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16. Abstract

A major safety concern on freeways is traffic flowing at normal speed encountering unexpected slow or stopped traffic. Traffic can be queued due to recurrent congestion, work zones, or collisions and/or other incidents. Drivers encountering queues are often faced with rapidly changing conditions in terms of queue length, sight distance to the end-of-queue, terrain, and available warning devices for traffic control. The rear-end collision is the most common type of multi-vehicle freeway collision, often due to slow/stopped traffic on the main lanes.

This report summarizes the first year of this effort, which 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. Additionally, in many instances, multiple lanes were 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, for which drivers are advised of the distance to the queue tail, require multiple detection stations and warning sign locations. Many factors remain to be addressed in future research; however, observations conducted in this project can provide guidance to those testing and implementing and operating systems for advance warning of slow/stopped traffic on freeways.

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ADVANCE WARNING OF STOPPED TRAFFIC ON FREEWAYS: CURRENT PRACTICES AND FIELD STUDIES OF QUEUE PROPAGATION SPEEDS

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- Mr. Jay Nelson, P.E., Texas Department of Transportation, Dallas District - 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. Wade Odell, P.E., Texas Department of Transportation, Research and Technology Implementation
- Mr. Walter Ragsdale, P.E., City of Richardson

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LIST OF ABBREVIATIONS

AADT	Average Annual Daily Traffic
AAS	Arterial Advisory Sign
AHWS	Automatic Holdup and Warning System
AID	Automatic Incident Detection
ASIS	Advanced Speed Information System
CAA	Canadian Automobile Association
Caltrans	California Department of Transportation
CAWS	Caltrans Automated Warning System
CCTV	Closed Circuit Television
CDPD	Cellular Digital Packet Data
CHIPS	Computerized Highway Information Processing System
CHP	California Highway Patrol
CTD	Congestion Tail Display
CTRE	Center for Transportation Research and Education
DFW	Dallas/Fort Worth
DOT	Department of Transportation
EIS	Electronic Integrated System
FHWA	Federal Highway Administration
FINRA	Finnish National Road Administration
FSP	Freeway Service Patrol
GTRI	Georgia Tech Research Institute
HA	Highways Agency
HAR	Highway Advisory Radio
HIOCC	High Occupancy Algorithm
HWA	Helsinki Western Artery
INFORMS	Institute for Operations Research and Management Sciences
INFOTEN	Multimodal Information and Traffic Management Systems on Trans-European Networks
ISDN	Integrated Services Digital Network
ITA	Illinois Tollway Authority
ITS	Intelligent Transportation System
LCS	Lane Control Signal
LED	Light Emitting Diode
MEPC	Metropolitan Expressway Public Corporation
MTJWS	Mobile Traffic Jam Warning System
MTO	Ministry of Transportation Ontario
MUTCD	Manual on Uniform Traffic Control Devices
NCTCOG	North Central Texas Council of Governments
NEWS	Node Event Warning System
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PMC	Project Monitoring Committee
PTMS	Portable Traffic Management System

LIST OF ABBREVIATIONS (continued)

QEW	Queen Elizabeth Way
QWS	Queue Warning System
RTMS	Remote Traffic Microwave Sensor
SAIC	Science Applications International Corporation
SH	State Highway
SHRP	Strategic Highway Research Program
SWS	Safety Warning System
TGDH	Turkish General Directorate of Highways
THP	Tennessee Highway Patrol
TIPS	Traffic Information and Prediction System
TMC	Traffic Management Center
TMT	Traffic Management Team
TRB	Transportation Research Board
TRL	Transport Research Laboratory
TROPIC	Traffic Optimization by the Integration of Information and Control
TTC	Time-to-Collision
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
VTS	Variable Traffic Sign

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 collisions. Operational concerns relate to the reliability and predictability of the freeway network. The primary type of multi-vehicle collision on a freeway facility has been determined to be the rear-end collision, comprising over 50% of freeway collisions 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 signs is difficult to keep current with ever-changing field conditions and rapidly fluctuating queues in congestion. Stopped traffic on the freeway may be due to a multitude of causes. This research will address issues relating to slow/stopped traffic for three major causes:

- Congestion related to recurrent traffic conditions
- Congestion related to work zones
- Congestion related to incidents

Warning drivers in advance of stopped freeway conditions requires detection and a means of alerting the driver. Vehicle type and the freeway geometric design further complicate providing queue warnings. Trucks have longer stopping distance requirements, although their sight distance may be longer than for passenger vehicles due to elevated driver height. All vehicles can be impacted by sight distance constraints to the tail end of a queue such as horizontal and vertical curves or obstructions such as bridge overpasses. Trucks can obstruct sight distance for passenger vehicles. Rural conditions and expectations differ from urban conditions. Queue reduction techniques will also be addressed in this project, since shorter queues can have the benefit of keeping the queue within the realm of typical traffic control and information devices.

1.2 THREE MAJOR CAUSES OF SLOW/STOPPED TRAFFIC

A. Congestion Related to Recurrent Traffic Conditions

A recent study in the Dallas/Fort Worth (DFW) area by the North Central Texas Council of Governments (NCTCOG) assessed the location and pattern of recurrent weekday peak period congestion.[3] This type of congestion is encountered and expected by commuters familiar with travel on their given routes, although queuing can vary considerably. This variation creates confusion even though the congestion is generally expected. Because of the speed at which queues can propagate under high-volume peak period conditions, even familiar drivers may have difficulty and frustration associated with encountering stopped traffic, and higher collision rates are often noted in these areas. Unfamiliar drivers may not expect queued conditions, which can exist across all or a few of the freeway lanes. NCTCOG's tally of recurrent congestion locations for the DFW area reveals some 50 locations of this type on interstate freeway routes in the AM peak, and 40 locations during the PM peak (Figures 1-1 and 1-2, respectively).

