Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-05/0-4413-2		

4. Title and Subtitle	5. Report Date
ADVANCE WARNING OF STOPPED TRAFFIC ON FREEWAYS: FIELD STUDIES OF CONGESTION WARNING SIGNS	March 2005
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Poonam B. Wiles, Scott A. Cooner, Yatin Rathod ,and Diana G. Wallace	Report 0-4413-2
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. 0-4413
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	Technical Report: September 2001 - August 2004
	14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

Project Title: Advance Warning of Stopped Traffic

16. Abstract

Stopped traffic on freeways poses safety and operational concerns to drivers, transportation agencies, construction and maintenance contractors, and enforcement and emergency service personnel. Safety issues relate to driver ability to make gradual transitions from freeway speeds to stopped conditions without erratic maneuvers or crashes. Operational concerns relate to the reliability and predictability of the freeway network. The primary type of multi-vehicle crash on a freeway facility is the rear-end collision, comprising over 50 percent of freeway crashes by some research findings, caused generally due to normal speed traffic encountering stopped traffic on the main lanes or ramps. Drivers frequently have minimal or no warning about downstream queuing, and information given on static signs is difficult to keep current with rapidly fluctuating queues in congested areas.

Stopped traffic on the freeway may be due to a multitude of causes. This research project evaluated issues relating to stopped or very slow traffic due to three major causes: recurrent traffic congestion due to over-capacity conditions during peak periods, congestion due to construction and maintenance work zones, and congestion due to incidents such as crashes.

In the first phase of this project, the research team conducted a literature review to determine current practices for advance warning for stopped traffic, observed field locations with traffic stopped due to various conditions, and determined advance warning techniques applicable to Texas. Report 4413-1 presents this information.

In the second phase of this project, researchers tested two advance warning techniques using static warning signs on Dallas area freeways. The research team synthesized the field test results and developed recommendations for further research and ways to improve the signing. This information is presented in this report. Many factors remain to be addressed in future research; however, observations conducted in this project can provide guidance to those testing and implementing operating systems for advance warning of slow/stopped traffic on freeways.

17. Key Words	18. Distribution Statement
Freeway, Queue, Detection, Warning, Rear-End, Collision	No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 http://www.ntis.gov

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	64	

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

ADVANCE WARNING OF STOPPED TRAFFIC ON FREEWAYS: FIELD STUDIES OF CONGESTION WARNING SIGNS

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DISCLAIMER

ACKNOWLEDGMENTS

The activities reported herein were performed by the Texas Transportation Institute as part of a project entitled: *Advance Warning of Stopped Traffic*, which was sponsored by TxDOT and FHWA. Ms. Poonam B. Wiles, P.E., of the Texas Transportation Institute served as research supervisor, and Mr. Robert E. Boykin, P.E., of the Texas Department of Transportation, Dallas District, served as the project director.

In addition to the project director, the authors wish to acknowledge the members of the Project Monitoring Committee (PMC), who provided assistance and guidance throughout the first-year project activities. These PMC members were:

- Mr. Wade Odell, P.E., Texas Department of Transportation, Research and Technology Implementation Office - Program Coordinator,
- Mr. Rick Berry, P.E., City of Mesquite,
- Mr. Greg Brinkmeyer, P.E., Texas Department of Transportation, Traffic Operations Division,
- Mr. Andy Oberlander, P.E., Texas Department of Transportation, Dallas District,
- Mr. Walter Ragsdale, P.E., City of Richardson.

The authors appreciated the participation and guidance of Ms. Terry Sams, P.E., TxDOT Dallas District, during project meetings. Researchers also were thankful for the assistance of the DalTrans traffic management center staff in providing data for the field studies.

Sign deployment and removal for each of the studies was provided courtesy of United Rental. United Rental met researchers out in the field on numerous occasions to go over sign placement details, and they came out with a several-member crew to place each sign according to safety requirements. Their assistance was invaluable in this project. Ronnie Johnson was the contact person with United Rental.

The authors gratefully acknowledge the assistance of Texas Transportation Institute staff that participated in various phases of this research. Mr. Bryan Miller assisted with setting up the collection of data via Internet data logs, and Ms. Christy Harris and Ms. Aruna Nathu provided assistance with support functions.

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LIST OF ABBREVIATIONS

AADT	Average Annual Daily Traffic
CCTV	Closed Circuit Television
DFW	Dallas/Fort Worth
DMS	Dynamic Message Sign
DOT	Department of Transportation
FHWA	Federal Highway Administration
FSP	Freeway Service Patrol
HAR	Highway Advisory Radio
ISDN	Integrated Services Digital Network
ITS	Intelligent Transportation System
LCS	Lane Control Signal
MUTCD	Manual on Uniform Traffic Control Devices
NCTCOG	North Central Texas Council of Governments
NHTSA	National Highway Traffic Safety Administration
PMC	Project Monitoring Committee
RTMS	Remote Traffic Microwave Sensor
SH	State Highway
SHRP	Strategic Highway Research Program
TMC	Traffic Management Center
TMT	Traffic Management Team
TRB	Transportation Research Board
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
VCR	Video Cassette Recorder
VDSS	Video Detection Surveillance Subsystem
VMS	Variable Message Sign
VSL	Variable Speed Limit
VSS	Variable Speed Signs

CHAPTER 1. INTRODUCTION

1.1 BACKGROUND AND SIGNIFICANCE OF WORK

Stopped traffic on freeways poses safety and operational concerns to drivers, transportation agencies, construction and maintenance contractors, and enforcement and emergency service personnel. Safety issues relate to driver ability to make gradual transitions from freeway speeds to stopped conditions without erratic maneuvers or crashes. Operational concerns relate to the reliability and predictability of the freeway network. Rear-end collisions are the primary type of multi-vehicle crashes on a freeway facility, comprising over 50 percent of freeway crashes by some research findings, caused generally due to normal speed traffic encountering stopped traffic on the main lanes or ramps. [1, 2] Drivers frequently have minimal or no warning about downstream queuing, and information given on warning signs is difficult to keep current with ever-changing field conditions and rapidly fluctuating queues in congested areas.

Warning drivers in advance of stopped freeway conditions requires the detection of the stopped traffic and a means of alerting drivers of stopped traffic ahead. Issues relating to vehicle type and the geometric design of the freeway further complicate this situation. Trucks have longer stopping distance requirements, although the sight distance may be longer than for passenger vehicles due to elevated driver height. Sight distance constraints can impact all vehicles to the tail end of a queue due to horizontal or vertical curves or obstructions such as bridge overpasses. Trucks can create obstructions to sight distance for passenger vehicles. Rural conditions and expectations differ from urban conditions.

Static and real-time methods of warning drivers of stopped traffic ahead include the following:

- Static Signing – traditional signs placed along the roadside at locations where queues are typically present.
- Dynamic Message Sign (DMS) – text or symbol message relating the presence of congestion or blockages ahead.
- Lane Control Signals (LCS) – overhead signals used to warn motorists of the flow status of individual freeway main lanes.
- Incident Response Vehicles – vehicles with flashing lights and/or dynamic message signs that follow the tail of the queue as it forms.
- In-Vehicle Device – message displayed on an in-vehicle navigation device that alerts the driver regarding the presence of queues ahead.

This research focuses on identifying current practices and developing innovative techniques to provide advance warning of stopped traffic on freeways, thereby increasing safety and mobility. The work effort has been divided into two phases, the first of which was reported and published as Research Report 4413-1, *Advance Warning of Stopped Traffic on Freeways: Current Practices and Field Studies of Queue Propagation Speeds.* [3]

After conducting the literature search and current practices review, it became evident to researchers that no sign standard exists that specifically warns drivers about the possibility of encountering stopped traffic on the freeway. The breadth and variety of sign sizes, shapes, messages, field placement and use of technology were significant, as well as indicative of the need to warn drivers of possible congestion. Although no uniformity was found in warning displays, the reasons for deploying the signs fell into several key areas. Thus, the potential exists to develop a new standard that addresses the need to warn the driver, while increasing effective communication to the driver via standardized messages. This research, after investigating alternative techniques used internationally, nationally, and at the state and local levels, was primed to develop sign messages for testing which could be a first step to a new standard. Promising text and pictogram messages were developed and evaluated within this research project.

Work tasks conducted in the research are identified below, with Tasks 1 through 5 reported in the Phase I research report, 4413-1, and Tasks 6 through 9 reported within this Phase II report. Subsequent sections of this report describe in further detail each task listed below.

Task 1: Conduct Literature Review for Advance Warning Techniques for Stopped Traffic.
Task 2: Identify Current Practices.
Task 3: Observational Field Studies.
Task 4: Evaluate Applicability of Advance Warning Techniques to TxDOT.
Task 5: Convene Panel Meeting and Summarize Interim Results.
Tasks 6: Identify Field Testing Techniques and Conduct Site Selection.
    Task 6a: Technique and Location Selection for Field Tests.
    Task 6b: Develop Field Test Plan.
Task 7: Perform Field Tests.
Task 8: Evaluate and Compare Findings from Field Tests.
Task 9: Produce Recommendations, Summary, and Documentation.

1.2 SUMMARY OF PHASE I RESEARCH REPORT 4413-1

Phase I of the research effort was to conduct the literature review, to determine current practices for advance warning for stopped traffic, to observe field locations with traffic stopped due to various congestion conditions, and to determine advance warning techniques applicable to Texas. In the observational field studies, researchers found instances of sustained, repetitive, and excessive queue propagation speeds, **sometimes exceeding 50 mph**. Researchers were particularly interested in the speed of the queue propagation during congested conditions on the freeway in urban conditions.

The speed of queue propagation is not a measure of queue length, but of how fast the queue is changing. Queue growth is of particular interest, since when queues are growing they are more likely to surprise oncoming drivers than when they are dissipating. Additionally, in many instances, multiple lanes were found to be impacted. Urban commuters, although generally aware of conditions encountered in their daily travels, might still be surprised by sudden and extensive queues. Unfamiliar drivers might experience conditions that tax their ability to respond without incident. All drivers are particularly vulnerable when geometric conditions unfavorably coincide with queue buildup.

Queue warning systems, in order to be effective, should be installed in consideration of rapidly fluctuating queues. This axiom means that warning signs placed too close to queue tails might be overrun, with the possibility of drivers encountering the queue before seeing the sign. Warning signs placed too far from the queue, if the downstream location of the queue is mentioned, can become inaccurate between the time drivers view the sign and encounter the queue. Conditions change too quickly for human operators to handle appropriate warning sign adjustments, necessitating an automated system for real-time adjustment of queue position. Geolocated queues, advising drivers of the distance to the queue tail, require multiple detection stations and warning sign locations.

Task 1: Conduct Literature Review for Advance Warning Techniques for Stopped Traffic

The Phase I research report summarizes the literature review findings. It includes techniques used to detect stopped traffic and queue formation; methods to alert drivers to stopped traffic ahead; queue reduction techniques; and products or devices manufactured for detection and warning of stopped traffic (or with potential to be adapted to this purpose). The results of internet searches have also been summarized relating to information from vendors on recent innovations in field equipment.

Task 2: Identify Current Practices

The current practices for advance warning of stopped traffic currently in use by representative TxDOT districts, other State Departments of Transportation (DOT), and European DOTs are also summarized in the Phase I research report. Innovative use of temporary and static (permanent) intelligent transportation system (ITS) elements and traffic handling techniques have been reviewed, as well as near-term technologies and techniques under consideration for use in the future.

Task 3: Observational Field Studies

Observational field studies were conducted for each of the three congestion types under study (recurrent, construction related and incident related). Information on topics such as queue formation (by lane, length, duration and speed of queue propagation), erratic maneuvers and abrupt stopping, freeway geometric issues, and the effect of trucks in the vehicle stream have been collected and reported in the Phase I research report.

Task 4: Evaluate Applicability of Advance Warning Techniques to TxDOT

The information from the literature search and current practices survey was evaluated for applicability to TxDOT, and summarized in the Phase I research report. Potential techniques were rated as to ease of deployment, cost of deployment, and whether current TxDOT standards were met by the technique. The evaluation did culminate in a set of recommended field-testing criteria that were used to help identify appropriate field test locations to specifically study some of the more promising advance warning techniques.

Task 5: Convene Panel Meeting and Summarize Interim Results

On September 11, 2002, the research team held a meeting at the TxDOT Dallas District with the TxDOT project director and the Project Monitoring Committee. The primary purpose of this meeting was to present and discuss the findings of Tasks 1 through 5. Also, as a part of Task 5, researchers produced the Phase I research report to summarize Tasks 1 through 4. The Phase I research report includes the literature review, the results from the current practices survey for advance warning of stopped traffic, information from the observational field studies, and applicability evaluation for use of advance warning techniques on Texas freeways.

1.3 RECOMMENDED INFRASTRUCTURE-BASED WARNING STRATEGIES

The research team developed some general guidelines for warning strategies based on the type of situation encountered by the driver. The following subsections outline some of the general guidelines and recommendations. Table 1-1 provides a summary of the research team's recommended warning strategies for the four major situations that create slow/stopped traffic on freeway facilities.

- *Warning Strategy for Geometric Constraints*
  If the problem encountered by drivers is a geometric constraint such as a vertical curve, horizontal curve, or other roadway feature, the research team recommends the use of static signs as the primary warning technique.

- *Warning Strategy for Congestion Related to Recurrent Traffic Conditions*
  If the problem is recurrent congestion on the freeway or spillback onto exit ramps from cross street intersections, the research team recommends the use of signs (static or variable) with some form of queue detection to activate flashers and/or the sign message as the primary warning technique for drivers.

- *Warning Strategy for Congestion Related to Work Zones*
  When a construction/maintenance work zone is the source of slow/stopped traffic, the research team recommends the use of single or multiple detection stations and multiple signs as the primary warning strategy.

- *Warning Strategy for Congestion Related to Incidents*
  When an incident (unpredictable time and location) is the cause of queuing, the research team recommends that TxDOT rely on existing ITS devices as the primary warning technique.

Table 1-1. Recommended Warning Strategies for Slow/Stopped Traffic.

Problem Type	Problem Description	Primary Warning Strategy
Sight distance constraints	Vertical and horizontal curves block driver's view	Static signs
Recurrent congestion	Predictable congestion	Static or variable signs with some form of queue detection
Construction/maintenance zones	Queue caused by reduced capacity from lane closures	Single or multiple detection stations and multiple signs (static or variable)
Incidents	Unpredictable time and location of congestion	Rely on use of existing ITS devices

1.4 RECOMMENDED DRIVER-BASED COUNTERMEASURES

Whether the cause of slow/stopped traffic is geometric constraints, recurrent traffic conditions, work zones, or incidents, drivers themselves can also be part of the solution of improving safety on freeway facilities. The following list summarizes countermeasures drivers can consider implementing in order to avoid collisions with slow/stopped traffic while traveling on freeway facilities:

- Look ahead further than the immediate car in front and scan for brake lights.
- Cover brake at first sign of brake lights.
- If traffic is stopped ahead, slow down gradually and pump brakes if there is time.
- Use emergency flashers to warn other drivers when positioned at the back of the queue.
- Avoid stopping short (sooner than necessary).
- Avoid changing lanes at the tail end of the queue. The tail end of the queue is often "ragged," meaning that all lanes are not queued up the same distance. It is probably safer to wait to change lanes until all lanes are queued. Traffic in the faster lane may need that room to stop.

