREAS IN WORK ZONES

WORK ZONE ENFORCEMENT PULLOUT AREAS

A visible law enforcement presence in a work zone promotes better motorist compliance with posted warning and regulatory signs, and encourages a safer driving environment overall. However, a lack of paved shoulders or other locations where officers can safely position themselves and/or pull violators over to issue citations can hinder enforcement activities. In these instances, it may be beneficial to consider including temporary enforcement pullout areas into the construction and traffic control plans for the project.

1.0 Verifying the Need for a Pullout Area

A project may justify one or more pullout areas if all of the following conditions exist:

- the project requires a reduction in the regulatory speed limit or the posting of other traffic regulations for safety considerations that could require significant enforcement efforts to achieve motorist compliance,
- the work area requirements for the project will lead to the elimination of emergency shoulders on both sides of the roadway, or
- the lack of emergency shoulders will extend continuously over several miles within the project.

Consideration of these conditions requires that law enforcement and TxDOT area office personnel begin discussions regarding the potential implications of a project early in the development process. Work zone features that may signal a possible motorist compliance problem include the following:

- use of a work zone design speed and/or posted speed limit lower than the normal design or posted speed limit for the roadway upstream of the project,
- lane shifts or vertical curvatures that restrict decision sight distances to downstream features,
- one or more construction area access points that do not provide acceleration lanes to construction vehicles attempting to enter the normal stream of traffic, and
- introduction of one or more new ramp meters or traffic signals within the project limits.

A pullout area will be effective only if it is utilized. Assurances are needed from the enforcement agencies having jurisdiction over the roadway that a pullout area would actually be used if included in the project. Once established, the relationship between those enforcement agencies and the local TxDOT office should continue throughout the development process.

2.0 Pullout Area Design

Pullout areas must meet a number of criteria in order to be both safe and effective. These criteria include:

- being wide enough to perform enforcement activities,
- being long enough to afford safe entry and exit to and from the normal traffic stream, and
- being spaced so as to be effectively utilized by both motorists and enforcement vehicles.

The following sections describe pullout area design parameters necessary to meet these criteria. These parameters are illustrated in Figure A-1.

2.1 Pullout Area Width

Pullout areas must be wide enough to allow an officer to stand next to a vehicle to issue a citation. Experiences with enforcement areas for HOV lanes on high-speed roadways indicate that a minimum of 12 feet in width is required, and that 14 to 15 feet widths are desirable. Consequently, enforcement pullout areas in work zones must be at least 12 feet wide.

2.2 Pullout Area Length

Pullout areas must be long enough to provide space for the violator and the enforcement vehicle. More importantly, the area must be long enough to provide the opportunity for a vehicle in the area to accelerate slightly prior to reentering the traffic stream. Limited field data from enforcement activities, existing roadway design criteria for vehicle accelerations, and experiences with HOV lane enforcement areas all indicate that this length should be at least 0.25 mile (1320 feet) for high-speed roadways.

2.3 Pullout Area Spacing

Proper pullout spacing is critical to the success of enforcement on contractor work activities. Placing pullouts too far apart negates any advantage they provide to enforcement personnel, and will likely result in those areas not being effectively utilized for enforcement purposes. Conversely, pullout areas placed too close together will significantly disrupt the contractor effectiveness and efficiency in completing necessary roadwork activities. Pullout areas placed approximately every 3 miles represent a reasonable compromise between enforcement and contractor needs.