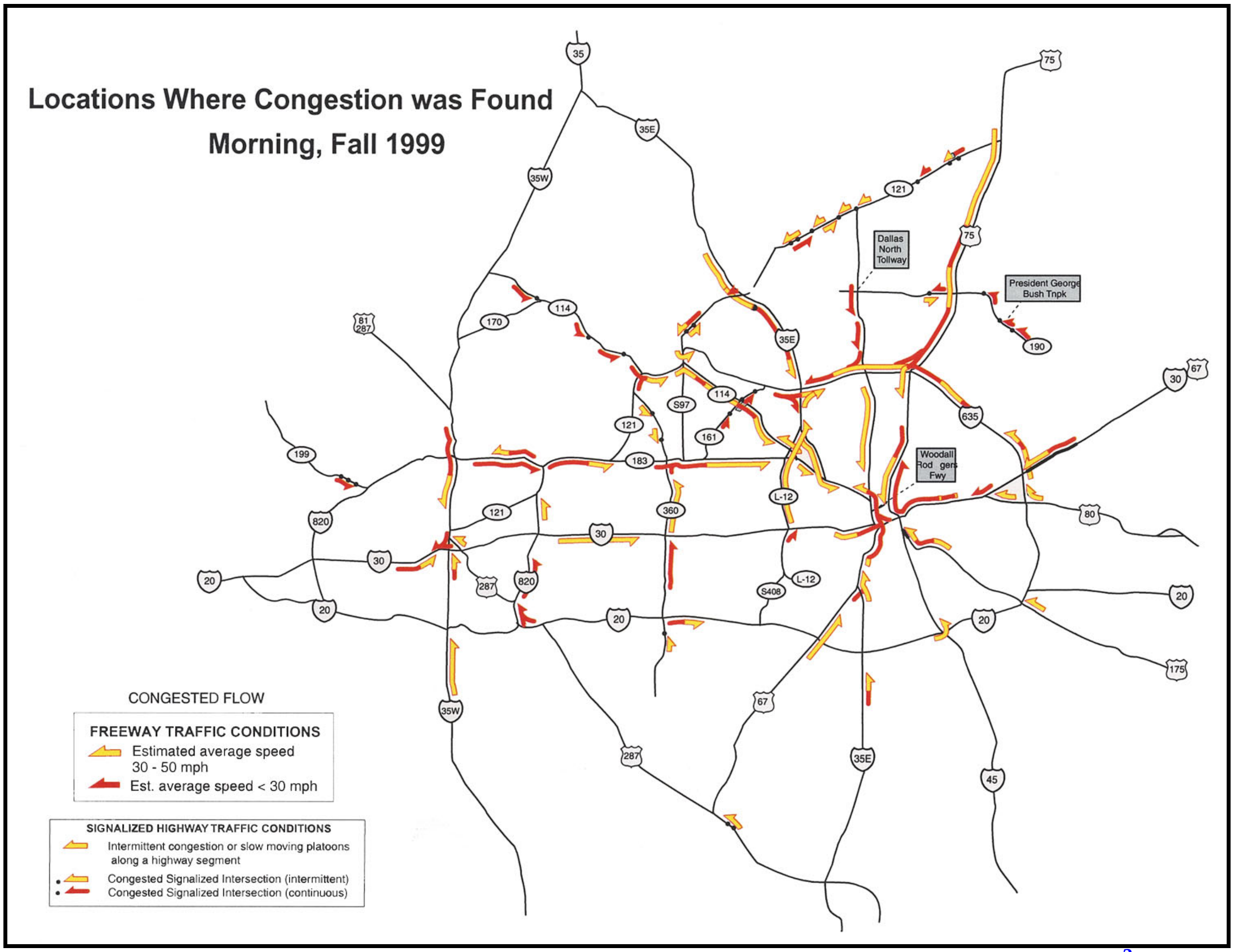

Figure 1-1. NCTCOG Congestion Survey of Dallas/Fort Worth for AM Peak.[3]

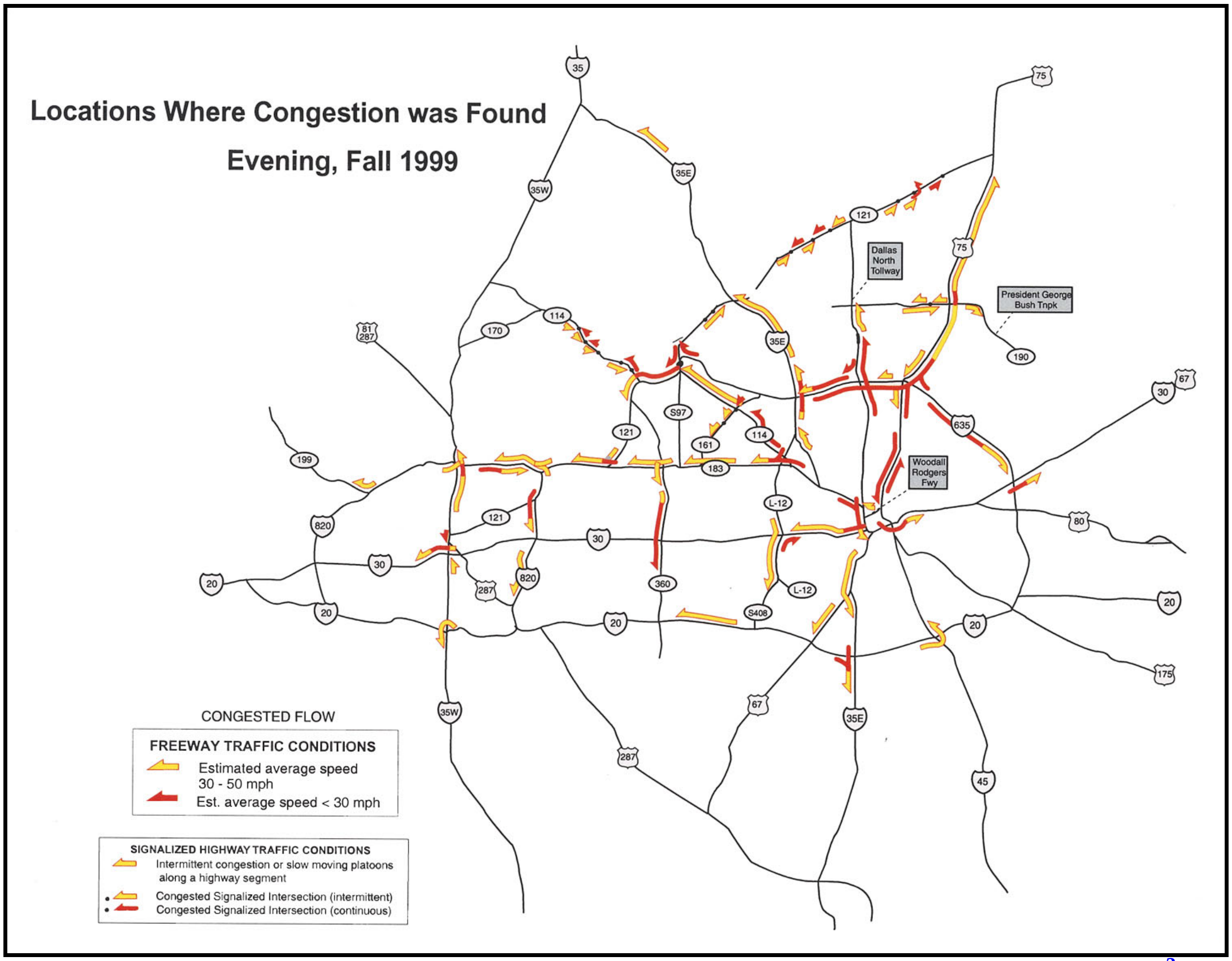

Figure 1-2. NCTCOG Congestion Survey of Dallas/Fort Worth for PM Peak.[3]

B. Congestion Related to Work Zones

Construction and maintenance work zones have the advantage of having signing set up to alert drivers to changing geometric conditions and speed limits due to the work zone, but again, rapid queue fluctuation outstrips the ability of static signing to provide the needed information. Enhancements and additions to work zone signing informing drivers of real-time conditions must consider driver workload in processing the information, and the speed and accuracy by which this information is provided. Several vendors have produced products that purport to address these needs. In construction and maintenance work zones the rapid buildup of freeway queues can occur such that the placement or use of work zone signing may not correlate with drivers' needs for advance warning. Data collected during research conducted in Iowa in rural work zones indicate that it is not uncommon for the tail end of the queue to grow at a rate of 30 mph, resulting in 65 mph approach traffic encountering conditions equivalent to a 95 mph driving speed in terms of the rate of closure upon the stopped traffic queue.[4] Static signs in a work zone typically inform drivers of the location and nature of a work zone, but not the real-time issues relating to congestion that drivers may need to know for safety reasons.

C. Congestion Related to Incidents

Collisions may pose the most difficult challenge for estimating resultant queues, since the location is unpredictable and the conditions vary considerably. Traditional intelligent transportation system (ITS) elements, if available and deployed where a problem occurs, can assist with queue detection and provide general information about the location and nature of the blockage, but drivers rarely are given specific real-time information as to queue status. Thus there remains much to do relating to assessment of queue status in real-time and in providing real-time queue alerts to drivers with enough advance warning such that they can take appropriate action.