1.5 PHASE II OF RESEARCH

Within the second phase, researchers conducted field testing of selected techniques for advance warning of stopped traffic, and analyzed results. This report summarizes these effort.

Task 6: Identify Field Testing Techniques and Conduct Site Selection

Task 6a: Technique and Location Selection for Field Tests

Using the criteria developed in Task 4, advance warning techniques were selected for field testing, and associated study locations were determined. Researchers coordinated with vendors to facilitate field testing, and obtained economy of resources by coordinating with TxDOT TMCs and facilities for data collection and monitoring.

Task 6b: Develop Field Test Plan

Researchers developed a field test plan for conducting field studies with these purposes:

- summarize the techniques and locations selected for testing,
- identify the personnel and equipment needed to conduct the field tests,
- determine the types of information to collect and methodologies selected,
- identify the evaluation strategy for field test results, and
- determine any notification and coordination needs of other agencies.

Task 7: Perform Field Tests

Field tests identified in Task 6 were conducted within this task according to the identified field test plan. Elements evaluated include both qualitative and quantitative measures. Qualitative measures provide a general comparison with the observational field studies conducted in Task 3, but the information collected within Task 7 will be conducted with advance warning for stopped traffic measures in place.

Task 8: Evaluate and Compare Findings from Field Tests

Both the quantitative and qualitative field test measures were evaluated in order to identify effective techniques for providing advance warning for stopped conditions on the freeway. The analysis was conducted for individual field test results and also comparatively between tested techniques.

Task 9: Produce Recommendations, Summary, and Documentation

Within Task 9 researchers determined research recommendations and findings and provided extensive documentation of the research project approach, analysis, evaluations, recommendations, findings and summary. The project research report and project summary report were produced. Project products include drafts of a Selection Strategy Flowchart, and Guidelines for Implementation of Advance Warning Techniques for Stopped Traffic

1.6 REPORT ORGANIZATION

The focus of this project is to identify current practices and develop innovative techniques to provide advance warning of stopped traffic on freeways, thereby increasing safety and mobility. The summary of Phase I of this research was published in research report 4413-1, *Advance Warning of Stopped Traffic on Freeways: Current Practices and Field Studies of Queue Propagation Speeds*. Phase II of the research, as identified above, is summarized within this document and is organized as follows:

- Chapter 1 provides background information, and summarizes the work tasks conducted in each phase of the research.
- Chapter 2 details field test technique and location selection for the two study sites.

- Chapter 3 discusses methodology and procedures related to conducting the field tests.
- Chapter 4 highlights the major findings and recommendations.
- Chapter 5 provides a brief discussion of future research needs.

The appendix contains additional information the research team collected on congestion warning techniques since the publication of research report 4413-1.

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CHAPTER 2. FIELD TEST TECHNIQUE AND LOCATION SELECTION

2.1 FIELD TEST WARNING DEVICE SELECTION

After extensive review of the findings of the first year of study reported in research project report 4413-1, the team agreed upon two methods for field testing by researchers and Project Management Committee members. Both initial field tests were selected to be of static warning signs of the traditional diamond shape on a yellow background. Since these signs would be deployed on freeways, the research team selected 48 inch x 48 inch signs for deployment in the field. One sign, adapted from the pictogram-type message seen in Europe, New Zealand, and Turkey among other places, depicted closely-spaced vehicles to connote congestion (see Figure 2-1 and Figure 2-2). The second sign was text-based, and utilized a message that was selected for clarity and applicability; "Watch for Stopped Traffic" (see Figure 2-3). The message was particularly developed so that the sign would serve as an alert, yet never be incorrect, since with static messages the signs would be present even when congested conditions did not exist.

TxDOT then requested approval from FHWA to deploy these signs during the 4413 research project with a request for experimentation. FHWA gave approval for both of these signs in June of 2003. Although FHWA also approved the use of the supplemental plaque "Watch for Stopped Traffic" as an option to be used in conjunction with the pictogram sign, the research team decided to conduct the initial field tests without it to discern the impact of the pictogram sign alone. Additionally, FHWA approved the use of signs with flashers and activated with detection. The use of flashers was not tested within this research project but remains one of the key next steps for additional research.

Figures 2-4 and 2-5 show United Kingdom versions of the pictogram sign. Figures 2-6 and 2-7 show Turkish and New Zealand versions. Note that researchers made several adjustments to these signs for the first American field test of a similar pictogram, including:

- Use of traditional yellow warning sign shape instead of international symbol triangle shape.
- Selection of vehicles "stacked" upward toward the left instead of toward the right (a reaction to an informal survey comment interpreting the other version as a request to exit the freeway).
- Depiction of vehicles as a more modern, rounded shape.
- Inclusion of a yellow gap between vehicles to improve symbol identification.
- Conversion of the depiction of tail lights to linear shapes instead of round shapes to minimize possible confusion as headlights.
- Inclusion of a license plate depiction to (possibly) aid in identifying the rear of the vehicle.

The supplemental plaques used on the United Kingdom signs were not always present (see Figure 2-4), and as shown, the messages sometimes varied. In lieu of frequent repetition of the sign, the "for 16 miles" text was added to the supplemental sign message "queues likely" (see Figure 2-5).

Figure 2-1. Conceptual Design of Pictogram Congestion Warning Sign.

Figure 2-2. Photograph of Pictogram Congestion Warning Sign Used in Field Study.

Figure 2-3. Conceptual Design of Text Congestion Warning Sign.

Figure 2-4. Congestion Warning Pictogram Sign in England (Photo by Poonam Wiles).

Figure 2-5. Congestion Warning Pictogram Sign in England with Distance (Photo by Poonam Wiles).

Figure 2-6. Portable Sign Deployment in Turkey. [1]

Reference: http://www.ortana.com/en/projects/traffic/mvms.htm

Figure 2-7. New Zealand Congestion Warning Sign. [2]

Researchers, in conjunction with the PMC, decided to test the pictogram sign without the supplemental plaque "Watch for Stopped Traffic." Subsequent field tests could include this plaque. An alternative text could be "Watch for Congestion." The "Watch for" part of the text message was desirable because it did not specifically require that the congestion be present. If congestion is detected in a real-time basis, then a flashing beacon and a "When Flashing" supplemental plaque could be used. Additionally, researchers made the pictogram symbol as large as possible on the sign face, while maintaining some yellow border around the symbol. Researchers recommend that future research use surveys to help determine preferred messages that correlate to specific needs.

Considerations for the text sign message included the determination of an appropriate test message. Various words were considered for warning drivers of stopped traffic, including the words "queue," "congestion" and "slow or stopped traffic." Researchers selected the words "stopped traffic" because of the specific nature of the words and the familiarity drivers might have with the words. The decision not to include slow traffic in the warning was because of the transient nature of slow or stopped conditions (see research report 4413-1) and because of a similar desired driver response to either condition.

In order to avoid drivers misinterpreting the signs as a need to stop *at that location*, the word "stopped" was placed on the right-hand side of the sign with a word in front of it. Also, the past tense was used so that the word "STOP" itself is not on the sign. For the same reason, researchers decided not to emphasize the word in relation to the other words on the sign by keeping them all the same text size. Researchers deemed redundant the addition of the word "CAUTION" in view of the deployment of the text sign on the traditional warning sign format of a diamond shape with yellow sign background and black text.

The Dallas District sign shop produced all signs used in the field tests as per detailed to-scale computerized drawings provided by the researchers.

2.2 FIELD TEST SITE SELECTION

Various sites were considered for study, primarily in the TxDOT Dallas District. The reason for this was to facilitate coordination with the ITS elements which researchers intended to utilize for data collection purposes. These included ITS field devices such as detection systems and cameras, as well as TMC coordination. The district's system is known as DalTrans, and web-based information can be located at http://dfwtraffic.dot.state.tx.us/.[3] Figure 2-8 shows some of the Dallas District's ITS elements which depict closed-circuit camera (CCTV) locations as well as dynamic message sign locations.

A number of sites were considered and eventually eliminated as possible study sites due to high variability of typical traffic conditions, and difficulty coordinating with major construction projects. Sites with highly predictable congestion conditions were preferred, whether peak-period or congestion related, since typical congestion could be assessed and then compared with incremental changes due to the presence of various warning devices. Widely fluctuating baseline conditions would not allow such comparisons.

After extensive review, two locations were selected. The first location was Spur 408, northbound, between I-20 and Loop 12. Nine CCTV cameras provide video coverage of much of the section. The second location was Loop 12, northbound, between SH-183 and I-35E. Two cameras were available with views of particular interest to the researchers. Figure 2-9 shows the general study locations as shaded areas.

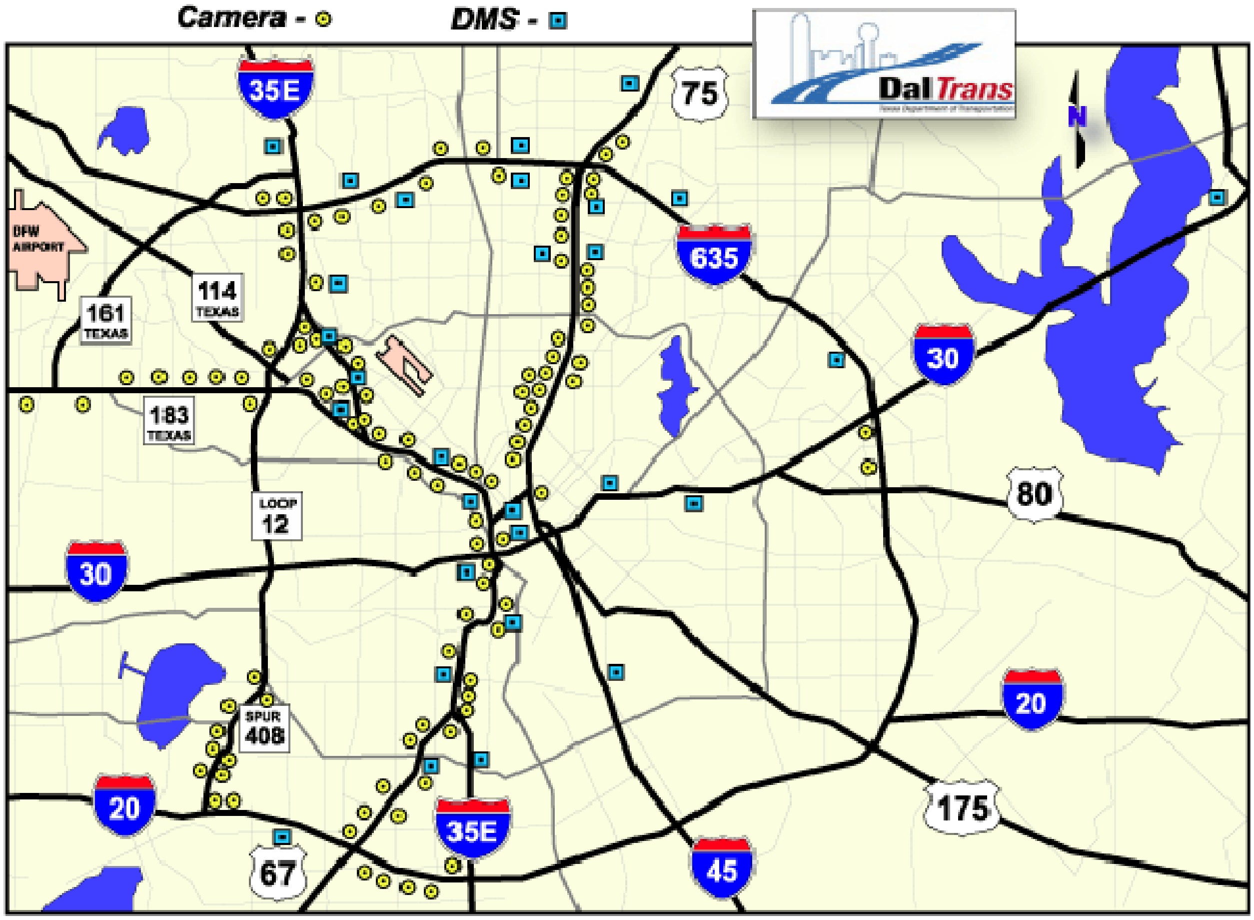

Figure 2-8. Depiction of CCTV and DMS Locations in the Dallas Area.

Aerial photographs, Figures 2-10 and 2-11, show the general layout of the sections. Researchers and PMC members agreed to study the deployment of the pictogram signs at the Spur 408 location, and the text signs at the Loop 12 location. If discernable differences could be seen between traffic flow characteristics before and during the sign deployment, then an assessment could possibly be made as to the signs' effectiveness.

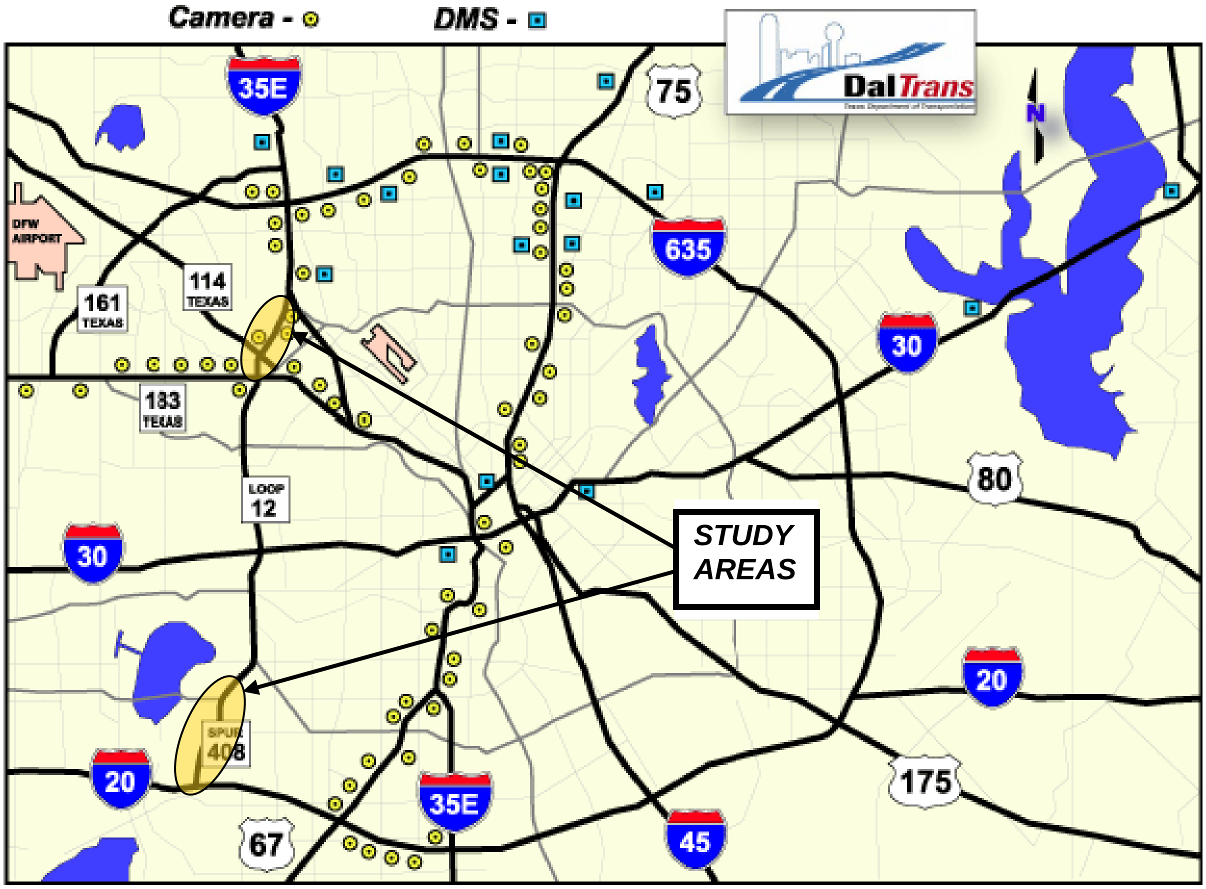

Figure 2-9. Depiction of the Two Field Study Sites.