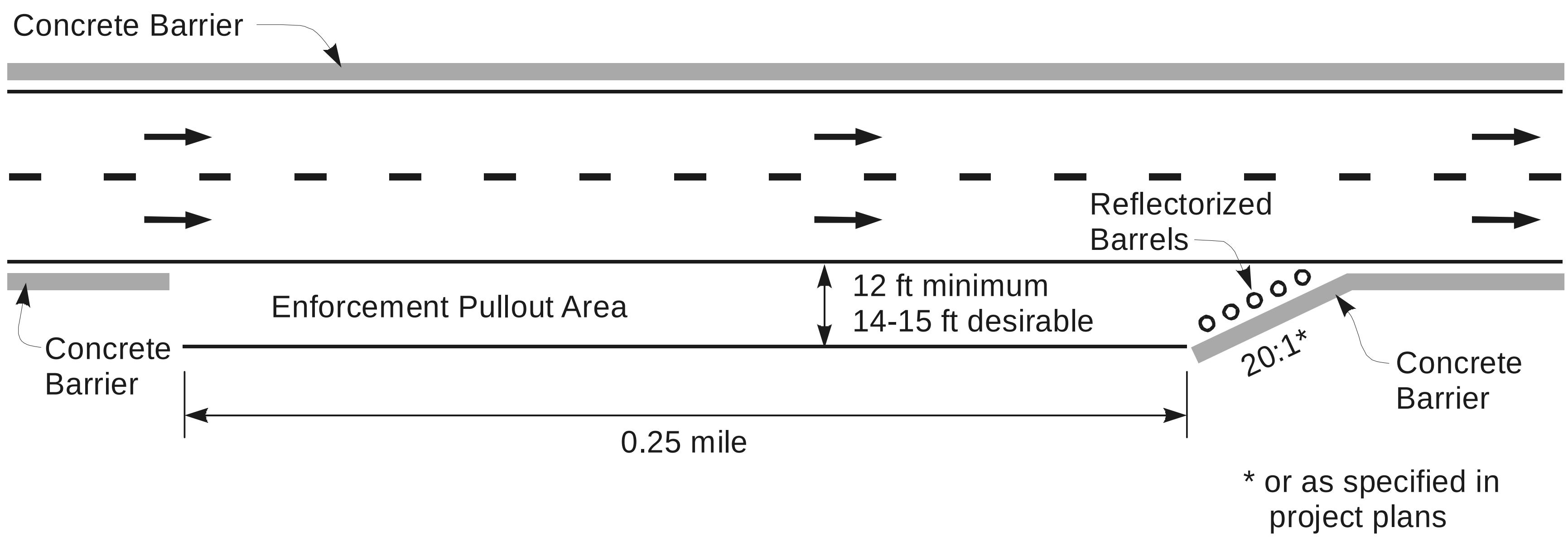

Figure A-1. Typical Application of a Work-Zone Enforcement Pullout Area.

2.4 Sight Distance Considerations

The safety of both motorists and enforcement personnel is the primary concern when determining where to place pullout areas within a work zone. Pullout areas should be located and designed so that motorists and enforcement personnel can safely perform the maneuvers required to utilize them. It is imperative that proper sight distance around the pullout area be provided. Two key driving maneuvers dictate sight distance requirements for pullout areas:

1. Vehicles approaching the pullout area in the normal travel lanes need to be able to safely stop if a vehicle in the area decides to pull back out into the traffic stream (i.e., stopping sight distance).
2. Vehicles in the pullout area need to be able to see upstream to find an acceptable gap in the traffic stream to allow them to safely reenter.

Analyses of both maneuvers using AASHTO and HCM data indicate that stopping sight distance needs typically dictate sight distance requirements under higher speeds (55 mph or greater) whereas acceptable gap requirements govern sight distance requirements under slower speeds. Table A-1 summarizes the sight distance required upstream of the pullout area for various operating speeds of the traffic stream. Because gap acceptance becomes more difficult when there are multiple lanes approaching from upstream, slightly higher sight distances are required for multi-lane approaches. Note that it is the expected operating speed on the roadway, not its design speed, which should be used to determine required sight distance. For crest vertical curves that have a design speed lower than the actual operating speed on the roadway, this means that a pullout area will typically need to be located beyond the end of the curve to ensure adequate sight distance.

Table A-1. Sight Distance Required for Pullout Areas.

Operating Speed (mph)	Required Sight Distance (ft)			
	One approach lane		Two or three approach lanes	
	Required	Rounded for Design	Required	Rounded for Design
35	318 [a]	325	355 [a]	375
45	409 [a]	425	456 [a]	475
55	537 [b]	550	557 [a]	575
65	724 [b]	725	724 [b]	725
75	945 [b]	950	945 [b]	950

[a] Acceptable gap criteria dictates acceptable sight distance
[b] Stopping sight distance dictates acceptable sight distance

Desirably, pullout areas should be located on flat, tangent sections of the roadway to maximize available sight distances. A pullout placed on a significant grade requires recalculating these sight distances according to procedures shown elsewhere. Also, sight triangles between vehicles approaching the pullout and vehicles within the pullout area should be checked to verify that concrete barriers, construction equipment, and traffic control devices do not obstruct the necessary sight distance.

3.0 Other Implementation Considerations

Accommodating pullout areas in a construction project can be challenging. The goal is to adequately support law enforcement efforts without dramatically detracting from the overall mission of completing the roadwork activity as quickly, safely, and efficiently as possible. The following sections offer a few additional insights and considerations for pullout areas to help ensure that this goal is met.