The 10-year plan for English motorways (freeways) includes the intent to install automatic traffic hold-up (queue) warning systems on 30% of all English motorways by 2004, in order to reduce accidents at the back of traffic queues on the most congested lengths.[5]

1.3 DETECTION OF SLOW/STOPPED TRAFFIC

One common method of queue detection is the traditional in-pavement loop detector. As vehicles on the roadway pass over the magnetic loop, parameters such as occupancy, length, and speed are measured. These parameters, particularly the occupancy, can be used in conjunction with detection algorithms to identify the location of stopped or queued traffic. A paper written by G. F. Newell documents the use of loop technology for detecting exit ramp queues extending onto the freeway main lanes.[6] The Virginia DOT has used a similar approach to detect truck queues, at an interstate highway weigh station, extending onto the main lanes.[7]

Another method of detection uses infrared detectors to determine the presence of queued traffic. The Pennsylvania DOT has employed the infrared detectors at work zones along US 22.[8] The detectors project an infrared beam across the roadway and measure the time it takes vehicles to cross through the beam. If this measurement exceeds a preset limit, it indicates that traffic has slowed or stopped.

A paper entitled *Road Safety Through Video Detection* by J. Versavel, presented at the 1999 annual meeting of the Institute of Transportation Engineers, relates experience in Belgium using video detection systems to determine the accuracy and reliability of detection of a freeway queue tail.[9] Versavel conducted pilot studies to determine if several flow monitoring methods and models compared with visual analysis of video images. Versavel tested a system that consisted of a series of video detection systems and dynamic message panels mounted on trailers and poles along the road. Communications occurred via cable or wireless connections to the detector controller. Queues were detected by alarms from each of the detectors in series.

Other detection strategies exist, including Doppler and wave radar. In some cases, detection may not be needed if conditions are so regular that transportation authorities can give pre-timed warnings based on time of day. Finally, user-activated warnings can be implemented, which require the system operator to activate a switch.

1.4 WARNING OF SLOW/STOPPED TRAFFIC

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

- Static Signing – traditional signs placed along the roadside at locations where queues are typically present.

- Variable Message Sign (VMS) – text or symbol messages on electronic signs relating the presence of congestion or blockages ahead.

- Lane Control Signals (LCSs) – overhead signals used to warn motorists of the status of all 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.

In subsequent sections of this report, each of these types of warnings will be addressed with the exception of in-vehicle devices.

1.5 ASSISTANCE AND INVOLVEMENT BY TXDOT AND PROJECT MONITORING COMMITTEE

TxDOT assistance from the project director or PMC has been vital at key junctures in the research to provide project guidance, to review preliminary research findings, to assist with field data test site selection, to coordinate with the DalTrans TMC for coordinated data collection activities, for assistance in implementing field tests on TxDOT freeways, and for routine communications about research status.

1.6 REPORT ORGANIZATION

The focus of this two-year project is to identify current practices and develop innovative techniques to provide advance warning of stopped traffic on freeways, thereby increasing safety and mobility. This report summarizes the first-year activities of the research team as follows:

- Conduct literature review.
- Identify current practices for advance warning for stopped traffic.
- Perform observational studies at field locations with stopped traffic.
- Determine the applicability of advance warning techniques to TxDOT.

The remainder of the report is organized as follows:

- Chapter 2 summarizes the literature review and current practices.

- Chapter 3 details the purpose, methodology, and findings of the observational field studies of queues on three Dallas-area freeway sites.
- Chapter 4 presents the applicability to TxDOT of each of the identified queue warning techniques and systems.
- Chapter 5 highlights the major findings and recommendations based on the first-year project tasks.
- Chapter 6 provides a brief discussion of future project activities.
- The Appendix contains graphs developed from the data collected during the Task 3 observational field studies.

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CHAPTER 2. LITERATURE REVIEW AND CURRENT PRACTICE

This chapter summarizes the results of Tasks 1 and 2 as follows:

- Task 1 – the research team performed a literature review on issues related to detecting and warning drivers of slow/stopped traffic ahead on freeways. This review is summarized in Section 2.1.
- Task 2 – the research team identified current practices in use by international agencies and state Departments of Transportation (DOTs) for detection and advance warning of slow/stopped traffic ahead on freeways. These practices are summarized in Section 2.2.

2.1 TASK 1: LITERATURE REVIEW

This section documents the results of the literature review and current practice for techniques to detect slow/stopped traffic and queue formation; methods to alert drivers of slow/stopped traffic ahead; queue reduction techniques and products manufactured for this purpose; and information procured from vendors on recent innovations in field equipment.

A. Federal Studies

Federal transportation agencies have performed several significant studies related to the scope of this research project. The following subsections will provide brief summaries of these studies:

1) NTSB Studies on Rear-End Collisions and Collision Warning Systems

In 2001 National Transportation Safety Board (NTSB) officials published a special investigation report entitled *Vehicle- and Infrastructure-Based Technology for the Prevention of Rear-End Collisions*.[1] Some of the highlights of this document are provided in the following list:

a) In 1999 more than 6 million collisions occurred on U.S. highways, killing over 41,000 people and injuring nearly 3.4 million others. Rear-end collisions accounted for almost one-third of these collisions (1.848 million) and 11.8% of multi-vehicle fatal collisions (1923). Commercial vehicles were involved in 40% of these fatal rear-end collisions (770), even though commercial vehicles only comprised 3% of vehicles and 7% of miles traveled on the nation's highways.
b) Between 1992 and 1998, the percentage of rear-end collisions involving all vehicles increased by 19%. Of those collisions, 94% occurred on straight roads and 70% occurred in daylight conditions. Driver inattention was a major causal factor in about 91% of the collisions.[2]
c) In 1999, 114 fatal collisions in work zones involved rear-end collisions, about 30% of the multi-vehicle fatal work zone collisions. Of these, 71 collisions (62%) involved commercial vehicles.

d) In 1999 and 2000, the NTSB investigated nine rear-end collisions in which 20 people died and 181 were injured (three collisions involved buses and one collision involved 24 vehicles):

- Common to all nine collisions was the rear following vehicle's degraded perception of traffic conditions ahead.[3]
- Some of these collisions occurred because ambient conditions, such as sun glare, fog, or smoke, interfered with the driver's ability to detect slow or stopped traffic ahead.
- In the other collisions, the driver did not notice that traffic had come to a halt due to congestion at work zones or as a result of another collision.
- No mechanical defects were found in the striking vehicles that would have contributed to the collision.
- In each case, the driver of the striking vehicle tested negative for alcohol or drugs.

The NTSB report cited a 1992 study by Daimler-Benz that determined that if passenger car drivers had 0.5 second additional warning time, about 60% of rear-end collisions could be prevented.[4] The Daimler-Benz study also estimated that an extra second of warning time for drivers would prevent about 90% of rear-end collisions. The NTSB study provides information on infrastructure-based systems that are designed to detect stopped or slowed traffic information, such as the location or the speed of the traffic queue, to drivers upstream of the end of the queue. These systems can be stationary, for instance at locations that experience frequent traffic congestion, or portable, such as in work zones. After reviewing the infrastructure-based systems, the NTSB concluded the following[5]:

e) Use of ITS to detect the queue ends and to warn traffic of queues is an efficient means of alleviating the accident risk due to slow/stopped traffic.

f) The number of collisions that continue to occur at construction work zones suggests that efforts to inform drivers of congestion at these work zone sites have not been adequate.

g) One of the most significant difficulties with queue length detection systems is that the end of the queue can vary by location or by time of day. Where to place the sensors so that upstream queues do not exceed the detection range but the message warning is not so far back that it loses relevance is difficult to determine. Many agencies have relied on the expertise and experience of field personnel who know how far back traffic typically queues along a given section of roadway. Tools do exist to predict queue length; however, according to the Work Zone Safety Information Clearinghouse, accurately predicting queue lengths with any degree of certainty prior to the formation of congestion is difficult because driver behavior can change dramatically in response to congestion. Therefore, the best solution might be multiple VMSs spaced upstream of the traffic and activated when the queue approaches that location.

h) A transportation research agency needs to develop a methodology so that states can conduct a risk analysis for queues created by work zones.

i) Guidelines and a procedure for the use of queue warning systems at work zones need to be developed and incorporated into the *Manual on Uniform Traffic Control Devices* (MUTCD).