Figure 2-10. Aerial Photograph of the Spur 408 Field Test Site[4].

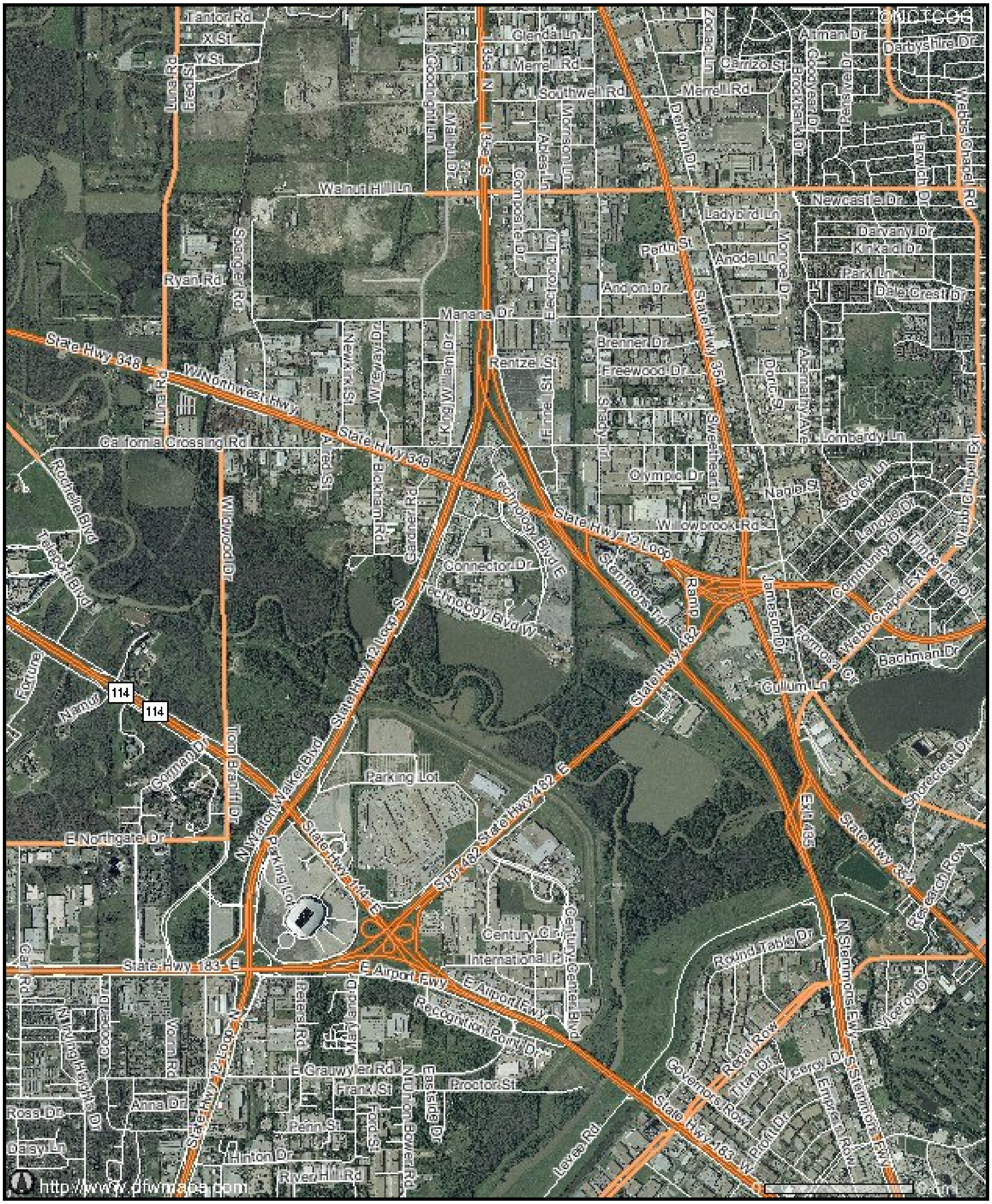

Figure 2-11. Aerial Photograph of Loop 12 Field Test Site.

2.3 SIGN DEPLOYMENT

For each field test, signs were deployed at three locations on the right-hand side of the freeway only, well in advance of any anticipated queuing, and prior to locations where queuing would be (typically) visible from the signs. Figures 2-12 and 2-13 show sign placement and detector availability for each study. Figures 2-14, 2-15, 2-16 and 2-17 show the deployment of the signs in the field during the test period.

Sign deployment and removal for each of the studies was provided courtesy of United Rental (Figure 2-18). During the study period they also provided sign supports and sandbags for each sign. United Rental met researchers out in the field on numerous occasions to go over sign placement details, and they came out with a several-member crew to place each sign according to safety requirements and mounting requirements. Their assistance was invaluable in this project.

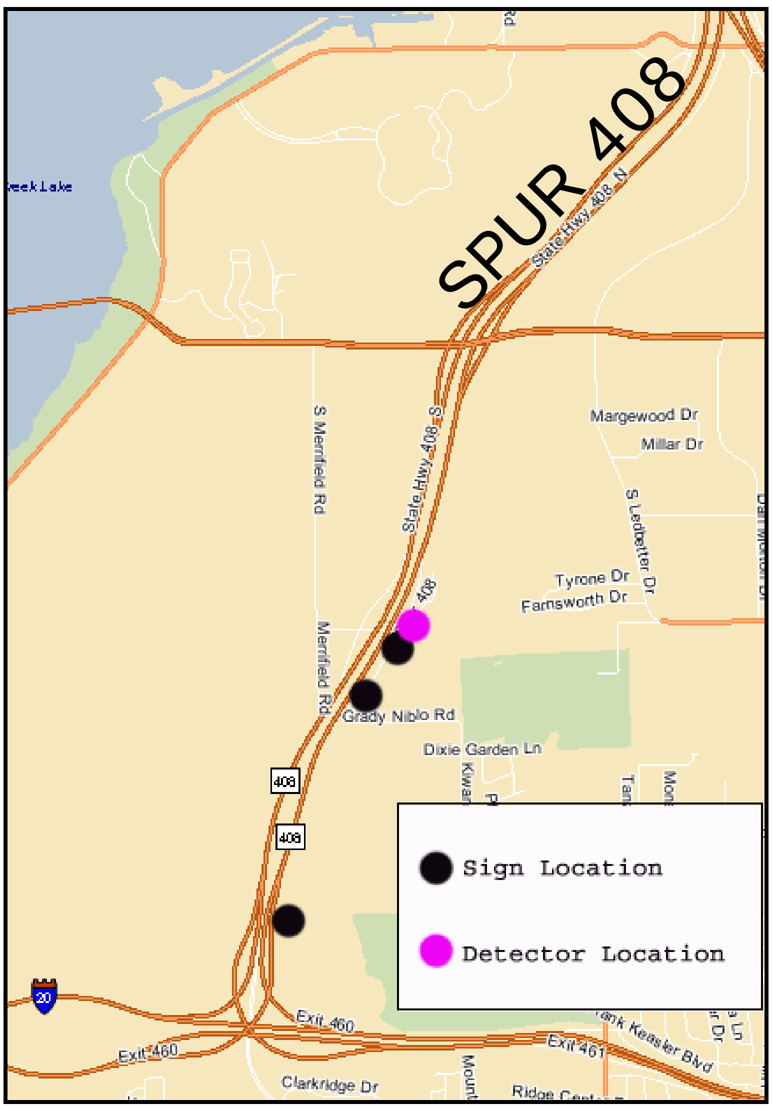

Figure 2-12. Spur 408 Field Test Sign and Detector Locations.

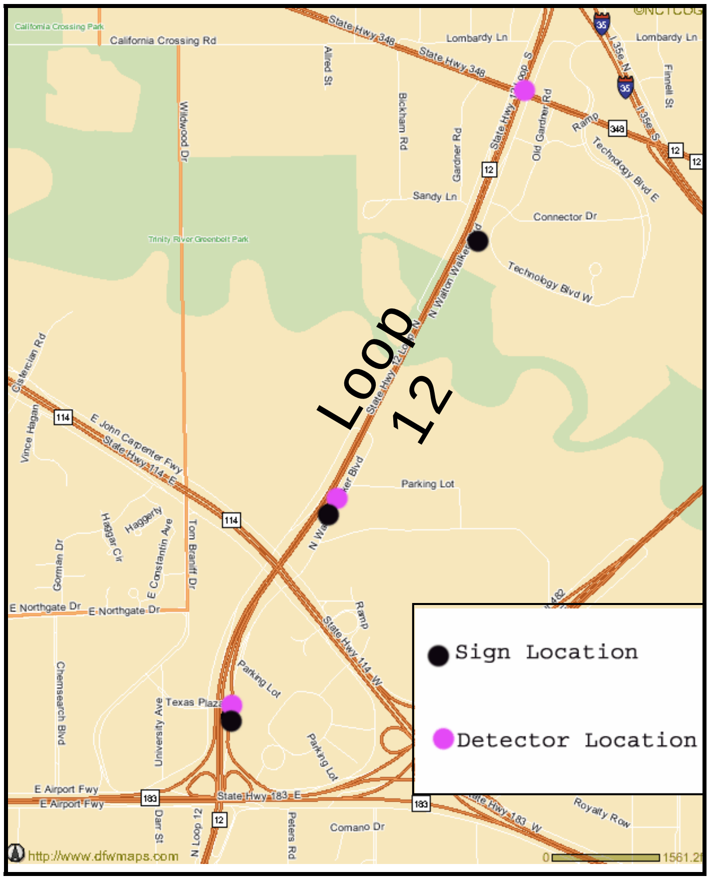

Figure 2-13. Loop 12 Field Test Sign and Detector Locations.

Figure 2-14. Pictogram Sign at Spur 408 Field Study Site.

Figure 2-15. Close-up View of Pictogram Sign at Spur 408 Field Study Site.

Figure 2-16. Text Sign at Loop 12 Field Study Site.

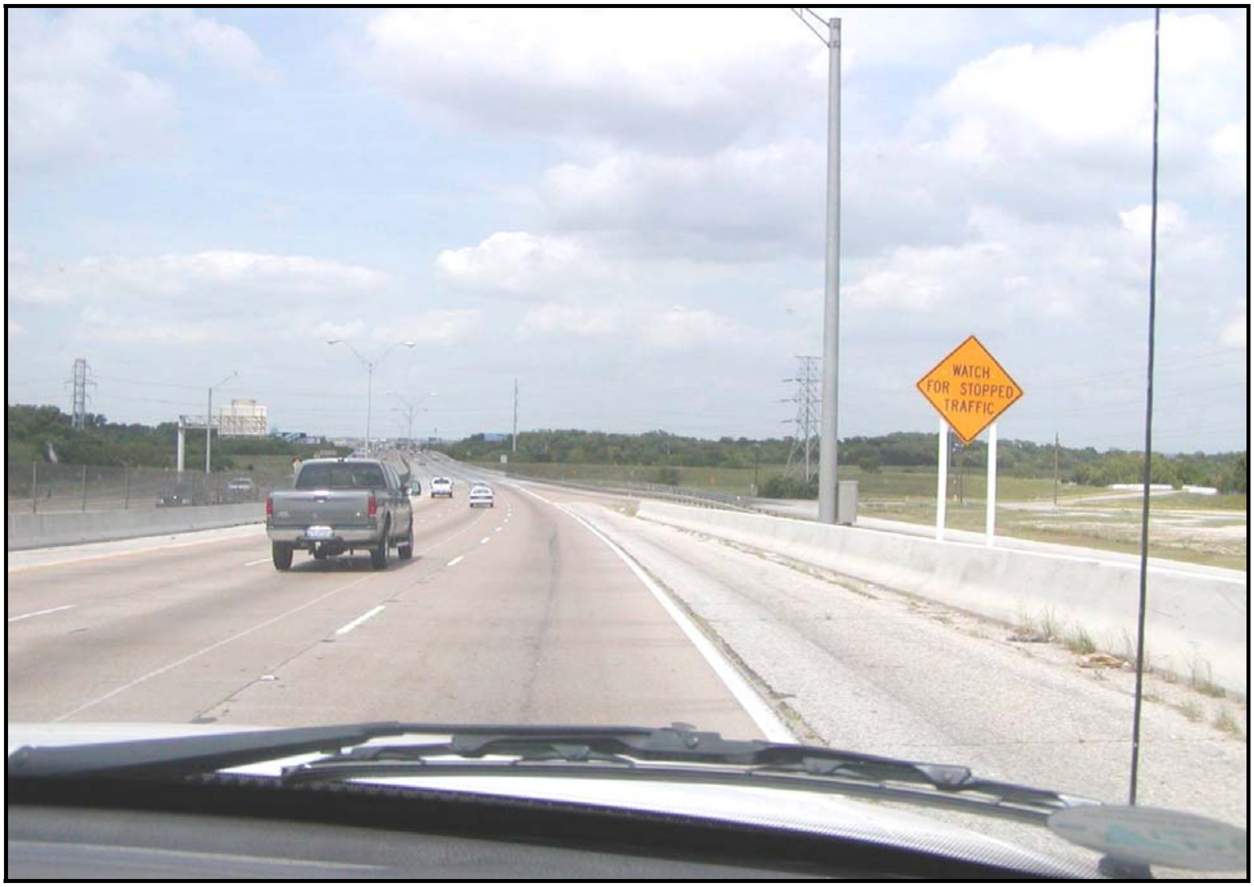

Figure 2-17. Text Sign at Loop 12 as Seen from Vehicle during Site Drive-Thru.

Figure 2-18. United Rental Crews Deploying Signs.

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CHAPTER 3. FIELD TEST METHODOLOGY AND PROCEDURES

3.1 FIELD TEST VIDEO AND CCTV INTERNET MONITORING

Field personnel located out of view of drivers in the area under study (see Figures 3-1 and 3-2) collected data via traditional video cameras. This video data was collected for the potential to view possible driver reactions to the signs such as increased braking. However, the primary data collection was conducted via the ITS systems in place on Spur 408 and Loop 12. The internet was used extensively in the data collection process. Personnel monitored the CCTV cameras located at each facility via the internet. Snapshots of traffic conditions were observed, such as those seen in Figures 3-3 and 3-4. These figures show free flow and congested conditions as seen via the internet web site at http://www.daltrans.org/. Monitoring of traffic conditions which could impact traffic flow in the study section was also conducted in this manner.

Figure 3-1. Video Tape Data Collection on Spur 408.

Figure 3-2. Video Tape Data Collection on Loop 12 (Observing Vehicles Moving Away from Camera).