3.1 Integration into the Overall Construction Sequencing and Phasing Plan

A pullout area does not have to be specially constructed within the limits of a project. The pullout area can be an existing section of emergency shoulder, a recently rebuilt section of shoulder, or a section of adjacent travel lane not yet open to traffic. The only stipulations are that pullout area width, length, and sight distance requirements are met.

One way of meeting the needs of enforcement personnel is to simply limit the length of roadway segment without emergency shoulders at any one time during construction. For example, a long project can be divided into multiple segments that are 3 miles long or shorter, and a special provision can be added to the contract that specifies that emergency shoulders in adjacent segments not be eliminated at the same time during the project.

3.2 Need for Advance Signing

One of the primary concerns of enforcement personnel in work zones is driver unpredictability once enforcement vehicle warning lights are activated to pull the driver over. The lack of a clear choice as to where to go and/or where the next opportunity to pull over is located can lead to unsafe driving decisions and behaviors (slowing down excessively or even stopping in the travel lanes, focusing attention on the enforcement vehicle behind rather than on traffic conditions ahead, etc.). Advance construction guide signing to notify motorists of the presence of a pullout area ahead (and the distance to that area) can be helpful in reducing driver indecision and unsafe behaviors. Signing should be placed at a location equal to the decision sight distance away from the start of the pullout area.

3.3 Location within the Roadway Right-of-Way

Enforcement pullout areas should be located on the right side of the travel lanes. Left-side pullout areas violate driver expectancy and should be avoided.

3.4 Use for Incident Management

When considering whether or not to include enforcement pullout areas in a project, keep in mind that such areas will serve a dual purpose as an emergency breakdown area for disabled motorists. This dual use can be a significant benefit to all travelers on the roadway, particularly during peak periods when a disabled vehicle on a travel lane even for a few minutes will result in large delays, secondary crashes, and driver frustration.

APPENDIX B:

CB WIZARD TRAFFIC CONTROL LAYOUTS

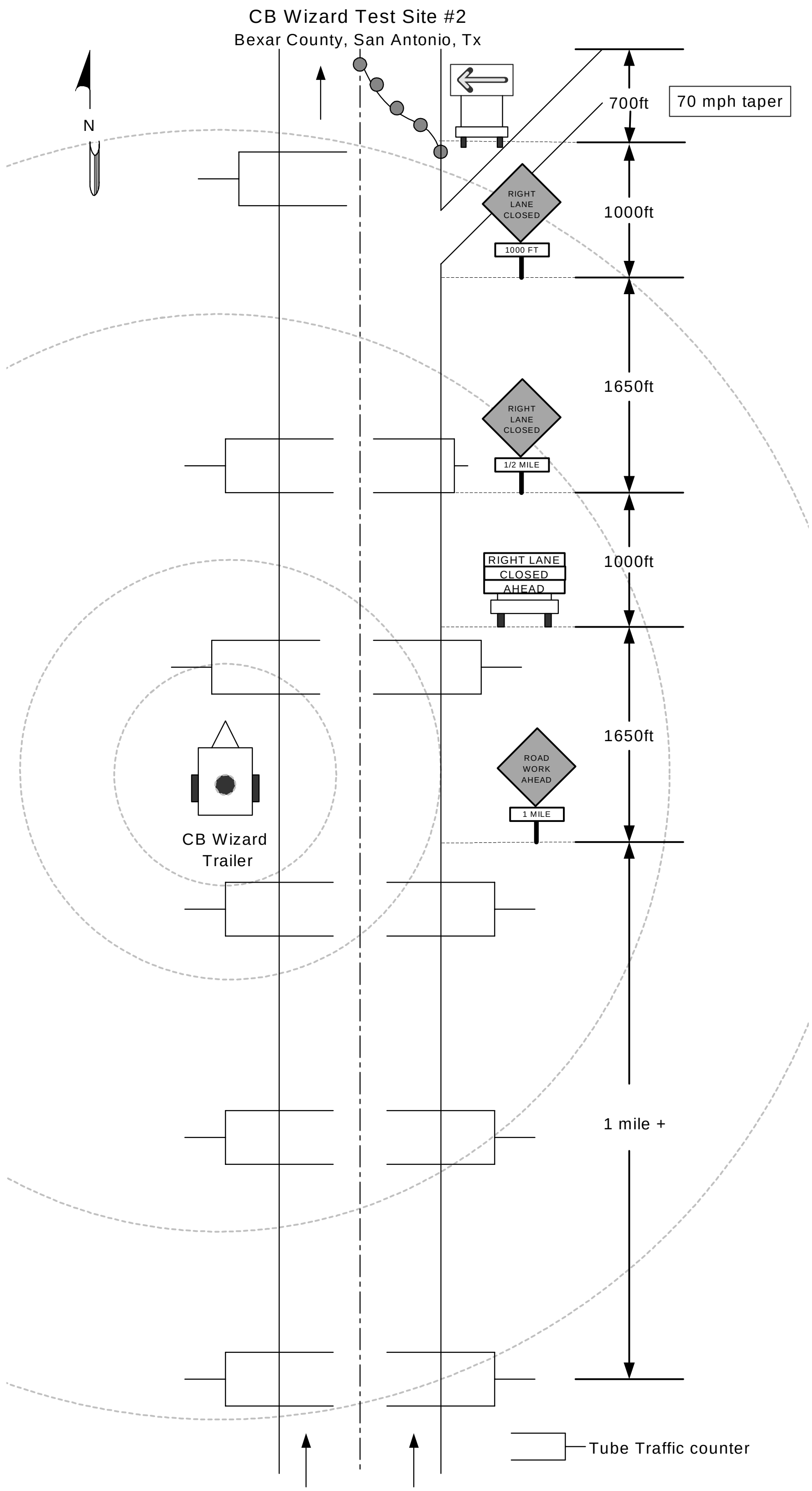

Figure B-1. Traffic Control Plan for Site 2.

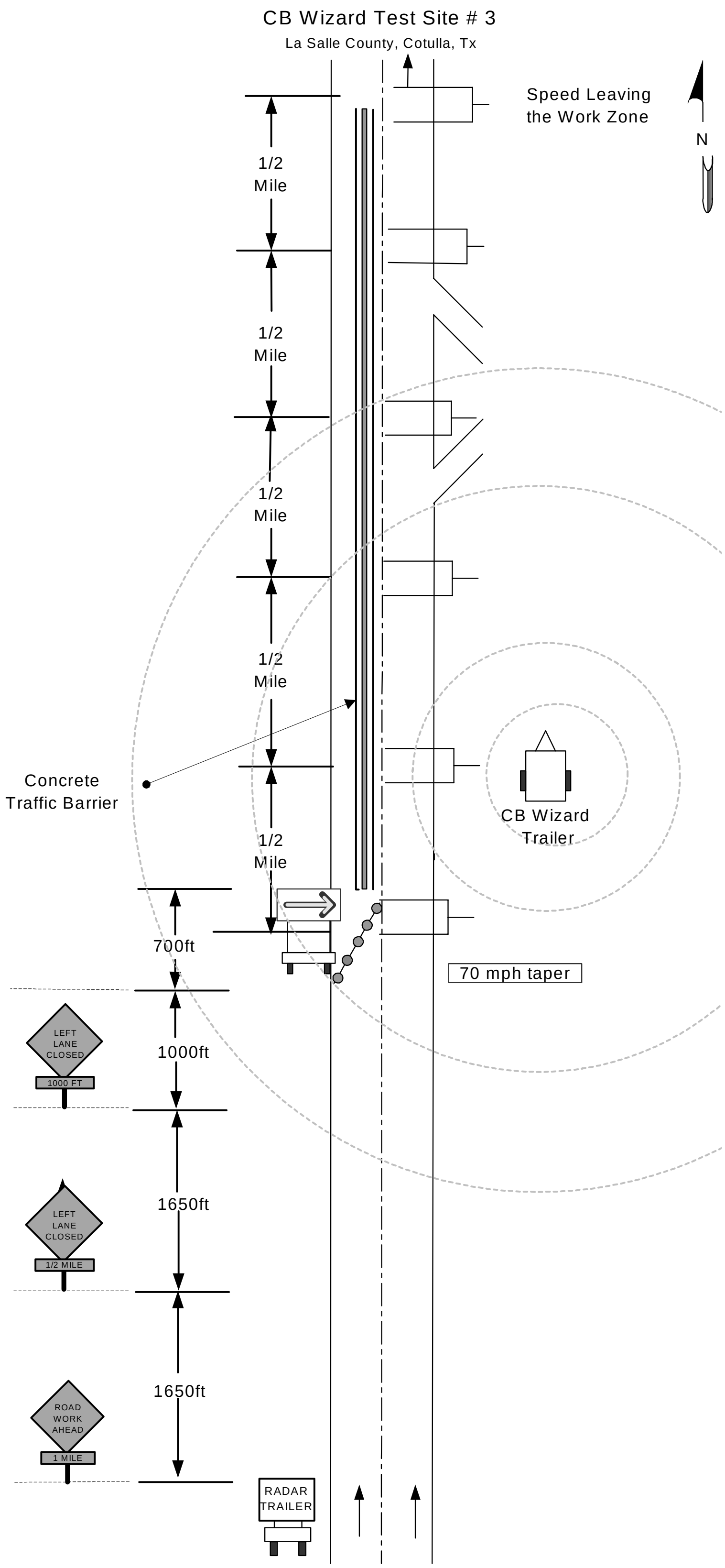

Figure B-2. Traffic Control Plan for Site 3.