2) Variable Speed Limit Study

Researchers at the Science Applications International Corporation (SAIC) consulting firm prepared a synthesis of variable speed limit (VSL) applications in the United States and foreign countries.[6] The use of VSL is another method of warning drivers of traffic conditions ahead. VSL utilizes traffic speed and volume detection, weather information, and road surface condition technology to determine appropriate speeds at which drivers should be traveling, given current roadway and traffic conditions. VSL systems have been deployed domestically in Arizona, Colorado, Michigan, Minnesota, Nevada, New Jersey, New Mexico, Oregon, and Washington State. Foreign countries with VSL implementations include Australia, Finland, France, Germany, the Netherlands, and the United Kingdom.

3) Coming to America: Innovative European Traffic Control Scanning Reports

In 1998, a scan team traveled to Europe, representing several different perspectives including the Federal Highway Administration (FHWA), three state DOTs (Utah, Virginia, and Wisconsin), a local agency (Montgomery County, Maryland), the Transportation Research Board (TRB) and the Texas Transportation Institute (TTI). During a two-week period, the scanning team met with officials in Gothenburg, Sweden; Frankfurt, Cologne, and Bonn, Germany; Paris, France; and London and Birmingham, England.[7,8,9]

The scan team observed freeway queue detection and protection systems in each country visited. Most countries installed sensors (primarily loop detectors) in freeway main lanes, and sometimes on shoulders, to detect queue formation and track the location of the back of the queue. The operating agencies used this queue information from detectors to provide drivers with advance notice of the presence of a queue with either an advisory speed, a regulatory speed limit, and/or congestion warning message (static or dynamic symbol and/or text). Some of these systems were fully automated from the initial detection of a queue presence through the display of information. Most systems are automated because a German system that used a human operator as part of the system found that the operator could not keep up with the continually changing conditions. In several of the countries, incident response vehicles with flashing lights and/or variable message signs on the shoulder at the end of the queue provided an additional measure for queue protection (Figure 2-1). These vehicles back up and track the back of the queue as it proceeds upstream so they can provide drivers with advance warning.

The benefits of queue protection systems in the four countries have been documented. The following list summarizes the documented benefits:

- Sweden – the scanning team learned that the traffic management system used in tunnels is the same as a system demonstrated in Amsterdam, where a study found a 23% decrease in overall accident rates, a 35% reduction in serious accidents, and a 46% reduction in secondary accidents at the back of the queue.
- Germany – an autobahn facility using queue protection and freeway lane control, accident rates decreased by 20%.
- England – a system reportedly paid for itself within a year based solely on accident reductions.

Figure 2-1. Pictures of Incident Response Vehicles in France and England.[7]

B. Other Studies

This section documents several other studies with findings relevant to the scope of this project.

1) Iowa State University Study

The Center for Transportation Research and Education (CTRE) at Iowa State University recently conducted a study of capacity of freeway work zone lane closures.[10,11] One unique aspect of the CTRE research was observing the rate at which the queue grew (more cars joining the end of the queue than leaving the front of the queue) and declined in length at a closure. They found that the queue grew (i.e., backward moving) and declined (i.e., forward shrinking) in surges.

In order to calculate the speed of queue propagation at the lane closure, the project team drove a vehicle on the opposite shoulder of the interstate highway in the direction of the traffic on the side with the closure. The team kept the vehicle even with the upstream end of the queue and recorded the milepost readings from ditch delineator posts. Using this method, the researchers determined that backward-moving queues grew at rates as high as 30 to 40 mph (Figure 2-2). These rates can create a large speed differential (100 mph) as a vehicle approaches the end of the queue at normal highway speeds (65 mph) with a backward-moving queue at 35 mph. This type of speed differential violates driver expectancy and can create unsafe conditions.[10]

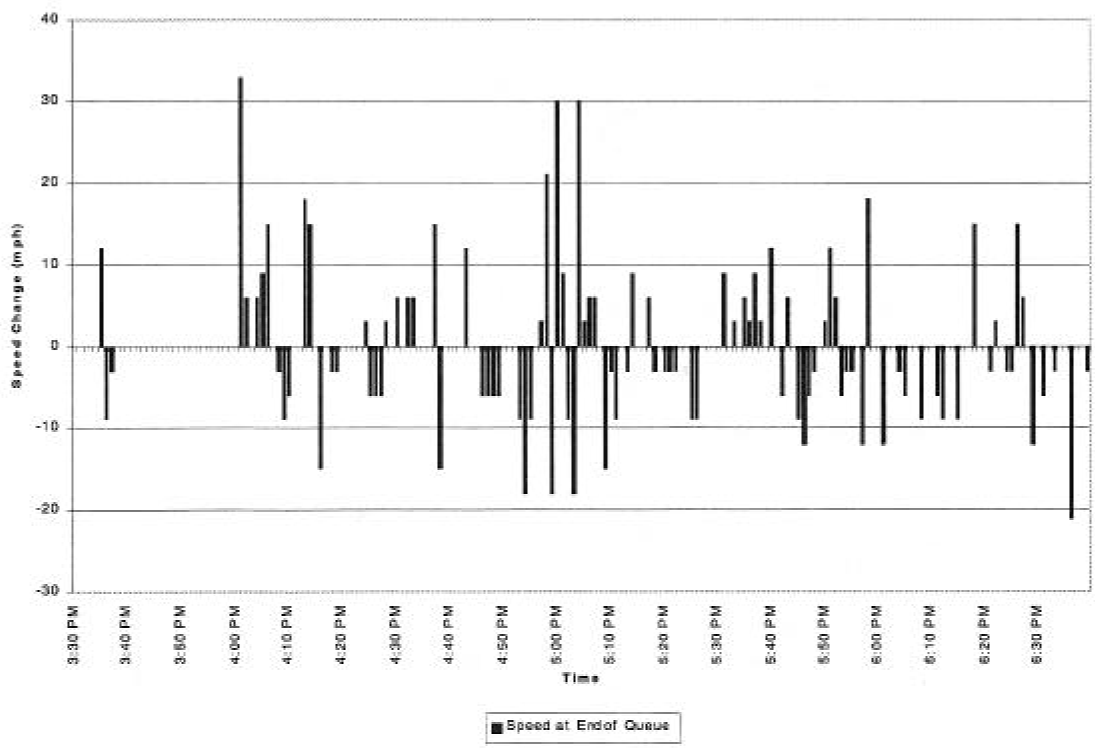

Figure 2-2. Iowa State Study on End of Queue Speed at Work Zone Lane Closure.[11]

2) Texas Transportation Institute Study

The Texas Transportation Institute performed Research Project 2137, A Review of Traffic Management and Enforcement Problems and Improvement Options at High-Volume, High-Speed Work Zones in Texas.[12] Researchers reviewed common safety issues at work zones on high-volume, high-speed facilities, as follows:

- High speeds upstream of and within the work zone area
- Severe braking and lane-changing prior to encountering and within a traffic queue
- Lane straddling by truckers
- Erratic exit maneuvers upstream of and within the queue created by the work zone

Researchers assessed traffic management and enforcement strategies for their feasibility in addressing these issues.