Figure 3-3. View to North, No Congestion.

Figure 3-4. View to North, Congested.

3.2 FIELD TEST DETECTION SYSTEM

Field tests utilized two types of detection systems. The SmartSensor by Wavetronix uses digital wave radar and was available for the Spur 408 study (Figure 3-5). Wide-area video vehicle detection via Autoscope was available for the Loop 12 study (Figure 3-6). Both detection methods **resulted in speed and traffic volume data available *by lane every 15 seconds*, and summarized every 5 minutes**. The data for these and many other detector locations in the Dallas District are archived on the internet (Figure 3-7). Researchers were able to facilitate obtaining the archived information, remotely accessed via the Internet, beginning on the day that the information was needed. Thus, this research project was the first to utilize many aspects of the Dallas ITS system for research purposes.

Researchers collected "before" data for several days prior to the deployment of the signs. The research team then collected "after" data for several days during the deployment of the signs. The first field test conducted was Spur 408, and the signs were deployed during the first week of May 2004. Data collection (and sign deployment) was avoided during Mondays and Fridays. The Loop 12 field test was conducted the third week of May 2004, again avoiding heavy peak periods on Mondays and Fridays.

3.3 FIELD TEST INTERNET DATA ARCHIVE

Figure 3-8 shows traffic volume and speed data from the field test sites that were summarized in five minute intervals and archived (by day) on the internet. Figure 3-9 depicts when one day is reviewed in detail. The data were sorted using Microsoft Access, and then tabulated and graphed using Microsoft Excel. Chapter 4 reports the findings.

Figure 3-5. SmartSensor by Wavetronix Detection Used on Spur 408.

Figure 3-6. Autoscope Video Detection Used on Loop 12.

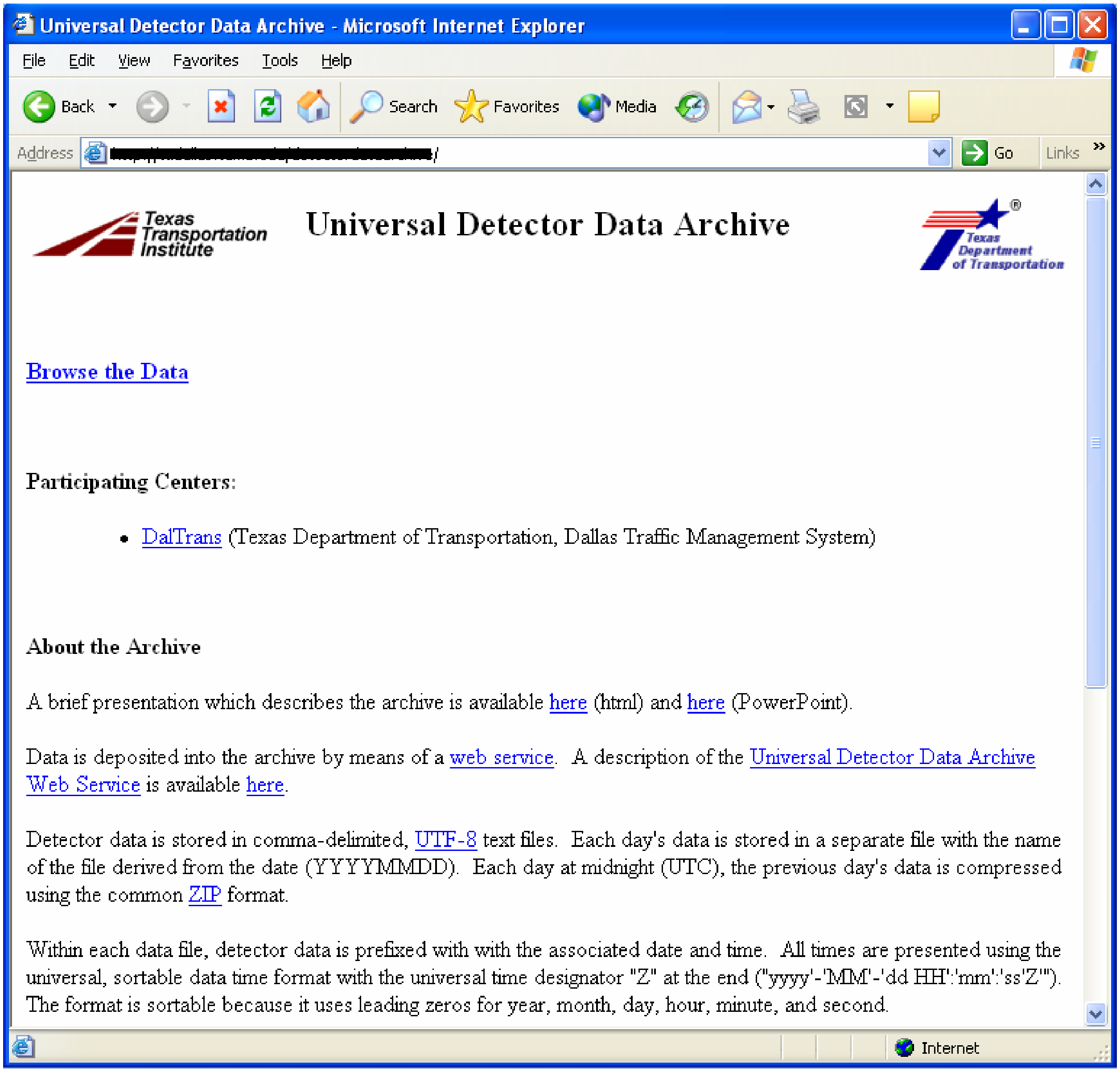


Figure 3-7. Internet-Based Universal Detector Data Archive.

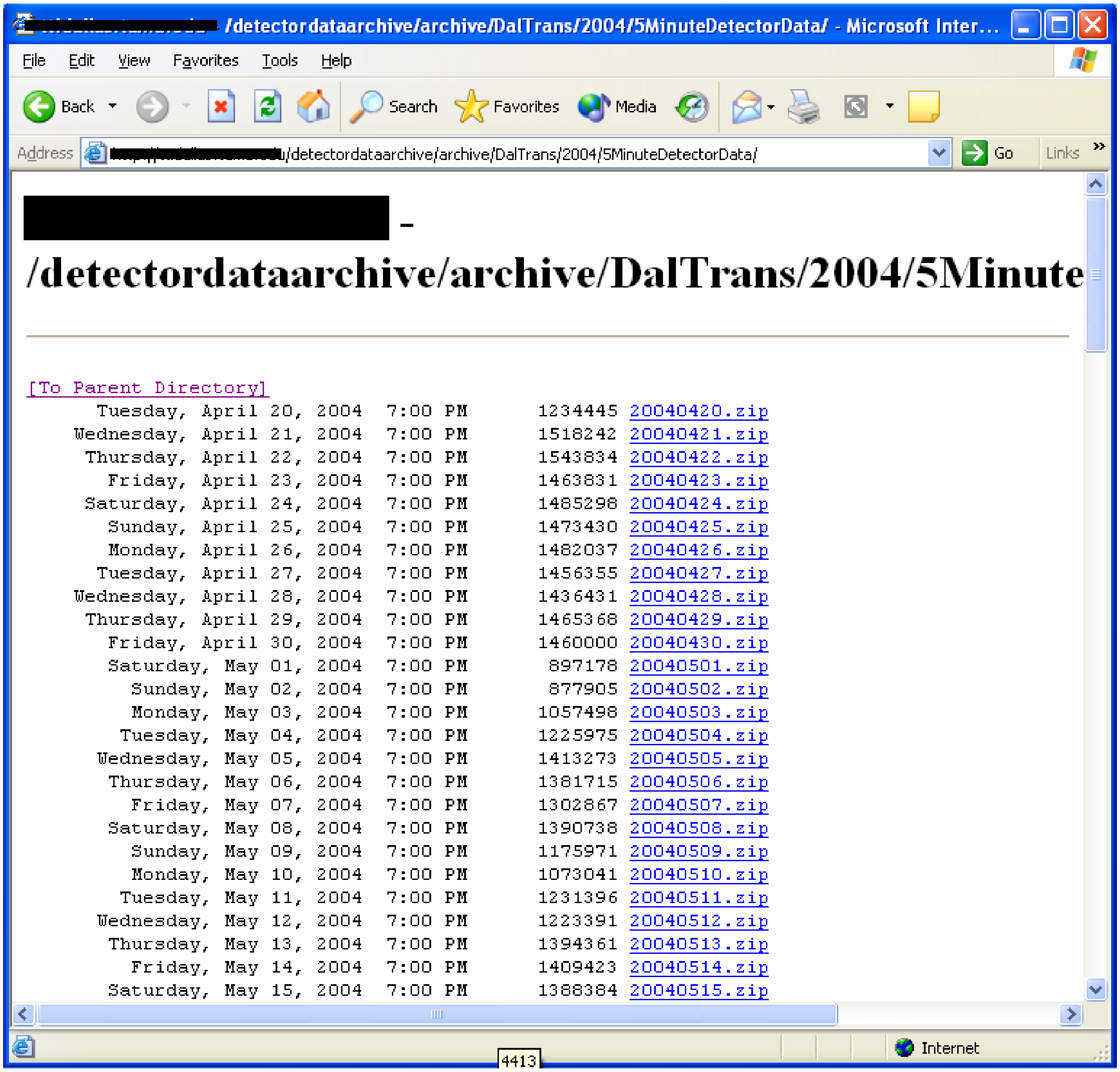
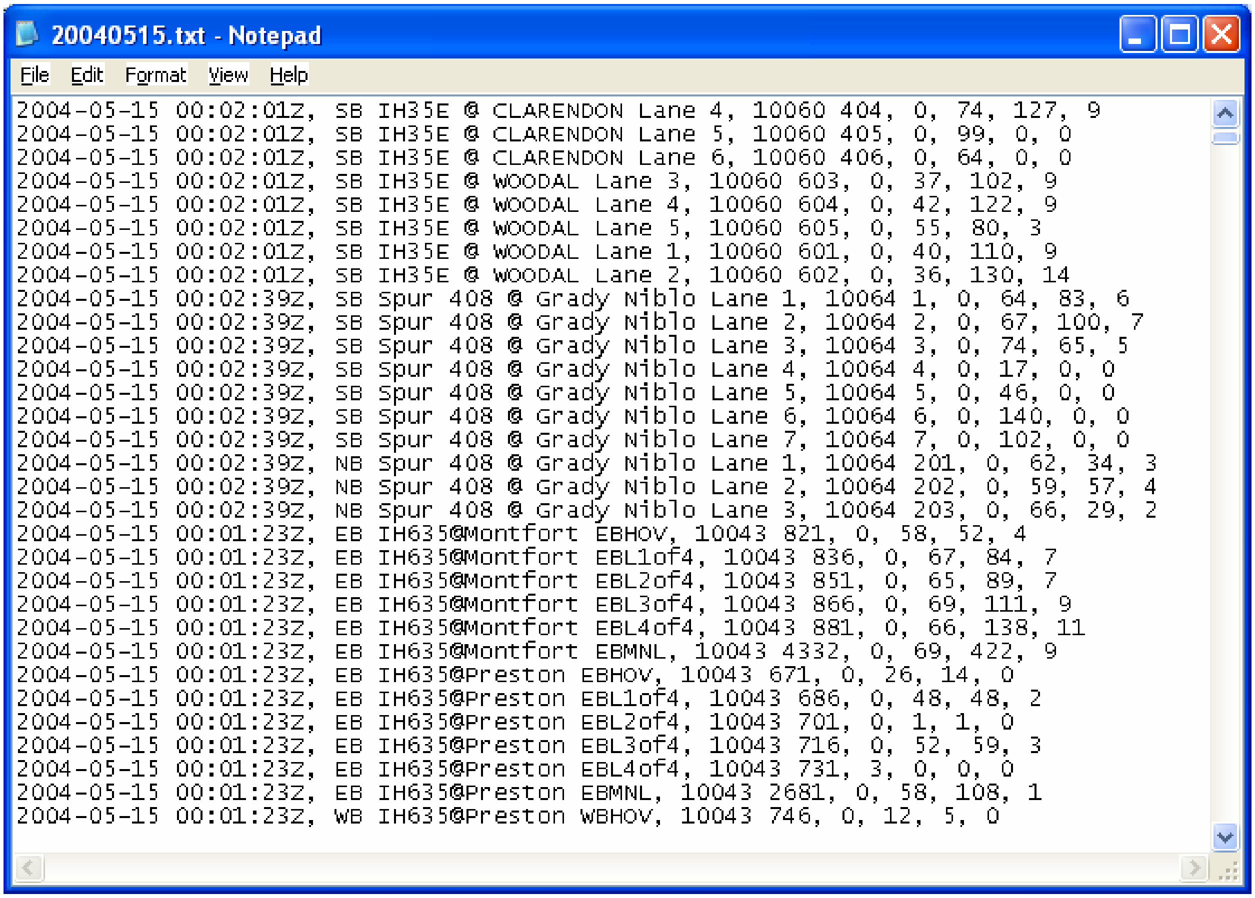


Figure 3-8. Internet-Based Detector Data Archive, by Day.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File Edit Format View Help

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2004-05-15 00:02:01Z, SB IH35E @ WOODAL Lane 2, 10060 602, 0, 36, 130, 14
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2004-05-15 00:01:23Z, EB IH635@Montfort EBL2of4, 10043 851, 0, 65, 89, 7
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2004-05-15 00:01:23Z, EB IH635@Montfort EBMNL, 10043 4332, 0, 69, 422, 9
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2004-05-15 00:01:23Z, WB IH635@Preston WBHOV, 10043 746, 0, 12, 5, 0
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Figure 3-9. Internet-Based Detector Data Archive, Five-Minute Data by Location.

CHAPTER 4. FIELD TEST FINDINGS AND RECOMMENDATIONS

4.1 FIELD TEST FINDINGS

As mentioned previously, researchers collected "before" data for several days prior to the deployment of the signs. Members of the research team collected "after" data for several days during the deployment of the signs. Each of the field test locations approached a section of freeway routinely congested during peak periods due to a lane drop prior to a merge with another freeway. These congestion areas were not readily visible from the study area, and the length and nature of the queuing varied based on time of day and travel lane.

Crews placed signs for the field tests such that drivers could view all three signs prior to being able to see congestion. Thus, any driver reaction could be attributed to the signs as opposed to a view of stopped traffic.

4.2 FIELD TEST FINDINGS: SPUR 408

The Spur 408 field test had one detection station available, located immediately following the last of the three signs viewed by drivers (Figure 2-12). Traffic volumes were similar for both the "before" and "after" study. Researchers collected "before" data the week before sign deployment and "after" data reflects conditions while the signs were in place. The speed data obtained was an average (over several days) spot speed, reported by lane. A review of the speeds during the AM peak period shows a marked drop in average speeds for each of the three lanes at the detection point when the pictogram signs were present, but only during the 7:15 AM to 7:45 AM timeframe (Figures 4-1, 4-2 and 4-3).

No other variable, other than the presence of the signs, was evident to researchers. The magnitude of the speed drop varies from about 15 mph to about 25 mph. Perhaps because drivers anticipate possible congestion during that timeframe, the speed in the "before" condition dropped from general approach speeds of around 65 mph to about 45 mph. With the presence of the pictogram signs in the "after" conditions, the drop in average speeds of an *additional* 15 mph to 25 mph resulted in approach speeds dropping to a low of about 28 mph.