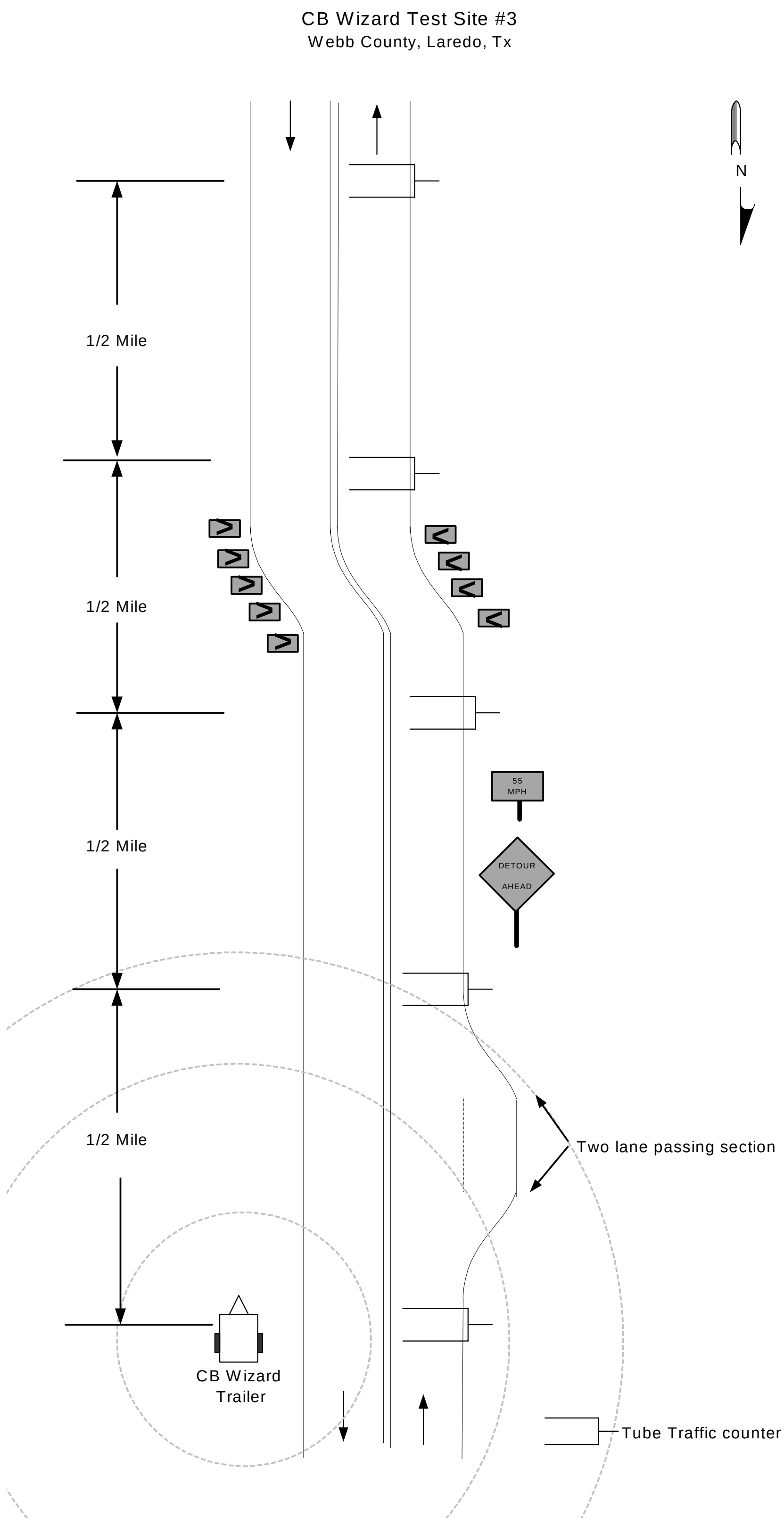

Figure B-3. Traffic Control Plan For Site 4.