Nationwide, several accident studies have documented higher frequencies of rear-end and/or sideswipe accidents at work zones. TTI researchers have observed similar results at urban work zones in Texas. It is generally believed that much of these increases are the result of severe vehicle interactions at the upstream end of traffic queues. The observational studies conducted in Texas tended to verify these beliefs. Researchers observed between 1 and 16 hard braking maneuvers (a significant drop in the vehicle nose) per 1000 approaching vehicles at two test sites. The frequency also tended to be much higher in the off-peak periods versus peak periods. Researchers hypothesized that the slightly lower volumes during off-peak time periods created less severe (and "dense") traffic queues that in turn made it more difficult for motorists to recognize that they were approaching a section of roadway where slower speeds were required.

3) University of Alabama Study

A research team at the University of Alabama performed a project to investigate the current status of work zone safety in Alabama and other states and to recommend possible safety-enhancement measures.[13] Researchers analyzed a database of collision report information to identify characteristics of collisions that occurred in Alabama, Michigan, and Tennessee and then compared characteristics of work zone collisions to non-work zone collisions. The research team determined that the 'typical' work zone collision involved the following characteristics:

- Male driver age 25 to 34
- Clear weather during mid-afternoon
- US highway or interstate
- Encounters slow or stopped traffic at a work zone
- Collides with another vehicle; or else in the process of avoiding such, collides with a barrier or equipment

According to the study, the characteristics used to describe the 'typical' collision did not occur in over 50% of work zone collisions. Rather, these collisions represented the 'most frequently found' characteristics. Another significant finding was that misjudging stopping distance and following too closely were the most frequent contributing factors cited by officers.

4) University of Northwestern Study

University of Northwestern researchers recently performed a study to identify methods for law enforcement agencies to enhance collision report forms for work zone-related collisions.[14] The research team developed a short, check-off supplemental report that officers could use in addition to the standard collision report form. Several police agencies agreed to assist with the research and use the supplemental forms. Some of the study findings related to the current research project are summarized as follows:

- The most frequent collision type for all the work zone locations was rear-end (56%). Within the work area, 64% of the collisions were rear-end; however, this type of collision occurred almost as frequently (63%) in the approach area. The research team concluded that sudden and unexpected slowing of vehicles where a queue formed as a result of merging traffic was probably the most likely contributing factor.

- Police officers checked stopping or sudden slowing as the driver action that contributed to a collision in 37% of all collisions (and even higher 44% of those collisions within the work area). The second most frequently checked factor was 'following too closely', occurring 24% of the time and occurred more frequently within the work zone.
- Cameras were located above the traffic on a bridge to observe driver behavior on the approach and within the study work zones. Occasionally the Northwestern research team observed drivers who rapidly approached the end of the queue despite the presence of advance warning signs indicating construction ahead, merging lanes, and/or slowing traffic. Researchers observed approximately 5% of drivers at the work zone sites exhibiting this type of behavior.

5) University of Waterloo Study

At the 2001 Institute for Operations Research and the Management Sciences (INFORMS), researchers from the University of Waterloo (Canada) made a presentation about a prototype queue tracking system.[15] The researchers developed the queue tracking system based on data showing greater than 20% of the freeway collisions in Canada were rear-end collisions, many of which occurred when high-speed traffic joined the back of a slow-moving queue. The Waterloo team used three methods for tracking the position of a queue tail on a freeway:

- Method 1 – used the INTEGRATION model to simulate queue position.
- Method 2 – used data from closely spaced (1640 ft / 500 m) loop detector stations on a section of the Gardiner Expressway in the Toronto area.
- Method 3 – used a video camera placed on a tall building pointed at the same 500 m (1640 ft) section of the Gardiner Expressway.

The researchers used roadway geometry features to determine a scale on the video image and to estimate the position of the queue every 20 seconds. The research is still ongoing, however, preliminary results showed that the INTEGRATION simulation model was able to closely replicate the true position of the queue based on field data. The most likely application of this research is to provide warning to drivers when queues form as a result of construction lane closures. This modeling approach will allow Canadian transportation agencies to design effective placement of detection and warning devices for a field queue warning system.

6) Freeway Accident Studies

Previous research findings have determined the primary type of multi-vehicle collision on a freeway facility to be the rear-end collision, comprising over 50% of freeway collisions, caused generally by normal speed traffic encountering stopped traffic on main lanes or ramps.[16,17]

A recent University of Michigan study examined rear-end collisions from the driver's perspective to identify self-reported reasons and causes of rear-end collisions, to identify commonalities in the self-reported causes and locations and circumstances of the collisions, and to explore the merit of using this approach to develop rear-end collision countermeasures.[18] Subjects were asked by researchers what could prevent their collision or rear-end collisions in general. Their prevention suggestions are listed by frequency of response as follows:

- Drivers should pay more attention
- Having more time to avoid the collision
- Drivers should leave more room between cars
- Better design of roads
- Device to let you know if the car ahead is slowing down or not moving
- Move big vehicles to a separate lane
- Better laws and enforcement
- Device that would not let you move if car immediately ahead was not moving
- Reduce the number of cars on the road

Another study performed by the National Highway Traffic Safety Administration (NHTSA) determined that in 29% of two-vehicle fatal collisions involving a large truck and another vehicle, both vehicles were impacted in the front.[19] The truck was struck in the rear more than twice as often as the other vehicle (18% and 7% respectively).

7) Manual on Uniform Traffic Control Devices

Guidance from the Millennium Edition of the *Manual on Uniform Traffic Control Devices* [20] indicates that the **BE PREPARED TO STOP** (W20-7b – Figure 2-3) sign "may be used to warn of stopped traffic caused by traffic control signals or in areas that regularly experience traffic congestion." As an option, the MUTCD states flashing beacons may supplement the sign. The MUTCD further states that "if the sign is interconnected with a queue detection system, the W20-7b sign should be supplemented with a **WHEN FLASHING** plaque." Figure 2-4 shows the **SLOW TRAFFIC AHEAD** sign that also has some application for queue warning.

2.2 TASK 2: QUEUE WARNING PRACTICES AND TECHNIQUES

This section documents the current queue warning practices and techniques being used by international agencies, state DOTs, and TxDOT.

A. International Queue Warning Practices and Techniques

This section documents information on international queue warning practices and techniques in 14 countries that researchers gathered from published documents, Internet searches, and direct correspondence (electronic mail, fax, etc.).

1) Australia/New Zealand

Transportation authorities in both Australia and New Zealand are starting to deal with the issue of rear-end-of-queue collisions. In Auckland, New Zealand, recent safety studies have shown that rear-end collisions are over-represented in the collision statistics for Auckland motorways, with four collisions in every 10 of this type.[21] In the period 1996 to 2000, 75% of the collisions were rear-end-of-queue collisions; rear-end collisions with a slower vehicle were the next most common type. Analysis of driver age and gender revealed that males aged 25 to 29 years were over-represented while the corresponding peak female age group was 20 to 24 years of age.