A drop in speed such as that observed might be undesirable under normal conditions. However, if drivers imminently face stopped traffic, speeds should ideally be lower approaching the tail end of the queue. Field observations do not show erratic maneuvers as drivers slowed the additional 15 mph to 25 mph.

Interestingly, outside of the timeframe during which drivers would expect to find congestion, no speed reductions were evident due to the presence of the pictogram signs. Researchers were unable to measure any increased state of alertness which drivers may have experienced due to the presence of the signs. It is possible that although there were no speed reductions, drivers may have been alert to the possibility of congestion, perhaps with an increased capacity to respond to such conditions if they were to occur.

This type of selective response may also reflect the comprehension of the pictogram symbol. Since the sign was obviously a static sign and not a real-time message, drivers may have selectively determined an appropriate response based on expectations for congestion (no response, increased alertness or speed reduction). Further research of driver interpretation of the pictogram sign, with and without the use of a supplemental explanatory plaque, are suggested.

Anecdotal comments about the pictogram signs as deployed at Spur 408 included several comments that the picture on the signs seemed very small. This comment was from drivers familiar with the pictogram. One reason for this could be that the adjacent auxiliary lane necessitated the placement of the sign farther to the right from through traffic than would generally be the case. Suggestions for improving the pictogram sign included making the picture as large as reasonable. Members of the Project Monitoring Committee also recommended the use of high intensity sheeting to make the sign more visible. This became a reasonable alternative after the production of the field test signs, and will be suggested for use in subsequent research. Additionally, the placement of the signs on temporary supports such as those used for construction zone signing was perceived as a possible influence on driver reaction to the signs.

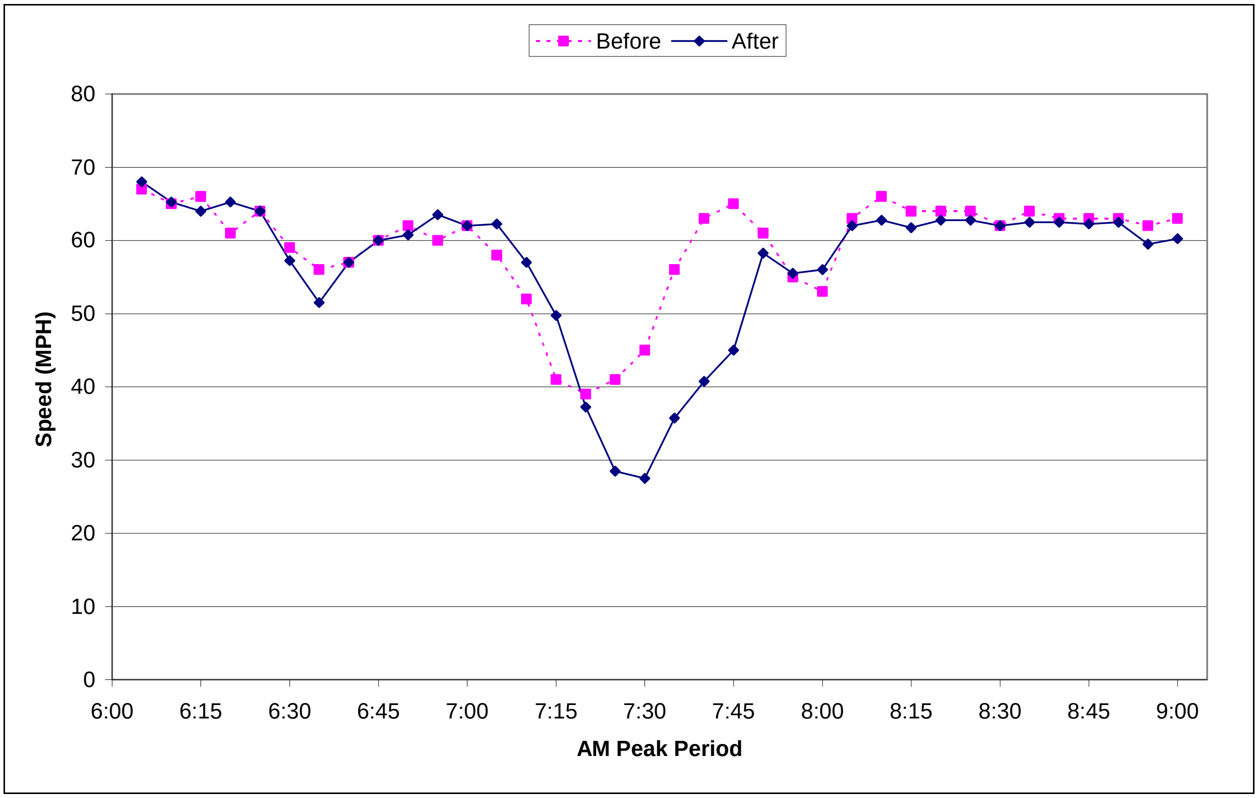

Figure 4-1. Comparison of Speeds at Spur 408 Field Site: Lane 1 AM.

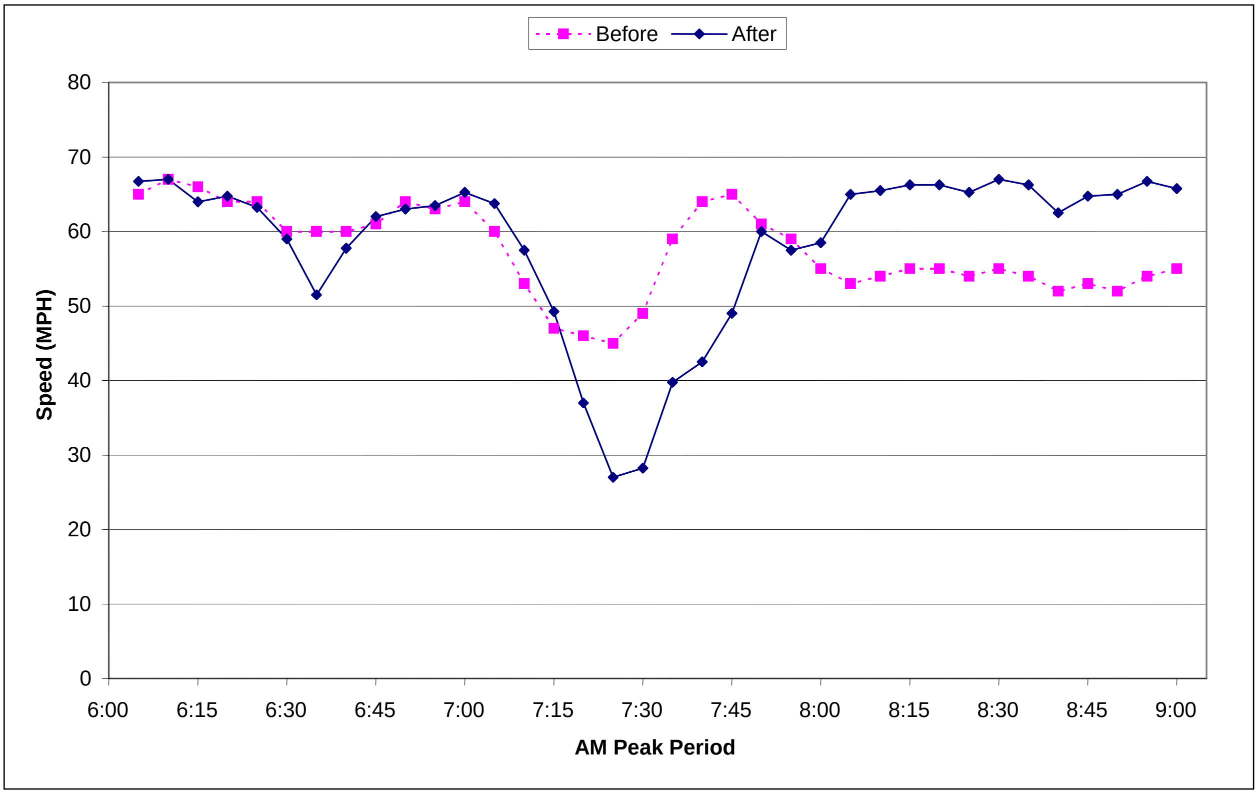

Figure 4-2. Comparison of Speeds at Spur 408 Field Site: Lane 2 AM.

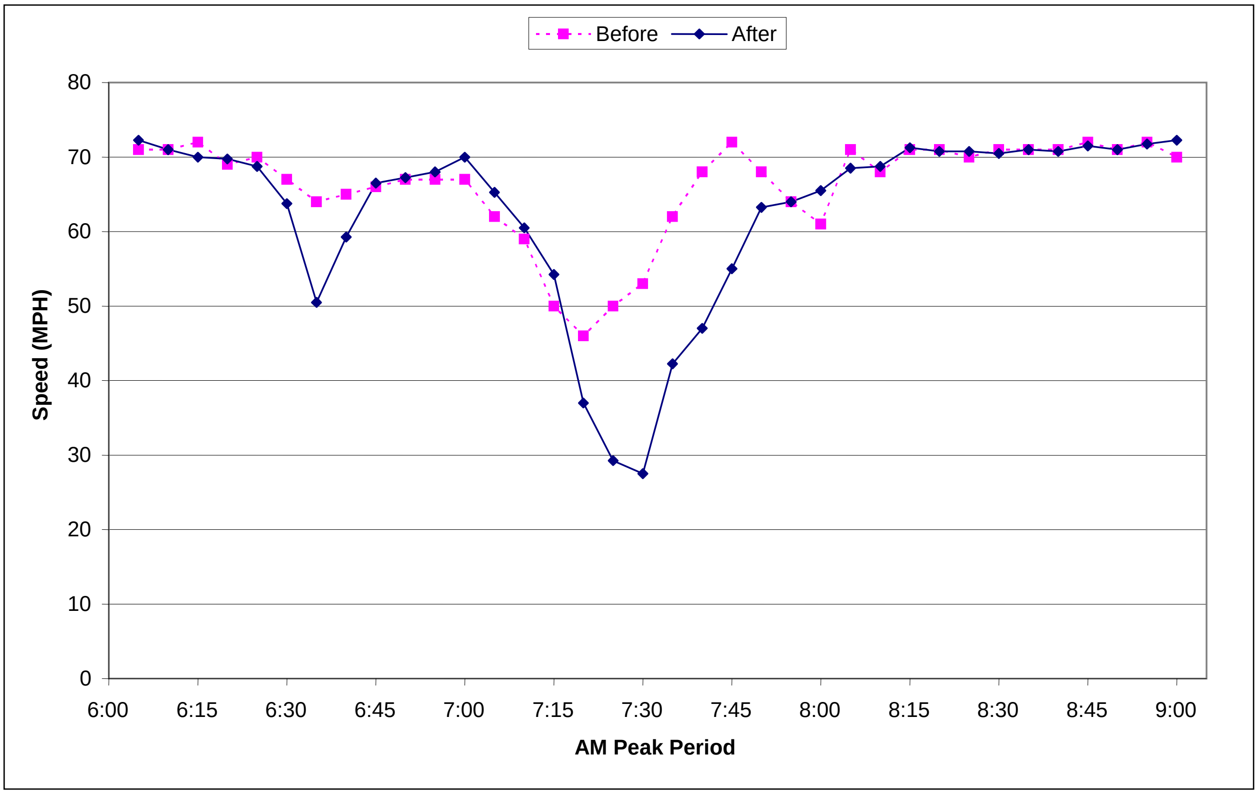

Figure 4-3. Comparison of Speeds at Spur 408 Field Site: Lane 3 AM.

4.3 FIELD TEST FINDINGS: LOOP 12

Figure 2-13 shows the three detection stations available in the Loop 12 field test. A detector station was located immediately after each of the three signs. The text signs were deployed on Loop 12, as shown in Figure 2-17, WATCH/FOR STOPPED/TRAFFIC. Traffic volumes were similar for both the "before" study prior to sign deployment and the "after" study with the signs in place. Again, the speeds obtained were average spot speeds collected over several days, reported by lane.

No variables, other than the absence or presence of the signs, were evident to the researchers. Both studies had similar lighting, pavement (dry) and operational conditions (no incidents). Researchers omitted data collected during congested conditions (under 20 mph) from the study.

Figures 4-4, 4-5 and 4-6 show speeds before and during sign deployment at Northwest (NW) Highway, a location where drivers have had the opportunity to view all three signs. Recurrent congestion routinely exists downstream of this location due to a lane drop at the merge of Loop 12 with I-35E. Figures 4-7, 4-8 and 4-9 show speeds after drivers have passed two signs (at SH 114), and Figures 4-10, 4-11 and 4-12 show speed conditions after drivers have viewed only one sign (at SH 183).

Because of a problem with the detector or with the communications link from the field to the Internet archiving, the NW Highway data are not available prior to about 7:00 AM. This is unfortunate because the 6:00 AM to 7:00 AM time period might have been of interest. However, the data that are available seems to indicate possible driver reaction to the signs *in the vicinity and during the timeframe* when congestion might be expected ahead due to the upcoming lane drop. For the SH 114 detector station and the SH 183 detector station, no difference is discernable. The 6:00 AM to 7:00 AM timeframe is shown for information purposes.

Findings for the Loop 12 study indicate that there might be some impact of drivers viewing the signs, again with the speed reduction occurring generally when and where drivers anticipate congestion. The NW Highway detector, shown in Figures 4-4, 4-5 and 4-6, indicates a drop in speeds of about 25 mph for about 15 minutes after 7:00 AM. Whether this type of speed drop would have been noted in the 6:00 AM to 7:00 AM timeframe is not certain, but some speed drop would have been probable. The remainder of the time period until 8:00 AM is unremarkable, with speeds with and without the text signs generally the same.

Field studies and future research should both consider some of the same issues, such as whether real-time information may be preferable if immediate driver response is desired. Testing of signs with detectors and flashers could also occur at locations and times where drivers do not anticipate congestion.