Figure 2-3. Be Prepared to Stop Sign (W20-7b) – 2000 MUTCD Edition.[20]

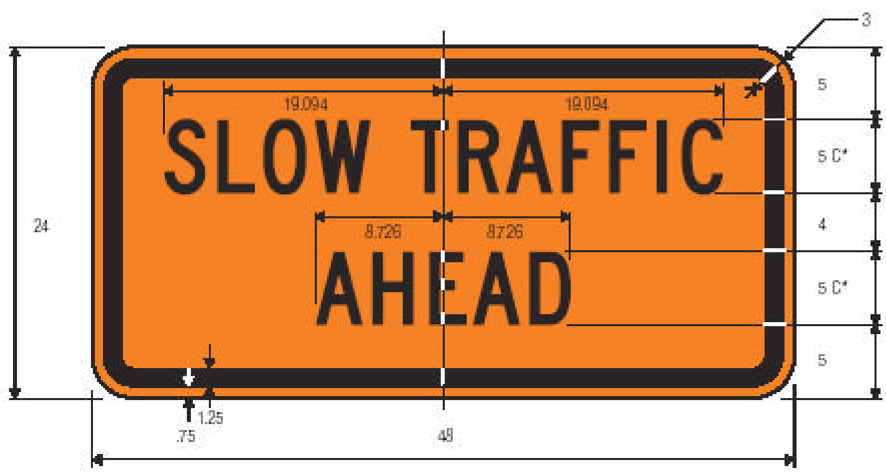

Figure 2-4. Slow Traffic Ahead Sign (W23-1) – 2000 MUTCD Edition.[20]

Following too close was identified as the single most common contributing factor. Other common factors included failure to notice slowing traffic (inattention) and driving too fast for conditions. The following are other significant statistics regarding the rear-end collisions on motorways:

- 72% on weekdays
- 33% during the afternoon peak travel period (4pm and 7pm)
- 31% on wet pavement
- 7% alcohol-involvement
- 13% involved speed as a factor

Some of the countermeasures to remedy the rear-end collision problems on Auckland motorways included:

- Continued support of educational campaigns targeted at safe following distance, safe lane changing, and use of appropriate speed for the prevailing traffic conditions
- Continued police enforcement for following distance, lane changing, and speed control
- Increased use of technology to warn motorists of unexpected queues and/or delays

In the Melbourne area of Australia a project is ongoing to add an electronic congestion warning system at the eastbound off ramp to the Hume Highway.[22] This system will be installed as part of a $12 million federal program of safety works on Melbourne's Western Ring Road. The electronic congestion warning system will consist of variable-speed signs (VSS) to assist in traffic management and additional signs to warn motorists of potential exit ramp spillback at the eastbound off ramp to the Hume Highway. Melbourne officials expect this project to be completed by June 2002.

In New Zealand, the W355 warning sign (Figure 2-5) is used to alert drivers to a possible hazard due to slow or stopped traffic on the roadway ahead caused by limited visibility due to roadway alignment or traffic density.[23] Furthermore, the explanation of the sign meaning from the Internet stated, "it may require that the driver significantly reduce speed or stop."

Figure 2-5. New Zealand Warning Sign for Slow or Stopped Traffic Ahead.[23]

2) Belgium

Traffic authorities in Belgium have been extremely active in the deployment of queue warning systems for recurrent congestion and work zone applications. The Flemish Government has installed queue warning systems (QWSs) on the ring roads around the cities of Antwerpen and Brussels.[24,25,26,27] Figure 2-6 provides a map of Europe that shows countries where QWSs were identified by the research team.

E313 Antwerpen to Hasselt: Traffic flow on the E313 freeway between Antwerpen and Hasselt, two large Belgian cities, is very heavy. Road works (i.e., construction) had been underway for some time with typical safety features such as road signs, radar control and police enforcement, and roadside speed-warning panels. These measures did not produce the desired lower collision rate, so the Flemish Government took the initiative to install a mobile queue detection and warning system along this stretch of roadway. The following list provides a brief synopsis of the goal, detection and warning methodology, and overall system execution for the mobile queue detection and warning system:

- Goal: to indicate the end of a queue by means of video detection systems (cameras) and information panels, mounted on trailers and poles along the road. These system components should reduce the frequency of collisions where cars or trucks run into the end of the queue.
- Detection and Warning: a monitoring camera, directed to the traffic on the E313 freeway, is used to detect the queue. This video detection camera measures the speed of traffic and the occupancy of each traffic lane. The occupancy is a number between 0% and 100% indicating how many seconds per minute a part of the traffic lane is being occupied. An occupancy of 0% indicates that there is no traffic at that detection station. The occupancy during normal flow is generally below 20%. When traffic is driving slowly, occupancy values are typically over 50%. When traffic is completely stopped, the occupancy is 100%. The E313 system thresholds for queue detection are, speed below 50 km/h (31 mph) in one or more lanes; and occupancy over 50%. When these thresholds are met, the video detector immediately passes an alarm on to the controller unit. The controller unit responds by activating the upstream VMS panels at 500 m (1640 ft) with the message **FILE 500 m** (translation: the word FILE means queue) and a second set of VMS panels at 1 km (0.62 mile) with the message **FILE 1000 m** (Figure 2-7). This design provides the road user warning 1 km (0.62 mile) before reaching the queue.
- Execution: this detection system is used in both directions on the E313 freeways from Antwerpen to Hasselt. Eighteen VMS panels were mounted on posts in the median every 500 m (1640 ft) in the direction of Hasselt and 12 panels mounted on median posts and 6 on portable trailers (Figure 2-8) in the direction of Antwerpen. Two of the trailers are equipped with the extra capability of allowing the police at Antwerpen to retrieve live images of the cameras. Two other trailers are equipped with a system that counts the cars and can classify them automatically into categories (motorcycle, car, and truck). The average speed of the traffic is also detected. This information is transmitted to a central computer at a monitoring facility in Antwerpen. When the construction project is complete, the panels can be removed and used elsewhere.