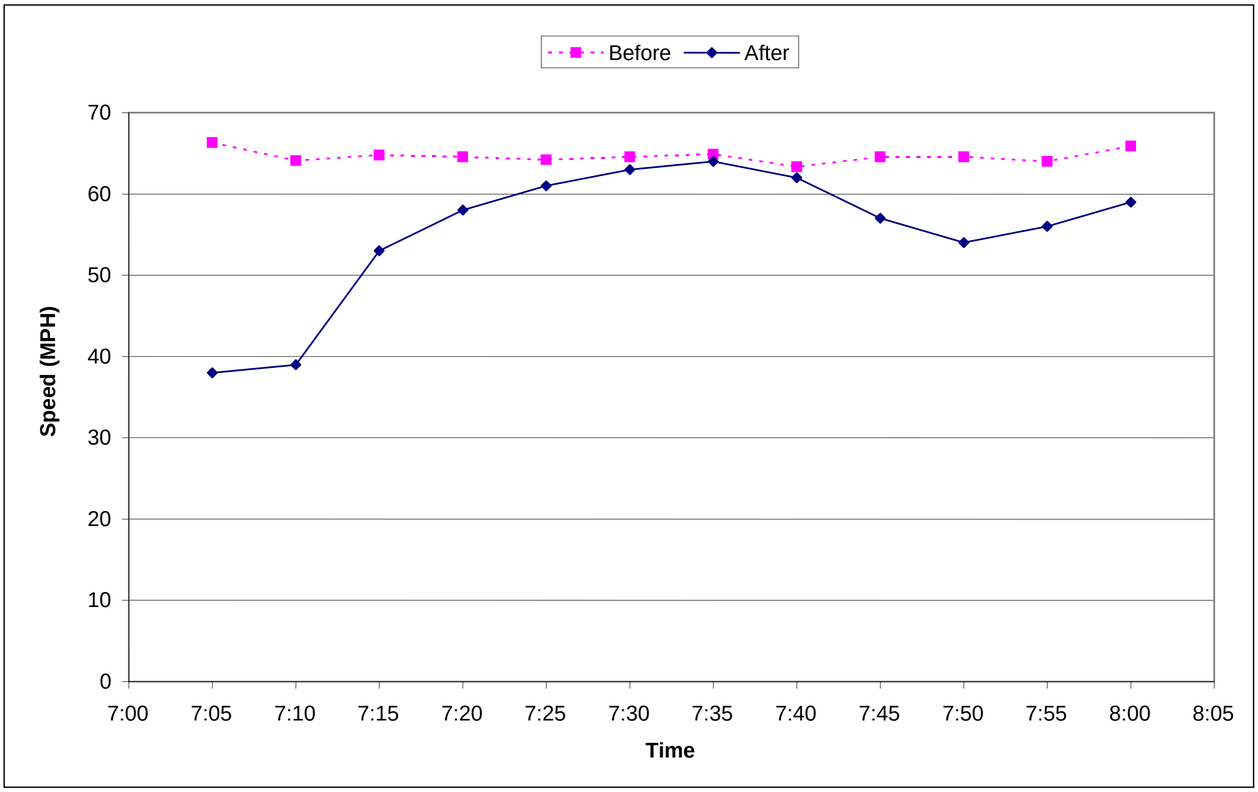

Figure 4-4. Comparison of Speeds at Northwest Highway Field Site: Lane 1 AM.

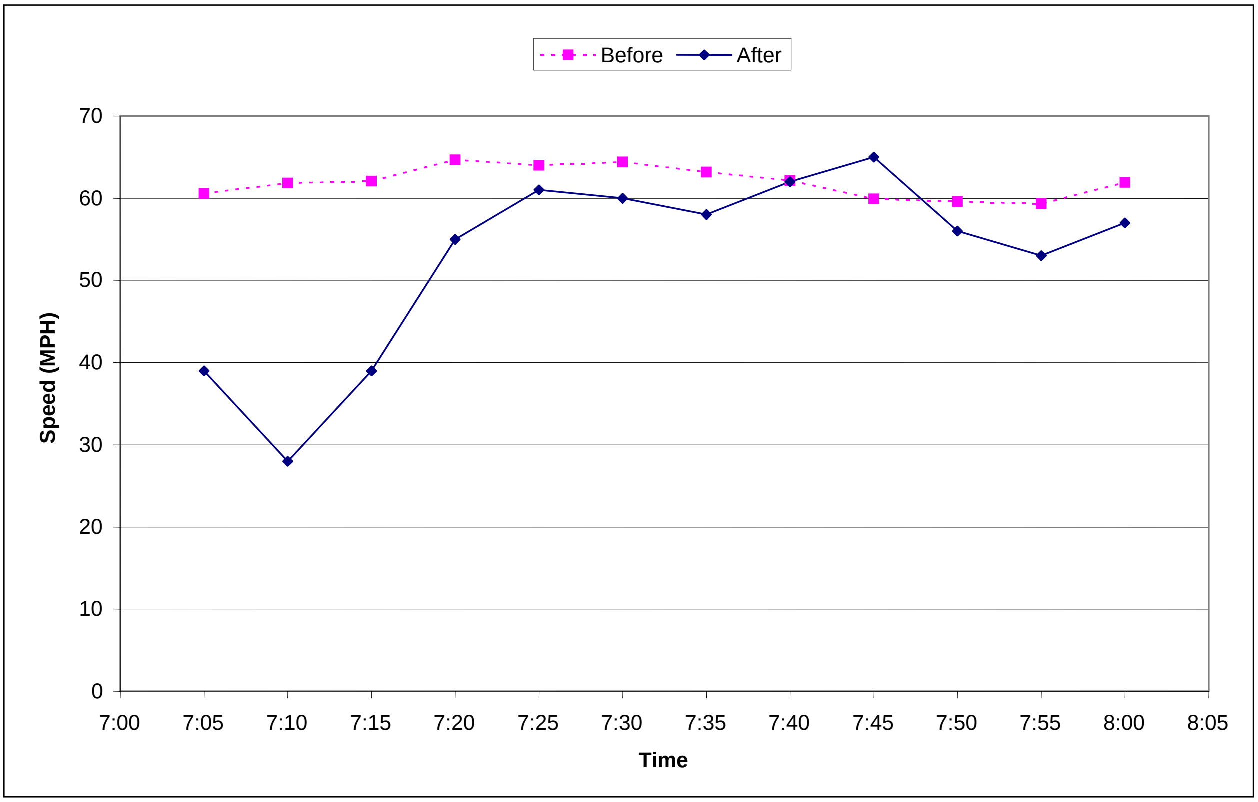

Figure 4-5. Comparison of Speeds at Northwest Highway Field Site: Lane 2 AM.

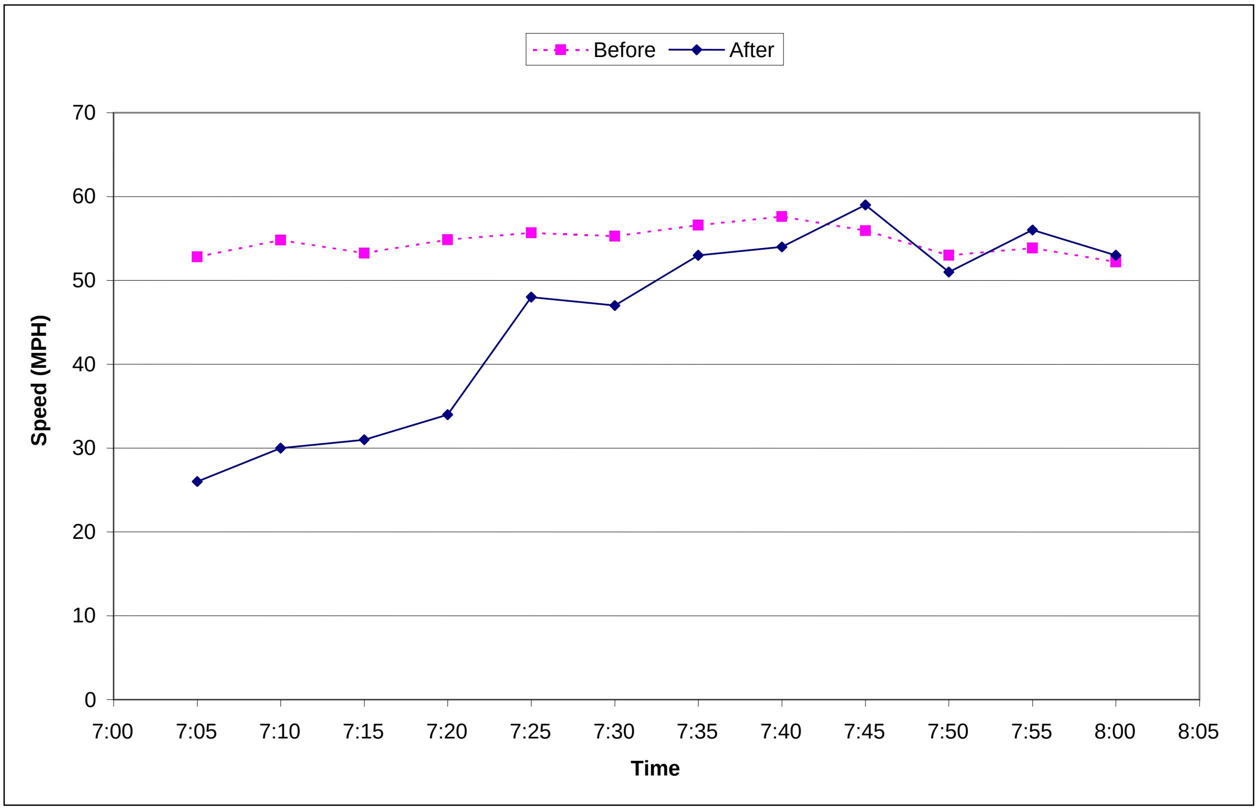

Figure 4-6. Comparison of Speeds at Northwest Highway Field Site: Lane 3 AM.

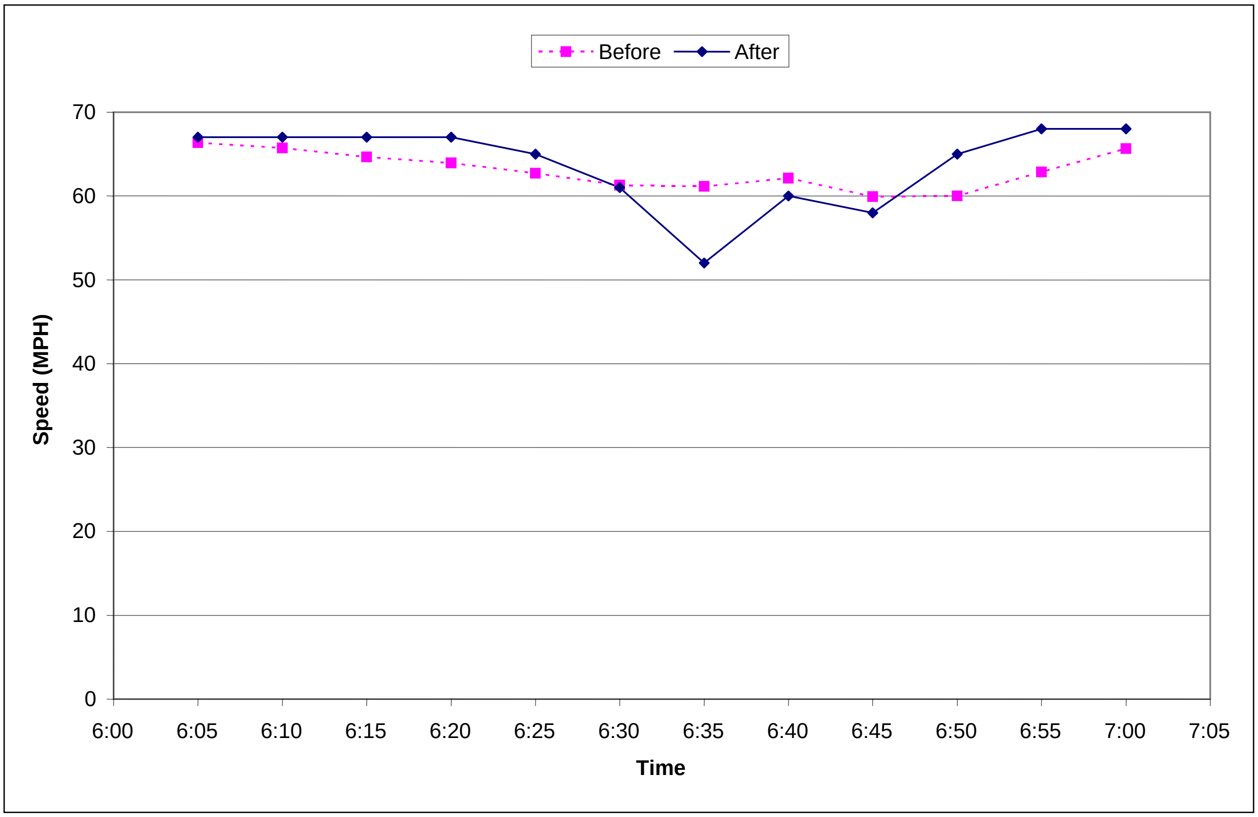

Figure 4-7. Comparison of Speeds at State Highway 114 Field Site: Lane 1 AM.

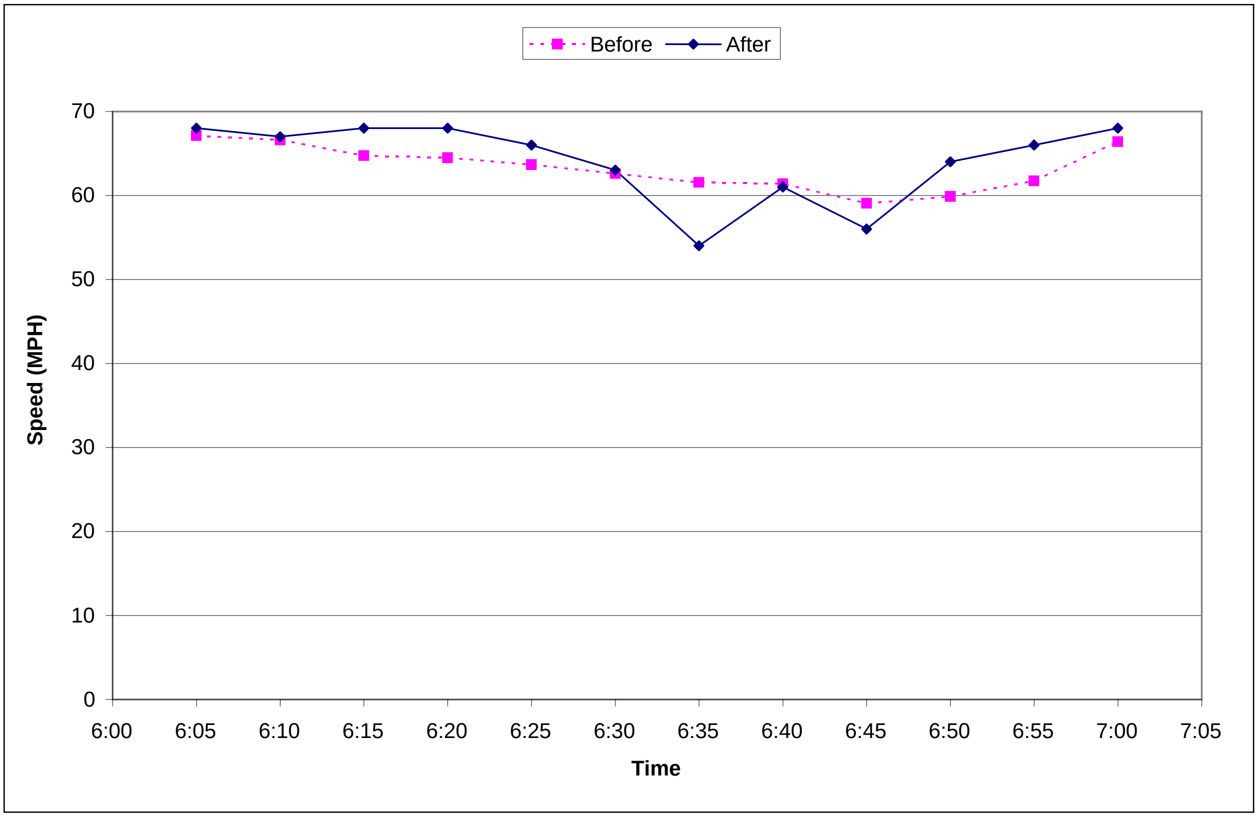

Figure 4-8. Comparison of Speeds at State Highway 114 Field Site: Lane 2 AM.