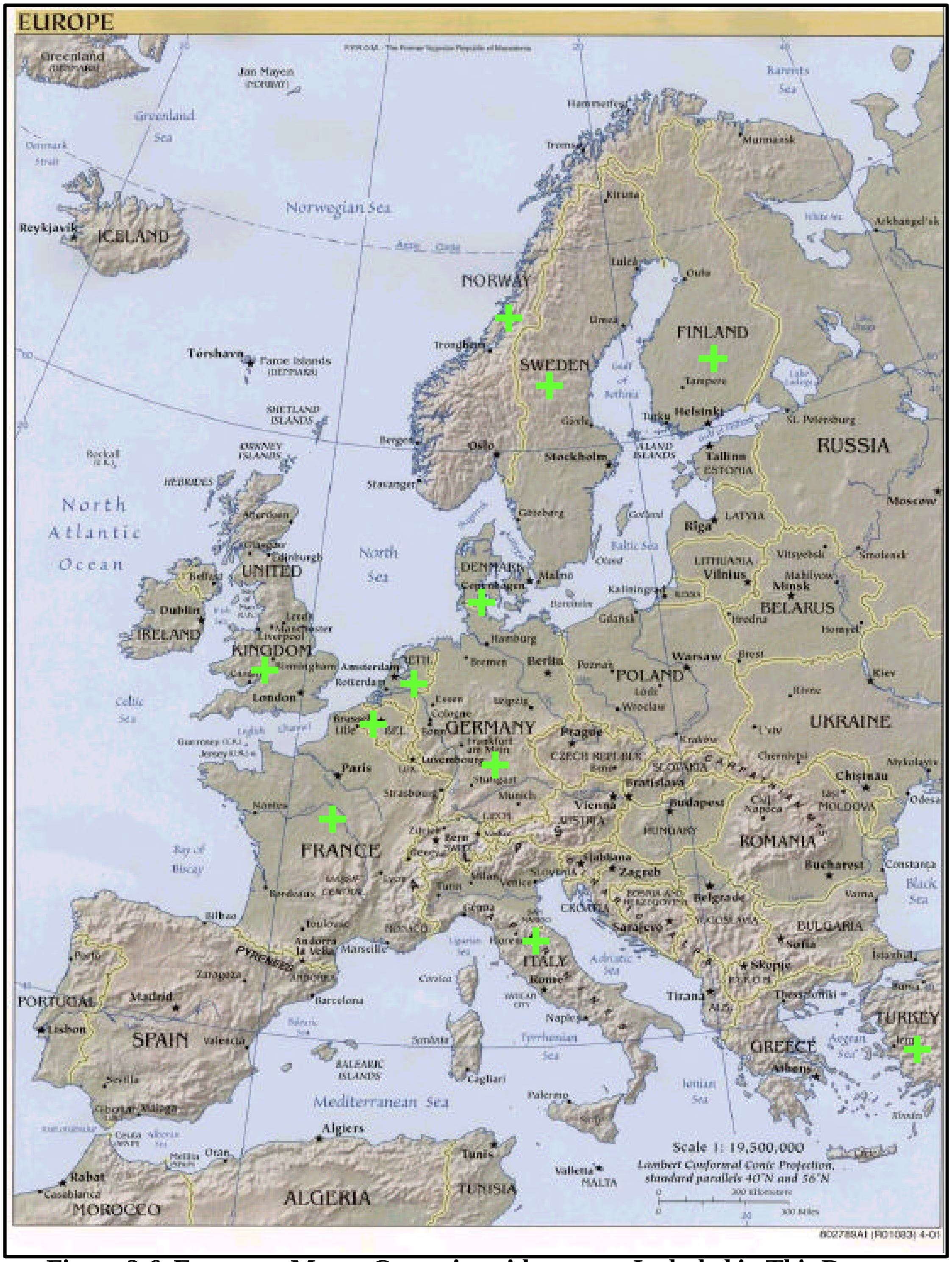

Figure 2-6. European Map – Countries with a + are Included in This Report.

(Base map courtesy of University of Texas library - http://www.lib.utexas.edu/maps/europe/europe_ref01.jpg)

Figure 2-7. Activated VMS Panels in the Queue Detection and Warning System.[27]

Figure 2-8. Trailer-Mounted VMS for Queue Detection and Warning.[27]

3) *Canada*

The Ministry of Transportation Ontario (MTO) has deployed several systems to detect and warn motorists of traffic conditions ahead. The COMPASS system in the Toronto metropolitan area utilizes large VMSs to advise travelers approaching adverse traffic conditions (Figure 2-9). The information displayed on the VMS about accidents and other slow downs allows drivers to make route decisions and may divert traffic away from problem areas on the roadway resulting in more efficient use of the roadway network.[28]

The MTO also has deployed a queue warning system that advises motorists traveling on the St. Catharine's Queen Elizabeth Way (QEW) of slow or stopped traffic. The St. Catharine's QEW is a major freeway connecting the Niagara peninsula to the greater Toronto area. It is a tourist and commercial route from Canada to New York State with an average annual daily traffic (AADT) of 75,000 vehicles that increases to approximately 100,000 vehicles in the summer months. The QWS was deployed based on a major two-year bridge rehabilitation project where the lane reductions required for construction were likely to cause major congestion and queue buildups. The primary objective of the QWS was to warn motorists so that they can approach slow traffic with anticipation and reduce their travel speed earlier, thus reducing rear-end collisions.

The operation of the QWS is relatively simple. When the differential speed between two microwave detection stations is high, upstream motorists are advised accordingly through dedicated elements. The system uses portable VMSs for the queue warning on the freeway mainline sections and arterial advisory signs (AAS) on a number of local roads that access the freeway. There are two types of AASs: (1) VMS panel; or (2) static sign with indicator beacons, which provide motorists an indication of traffic conditions on the QEW. Figure 2-10 shows one of the VMS panel AAS near an entrance ramp. A rendering of the AAS with indicator beacons is provided in Figure 2-11.

Figure 2-9. Large VMS Display in the Toronto Area.[28]

Figure 2-10. Arterial Advisory Sign with VMS Panel.[28]

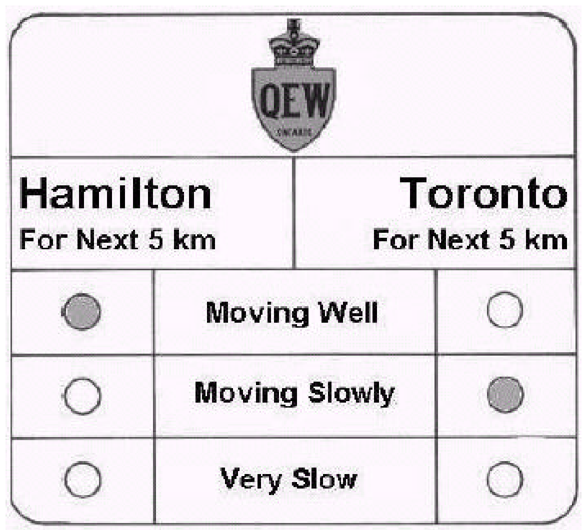

Figure 2-11. Arterial Advisory Sign with Indicator Beacons.[28]

Some typical messages are as follows[28]:

- <u>Off-Mainline AAS (changeable portion)</u>:
  SLOW FROM
  [queue end]
  TO [queue head]

  Sample:
  SLOW FROM
  MOUNTAIN RD
  TO GLENDALE

- <u>Mainline Portable VMS on adjoining freeways</u>:
  QEW SLOW
  TO
  GLENDALE

Phase 1	Phase 2
QEW	**SLOW**
NIAGARA	**TO**
BOUND	**LAKE ST.**

- <u>Mainline overhead CMS</u>:
  QEW SLOW
  BEYOND [queue end location]
  TO [queue head location]

  Sample:
  QEW SLOW
  BEYOND NIAGARA ST.
  TO GLENDALE

Border Queue Warning System: The MTO has deployed a system near a United States (US) border crossing designed to detect and warn motorists of queues on the approach highway.[29] The impetus for installation of the queue warning system was a situation where more vehicles than normal crossing from Canada to the US caused the queue to grow rapidly, spilling back onto the approach highway. This situation became catastrophic when the sudden arrival of heavy fog engulfed the end of the queue on the highway on the Canadian side of the border, in the province of Ontario, at a point where traffic is still typically moving very fast. Within minutes, there was a chain reaction of collisions as dozens of vehicles rammed into the back of the queue at high speed. As a result of the multiple collisions, a significant fire started and further contributed to the number of casualties.

To prevent a recurrence of this type of incident, the MTO installed a safety system called Node Event Warning System (NEWS).[30,31] This system measures traffic along the three-lane roadway approaching the border crossing using a remote traffic microwave sensor (RTMS). The RTMS station relays the detection data by spread-spectrum RF modems back to a controller unit located several kilometers away. When the end of the queue reaches the RTMS sensor station, the NEWS controller activates flashing lights on a warning sign with the message **PREPARE TO STOP WHEN FLASHING**. This sign is a typical yellow diamond warning sign with black text and a side-mounted flasher assembly. Two of these systems, spaced several kilometers (1.25 mile) apart, provide drivers warning of a queue extending back from the border crossing.

Reaction to Slow-Moving Vehicles Study: The Canadian Automobile Association (CAA) prepared a report with recommendations for improving safety on Highway 401 west of London in the Ontario province.[32] The CAA's safety recommendations were in response to the number and severity of tragedies on Highway 401. One of the problems identified by independent safety specialists commissioned by the CAA was reaction to slow-moving vehicles.