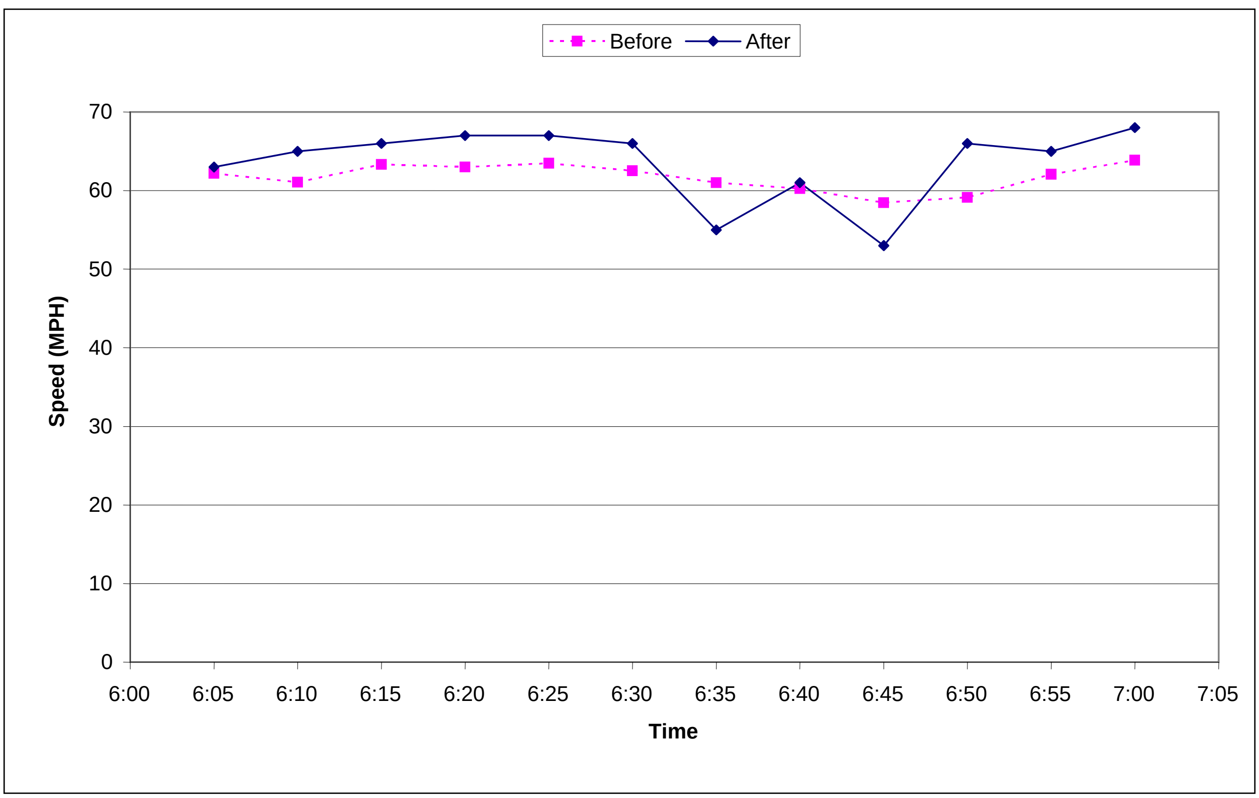

Figure 4-9. Comparison of Speeds at State Highway 114 Field Site: Lane 3 AM.

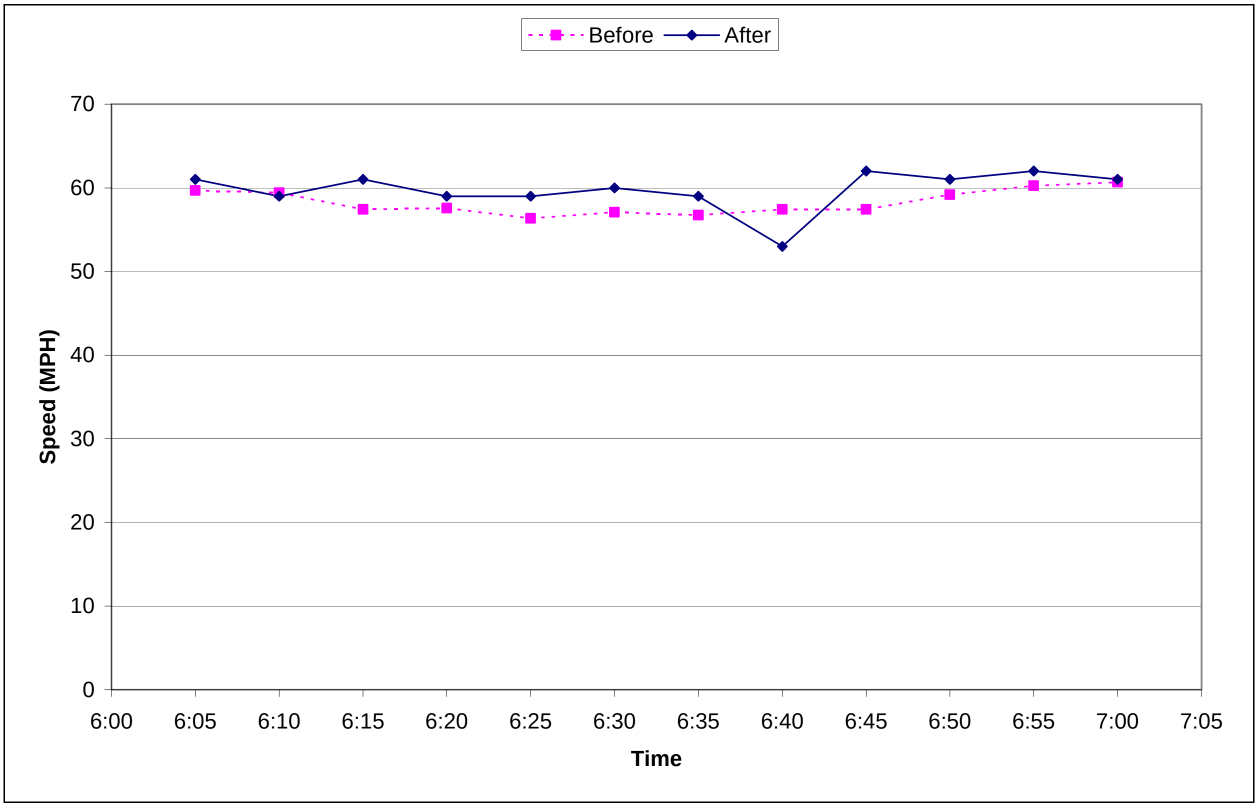

Figure 4-10. Comparison of Speeds at State Highway 183 Field Site: Lane 1 AM.

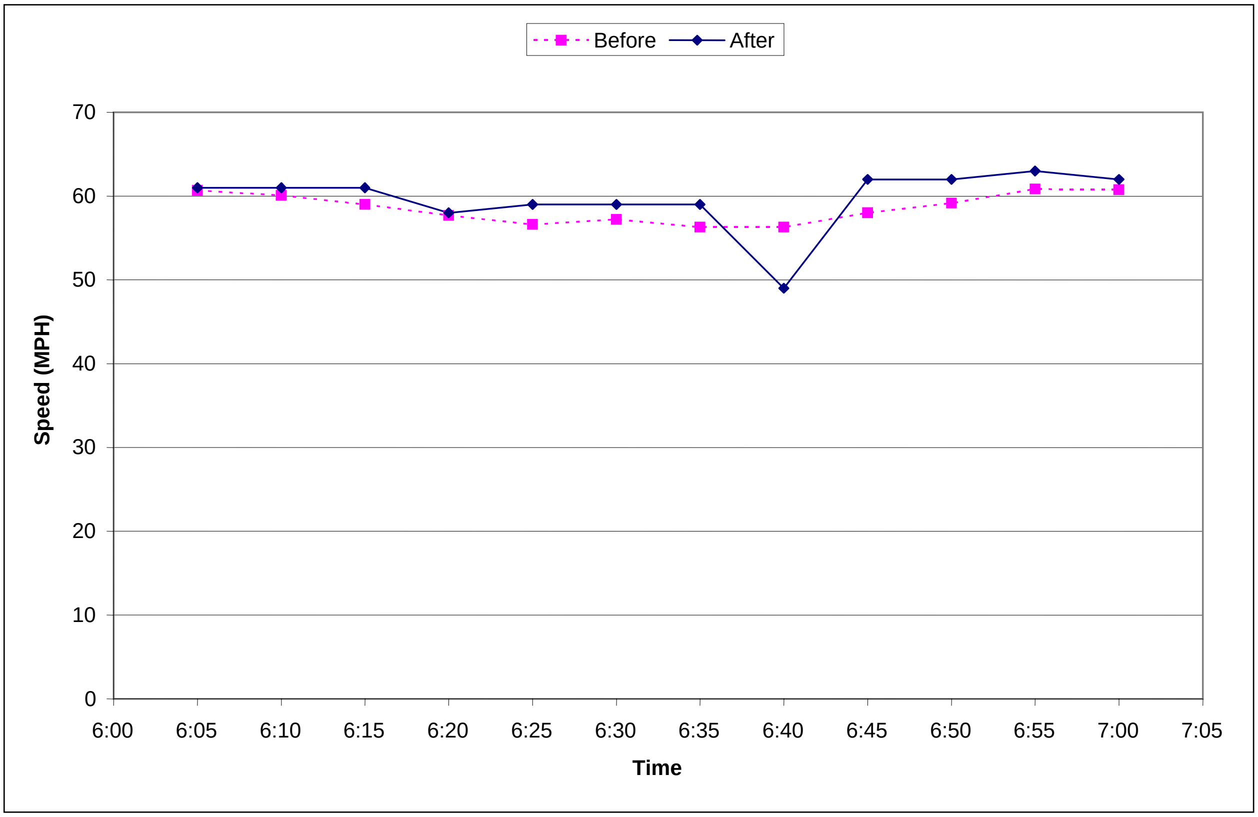

Figure 4-11. Comparison of Speeds at State Highway 183 Field Site: Lane 2 AM.

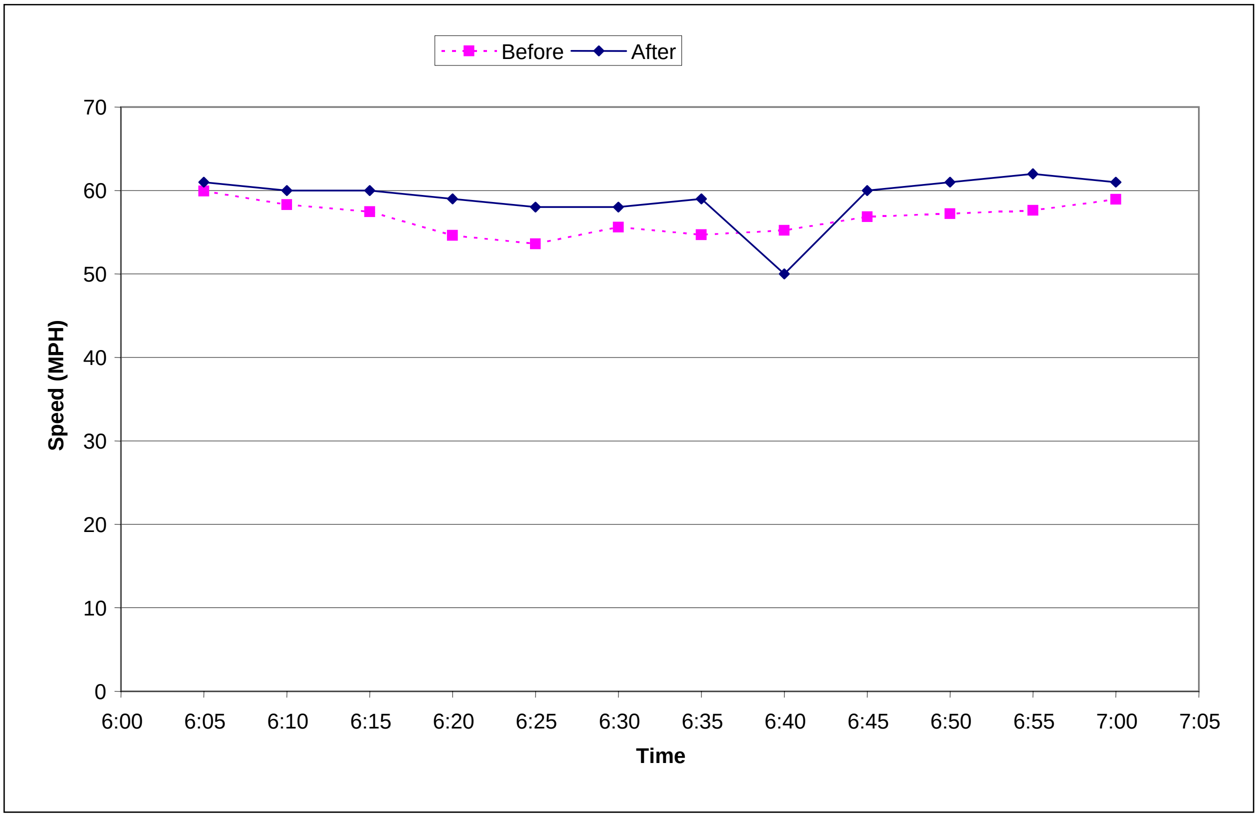

Figure 4-12 Comparison of Speeds at State Highway 183 Field Site: Lane 3 AM.

4.4 RECOMMENDATIONS: GUIDELINES FOR IMPLEMENTATION

The following list provides general recommendations and findings for this research:

- Queue warning systems, in order to be effective, should be installed in consideration of rapidly fluctuating queues. This means that warning signs placed too close to queue tails might be overrun, with the possibility of drivers encountering the queue before they see the sign. Warning signs placed too far from the queue, if the downstream location of the queue is mentioned, can become inaccurate between the time drivers view the sign and encounter the queue.
- Conditions change too quickly for human operators to handle appropriate warning sign adjustments, necessitating an automated system if real-time adjustments to geolocate the queues are needed.
- Geolocated queues, for which drivers are advised of the distance to the queue tail, will require multiple detection stations, as well as multiple advance warning sign locations.
- Many factors remain to be addressed in future research; however, observations conducted within Task 3 of this project (Chapter 3) can assist in providing guidance to those testing and implementing and operating systems for advance warning of stopped traffic on freeways.

4.5 RECOMMENDATIONS: SELECTION STRATEGY CHART

Although prior to conducting this research it was envisioned that one of the products would be a flowchart to convey selection strategy information, the net result is in the format of a traditional table, or chart, for greater clarity. **The Chart is envisioned to be updated and enhanced as research continues on this subject.** Table 4-1 shows Version 1, entitled, "Advance Warning: Selection Strategy Chart." The elements within this chart have been conglomerated from a variety of sources over a several-year period. Some of the sources are listed below.

One source, information from Phase I (Research Report 4413-1) includes:

- Literature search information.
- Current practices survey (international, national, TX, and local).
- Observational field studies.

Another source, information from Phase II (this report) includes:

- Field studies.
- Information collected during the site selection task.
- Updated information on current practices.

Four basic problem types where drivers might need advance warning of stopped traffic are addressed in the advance warning selection strategy chart. These problem types are sight distance constraints, recurrent congestion, construction and maintenance zones, and incidents. The following section discusses each of these areas which the advance warning selection strategy chart summarizes.

Sight Distance Constraints

When geometric conditions exist which might impact a driver's view of stopped traffic, such as vertical or horizontal curves, drivers might benefit from advance warning. Examples of this type of condition include hills which might hide frequent congestion due to a high traffic entrance ramp, or a horizontal curve of such severity that tail lights might not be visible in time to minimize secondary incidents.

For these situations, as a minimum, static signing would be desirable. Signs can be traditional diamond-shaped warning signs, rectangular signs, and even panels appended to traditional guide signs. Figures 4-13 through 4-15 show examples of these signs.

The color of these types of signs is recommended to be yellow background with black text.
Appropriate messages include those listed in the chart: WATCH FOR STOPPED TRAFFIC and WATCH FOR CONGESTION. The word AHEAD may be added to the message. If a rectangular sign is used, the word CAUTION can be added to the message, since a warning is not inherently implied by the sign shape. The congestion pictogram, although promising, is not currently approved for use. It is worthy of additional research and development. Other sign messages observed in the current practices review include the following:

- PREPARE TO STOP WHEN FLASHING
- CONGESTION AHEAD – RAMP CONGESTION WHEN FLASHING

Table 4-1. Advance Warning: Selection Strategy Chart (Version 1)

Problem Type	Problem Description	Primary Warning Strategy	Shape	Color	Possible Text Message/ Pictogram*	Detection/ Flashers	Supplemental Plaque	Deployment Strategy	Cost
Sight Distance Constraints	Vertical and horizontal curves block driver's view	Static or variable signs with some form of queue detection	Diamond, Rectangle or Panel	Yellow or High-Intensity Yellow	WATCH FOR STOPPED TRAFFIC WATCH FOR CONGESTION Congestion Pictogram*	Optional	With Pictogram*: Watch for Stopped Traffic or Watch for Congestion	<u>Sign 1</u> 1500' before typical queue <u>Sign 2</u> 1000' before Sign 1, or before max queue; gate-posting OK	$ to $$
Recurrent Congestion	Predictable congestion	Static or variable signs with some form of queue detection	Diamond, Rectangle or Panel	Yellow or High-Intensity Yellow	WATCH FOR STOPPED TRAFFIC WATCH FOR CONGESTION Congestion Pictogram*	Optional	With detection and flashers: When Flashing	<u>Sign 1</u> 1500' before typical queue <u>Sign 2</u> 1000' before Sign 1, or before max queue; gate-posting OK	$ to $$
Construction/ Maintenance Zones	Queues caused by reduced capacity from lane closures	Single or multiple detection stations and multiple signs (static or variable)	Diamond	Yellow, High-Intensity Yellow or Orange in construction zones	WATCH FOR STOPPED TRAFFIC CONGESTION AHEAD Congestion Pictogram*	Optional or desirable	With detection and flashers: When Flashing	<u>Sign 1</u> 1500' before typical queue <u>Sign 2</u> 1000' before Sign 1, or before max queue <u>Sign 3</u> 1-5 miles prior to Sign 2; gate-posting OK.	$$ to $$$
Incidents	Unpredictable time and location of congestion	Rely on use of existing ITS devices	N/A	N/A	WATCH FOR STOPPED TRAFFIC CONGESTION AHEAD	N/A	N/A	As Available	0

* Pictogram not currently approved for use.

- WATCH FOR SLOWING TRAFFIC
- CONGESTION AHEAD – NEXT 2 MILES
- CONGESTION AHEAD
- LEFT EXIT AHEAD – BE ALERT
- TRAFFIC CONGESTION AHEAD – WHEN FLASHING
- WORK ZONE – STAY ALERT – PREPARE FOR SLOW MOVING TRAFFIC
- CAUTION – WATCH FOR SLOW TRAFFIC AHEAD
- SLOW TRAFFIC AHEAD – BE PREPARED TO STOP
- EXPECT SLOW OR STOPPED TRAFFIC- WHEN FLASHING

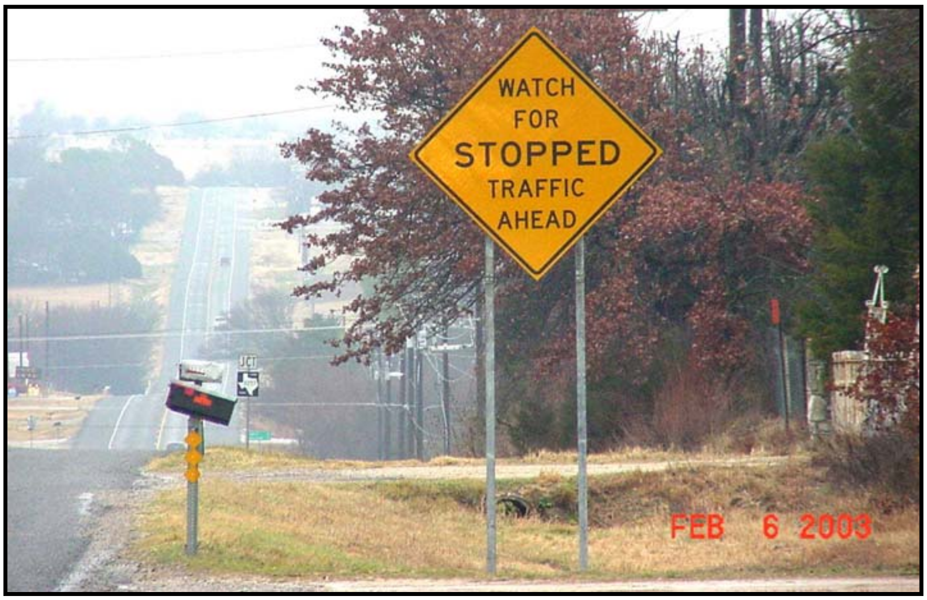

Figure 4-13. Example of Diamond-Shaped Warning Sign – Fort Worth, Texas.

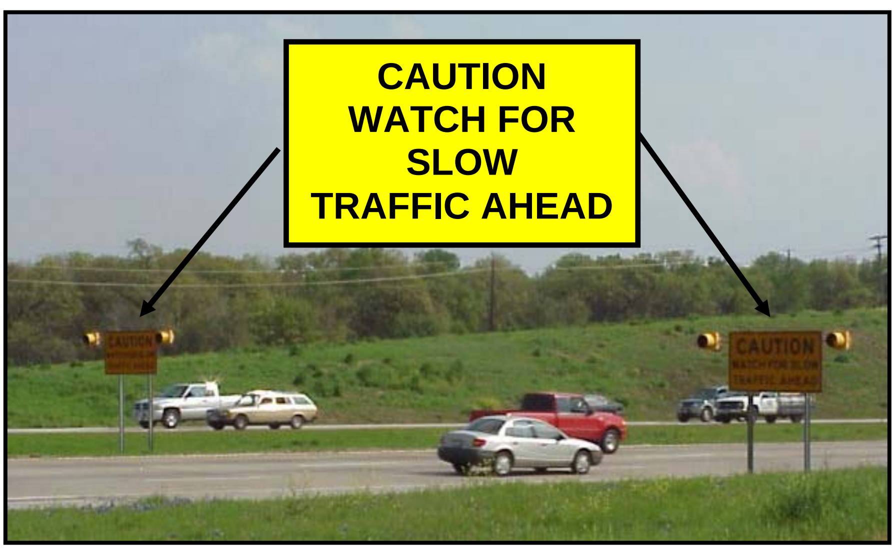

Figure 4-14. Example of Rectangular-Shaped Warning Sign – Fort Worth, Texas.

Figure 4-15. Example of Sign Panel on Guide Sign. [1]

The use of detection of congested conditions may be appropriate, especially if congestion frequently exists or tend to create secondary incidents. Various vehicle types should be particularly considered because of the difference in stopping distance between, for example, passenger cars and large trucks. If detection is used, then flashers may be installed, and the supplemental plaque may be added to the sign referencing the sign's applicability when the flashers are active (WHEN FLASHING). The WATCH FOR text may not be needed if detection and flashers are in place. If flashers are always active, the supplemental plaque is optional.

The deployment strategy is to place the sign closest to the congestion about 1500 feet in advance of the obstruction or the typical tail end of queue (whichever is farther). This distance is based on several deployments of systems in Europe (see Phase I research). If using additional signs, consider spacing ranging from 500 to 1000 feet. Gateposting, which is placing signs on both sides of the freeway, is optional but recommended for wide freeways or especially when congestion spans all lanes, if space allows.

Recurrent Congestion

Predictable congestion during peak periods, or due to spillback onto the freeway from ramps or connections, is a common problem in urban areas. In order to provide advance warning of these conditions, static or variable signs can be used as described for the sight distance constraints above. However, particular care must be given to the location of the maximum queue. As shown in Phase I of this research, a wide fluctuation in queue length can be expected under many congested conditions. Therefore, particular care should be taken to place at least one of the advance warning signs prior to the location of the maximum anticipated queue. Gateposting is optional but is less needed when congestion is mostly confined to the right lane, such as with ramp spillback.

Construction and Maintenance Zones

Queues caused by reduced capacity from construction or maintenance-related lane closures are a major cause of congestion of freeways. Construction zones can have highly variable congestion conditions. The construction zone may be heavily congested at certain times during the day and high speed and uncongested at night. For this scenario, the primary warning strategy might be to utilize single or multiple detection locations and multiple signs, which can be static or variable.

For construction and maintenance zones, a diamond-shaped warning sign, orange background with black text, may be desirable. If the sign is significantly in advance of the defined construction zone, the operating agency or the contractor may prefer to use a yellow background. Construction zones may make particular use of portable variable message signs because of the transient nature of the need for a warning, and due to high night-time visibility. Message guidance remains the same as above, however, with variable signs messages may need to be adapted to fit. The ability to cycle messages (using two stages) somewhat counteracts the short words that may need to be used.

Construction zones may need one or more signs placed very far in advance of the typical tail end of the queue, since the maximum queue length can be significantly longer than the typical queue. Additionally, portable variable signs need to be placed in consideration of the space needed to deploy them safely. Gateposting is optional but desirable for wide freeways.

Incidents

Incidents occur at unpredictable times and locations. Thus, they do not lend themselves to the traditional signing techniques mentioned above. For incidents, the primary means of communicating to drivers may be ITS elements already in place. This could include small or large variable message signs, or lane control signals that depict which lanes are open and which are closed, as well as highway advisory radio (HAR) and other ITS tools. If variable signs are available, consider messages as indicated above in the absence of a standard.

4.6 FUTURE RESEARCH NEEDS

Interest from Urban Areas

During the research study period, various TxDOT districts have expressed interest in the research and findings. The Fort Worth and Dallas districts have both deployed signs warning drivers of the potential for stopped traffic, and the Austin District is imminently considering a sign deployment with advice from research staff. Researchers have also been contacted by the El Paso and Houston districts about locations for which such warning signs might be desirable, and for consideration as possible research test locations.

Recommended Areas for Additional Research

Researchers found that no sign standard currently exists which specifically warns drivers about the possibility of encountering stopped traffic on the freeway. The current breadth and variety of sign sizes, shapes, messages, field placement and use of technology are significant, as well as indicative of the need to warn drivers of possible congestion. Although fining no uniformity in warning displays, the reasons for deploying the signs fell to several key areas. Thus, the potential exists to develop a new standard that addresses the need to warn the driver, while increasing effective communication to the drivers via standardized messages. This research, after investigating alternative techniques used internationally, nationally, and at the state and local levels, was primed to develop sign messages for testing which could be a first step to a new standard. This research project developed and evaluated promising text and pictogram messages.

As a goal, it would be desirable to have a recommended message or series of messages available for use in areas that experience congestion. Without this guidance, deployment of messages will occur on an individual basis without the benefit of standardization. Many factors remain for researchers to address in the future, including:

- Desirable messages for various conditions.
- Test of pictogram sign with supplemental plaque "Watch for Stopped Traffic."
- Test of pictogram sign with high-intensity sheeting to increase conspicuity.
- Test of queue-activated sign "When Flashing."
- Survey of pictogram sign interpretation.
- Assessment of the prevalence of rear-end crashes where congestion and horizontal or vertical alignment visibility constraints exist.

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[1] Illinois Tollway Web Site. Grand Avenue Interchange Improvements. [Online]. Available: http://www.illinoistollway.com/coverview1.html. Site accessed August 27, 2004.

APPENDIX:

PHASE II LITERATURE SEARCH AND CURRENT PRACTICES UPDATE

Interstate 26 Queue Detection System in Asheville, North Carolina

Location: Westbound Interstate 26 on the approach to the Interstate 40 interchange in Asheville, North Carolina.

System Description: The queue warning system consists of three basic components: (1) solar power system; (2) rectangular warning sign with EXPECT SLOW OR STOPPED TRAFFIC WHEN FLASHING message (Figure A-1) and side-mounted yellow flashers; and (3) closed-circuit television camera for detection of traffic queues.

Installation Rationale: The primary reason for installing the system is the periodic severe congestion on westbound Interstate 26 approaching the Interstate 40 interchange. The condition typically lasts approximately 3 to 4 hours per day during the summer season and there were safety concerns due to the limited sight distance created by rolling terrain.

Project Benefits: North Carolina DOT performed a before and after crash analysis and found some positive benefits for the queue warning system:

Variable	Before	After
Number of Crashes	36	27
Crash Rate	119.98	91.89
Severity Index	5.96	2.37

Further Information: Mark Teague, P.E., Division Traffic Engineer
North Carolina DOT, Division 13 – Asheville
mteague@dot.state.nc.us

Figure A-1. Picture of Queue Warning Sign on Interstate 26 in Asheville, North Carolina.

Interstate 20 Queue Warning Signs in Dallas, Texas

Location: Eastbound (EB) Interstate 20 on the approach to the northbound (NB) Interstate 45 direct connect ramp in Dallas, Texas.

System Description: The queue warning consists of three warning signs: (1) Sign #1 is a diamond shaped yellow warning sign with WATCH FOR STOPPED TRAFFIC AHEAD message (Figure A-2); and (2) Signs #2 and #3 are diamond shaped yellow warning signs with the WATCH FOR STOPPED TRAFFIC AHEAD message with a supplemental warning plaque with RIGHT LANE as the text (Figure A-3).

Installation Rationale: The primary reason for installing the queue warning signs is the recurrent congestion on eastbound Interstate 20 approaching the Interstate 45 interchange. The EB to NB ramp typically backs up during the morning peak period. The queue is normally present only in the rightmost lane of the four EB lanes. There are also safety concerns due to the limited sight distance created by the rolling terrain and the high percentage of trucks in the traffic stream.

Project Benefits: The Texas Department of Transportation (TxDOT) has not performed an evaluation of the project benefits because the system was recently installed. Once sufficient after-crash data are available, an evaluation will be performed.

Further Information: Linden Burgess, TxDOT Dallas District – Traffic Operations Section, lburges@dot.state.tx.us

Figure A-2. First Queue Warning Sign on Interstate 20 in Dallas, Texas.

Figure A-3. Second and Third Queue Warning Sign on Interstate 20 in Dallas, Texas.

Figure A-4. Queuing in the Right Lane of Interstate 20 in Dallas, Texas.