The study revealed that a number of the fatal collisions involved poor perception of slower-moving vehicles. A human factors expert, Dr. Allison Smiley of Human Factors North, Inc., described the typical poor perception process as:

> "*Drivers are usually aware that they are closing in on a slower vehicle; however, if there is a large speed differential [over 40 km/h (25 mph)] they often have a very poor perception of just how quickly they are closing in until they get very close to the slower vehicle. Often that can be too late, especially when the faster vehicle is a heavy vehicle that needs more room to brake. The slower vehicles risk getting rear-ended; the faster ones risk being cut off by turning or lane-changing drivers who think they have an adequate gap in traffic but do not*."

Smiley also noted that the wider the speed differential between the vehicles, the more likely there will be a misperception and the more likely that misperception will lead to a collision. The CAA recommended education on the importance of maintaining a steady, uniform speed and flow of traffic, and police enforcement as the countermeasures to combat this problem.

4) Denmark

The Road Directorate of Denmark currently has one queue warning system in operation on a motorway in the northern part of Jutland near the city of Aalborg.[33] The system sets VMS with speed limits based on speed measurements from detection devices. The system is activated whenever the speed of traffic is below 50 km/h (31 mph). Motorists see successive VMS with speed limits of 90, 70, and 50 km/h (56, 44, and 31 mph) before they meet the tail of the queue.

5) Finland

The Finnish National Road Administration (FINRA) installed a QWS on the Helsinki Western Artery (HWA) in the summer of 1996 for approximately 30 million dollars.[34] The weather and the road conditions change rapidly on the section of the HWA where the system was installed because it is adjacent to the Gulf of Finland coastline. FINRA engineers implemented the QWS to improve safety and to make traffic flow more efficient. FINRA installed the following system components on the HWA between Katajaharju and Haukilahti:

- 18 traffic detection stations (96 loop detectors) with associated measuring devices
- 14 VMS with associated control devices and 1 variable prismatic sign
- Control and monitoring workstations
- Traffic camera surveillance system (6 measuring and 3 control cameras)
- Communications network with associated terminal fittings (copper / fiber-optic cable)

FINRA conducted a study in 1998 to assess the effectiveness of the QWS on the efficiency and safety of the traffic flow on the HWA motorway.[35] The study team evaluated the effectiveness by comparing collisions and traffic flow characteristics before and after the installation of the QWS. In the evaluation, FINRA used data on vehicle speeds and traffic volumes measured by the loop detectors and also travel time and fuel consumption information that was collected using the floating car method. According to reports generated by the QWS, queue warnings were primarily displayed during the morning peak hour — therefore FINRA decided to restrict the evaluation to analysis of the morning peak hour traffic traveling into Helsinki. The study team post-processed the measurement data to evaluate how much of the changes were due to the congestion and the percentage due to warnings on the VMS.

During the morning peak hour, the loop system measured the maximum traffic volume toward Helsinki as 3200 vehicles per hour (vph). The data showed that traffic volumes on the right lane varied between 1200 and 1400 vph and on the left lane between 1400 and 1800 vph, respectively. FINRA personnel estimated the capacity of the right lane between 1400 to 1800 vph and between 1800 to 1950 vph on the left lane.

The FINRA study determined that based on the behavior of the vehicle platoons, a **60 km/h (37 mph) speed limit + queue warning symbol** displayed at the beginning of congestion reduced the vehicle speeds and also the standard deviation of speed. During sustained congestion, the standard deviation increased and the traffic flows became unstable. During a long period of congestion, the effect of a speed limit decreased and FINRA personnel observed significantly high single-vehicle speeds. During time periods where the 80 km/h (50 mph) speed limit was displayed, FINRA determined that the speed of the traffic stream was more homogenous. During congested morning rush hours, average vehicle speeds were 56.5 / 56.8 km/h (35.1 / 35.3 mph) (right lane / left lane) and standard deviations were 6.9 / 7.4 km/h (4.3 / 4.6). During normal control, these characteristics were 71.5 / 74.1 km/h (44.4 / 46.0 mph) and 5.0 / 5.2 km/h (3.1 / 3.2 mph). Before the Lapinlahti Bridge, a queue warning sign lowered the vehicle speeds by 3.9 km/h (2.4 mph) on the right lane and 5.5 km/h (3.4 mph) on the left lane.

The study team concluded that a statistically reliable evaluation on the QWS safety benefits could be concluded only after several years of data are available. FINRA plans to conduct a statistical accident analysis after the year 2003, when five years of accident data are available.

6) Germany/Italy

Companion Queue Warning System: The Multimodal Information and Traffic Management Systems on Trans-European Networks (INFOTEN) project (January 1996 to March 1999) introduced language-independent systems for traffic information exchange, multi-modal traveler information services, and advance driver warning in the Alpine area and in Central Europe. A major component of the INFOTEN project was the deployment of the COMPANION system in Germany and Italy.[36,37]

COMPANION is a roadside warning and information system that utilizes flashing lights to warn drivers of any kind of unexpected events ahead (i.e., current incidents — collisions, congestion, fog, etc.). The warning lights are integrated into beacon posts installed along the median or outside shoulder. Figure 2-12 provides a graphical depiction of the COMPANION system components. The COMPANION posts are interconnected by cable and controlled from a central control unit at a traffic management center. Variable flashing patterns and frequencies, brightness, colors, and warning lengths can be applied to specific conditions (e.g., light conditions, location of the incident, etc.). Figure 2-13 is a flowchart that describes the process the COMPANION warning system undergoes during the incident management and message handling and display phases.

In Italy, transportation officials installed the COMPANION system in the winter of 1997 on a stretch of motorway between Soave and Montebello close to Verona. The system is installed on 9 km (5.6 miles) in both directions so a total of 18 km (11.2 miles) is instrumented. This test site, known for a big fog-related collision during the winter of 1995 (11 fatalities, 49 injured, and more than 200 vehicles involved), is characterized by a very high traffic density of passenger cars and heavy vehicles and a frequent presence of fog in the winter season. Italian engineers placed COMPANION posts inside the median barrier with 50 m (164 ft) spacing between posts (Figure 2-14).

In Germany, the COMPANION system was installed near Munich on a section of Autobahn 92 from the Airport Munich II to the motorway crossing AK Neufahrn. Similar to the Italian installation, COMPANION was installed on 9 km (5.6 miles) in both directions for a total of 18 km (11.2 miles) equipped. Along this section COMPANION posts were installed on a 50 m (164 ft) spacing and connected to the motorway control center in Freimann. German officials placed COMPANION posts along the outside shoulder instead of the median (Figure 2-14).

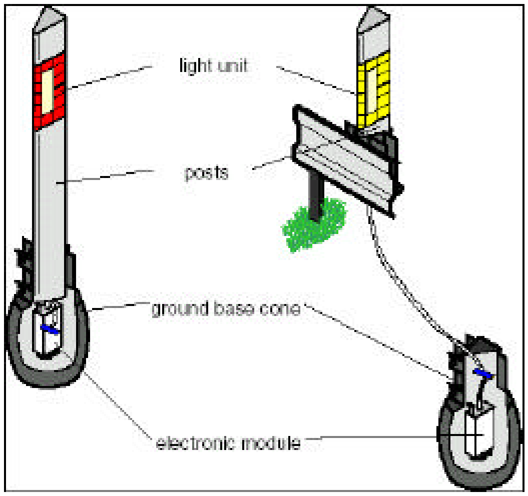

Figure 2-12. Graphical Depiction of COMPANION System Components.[36,37]

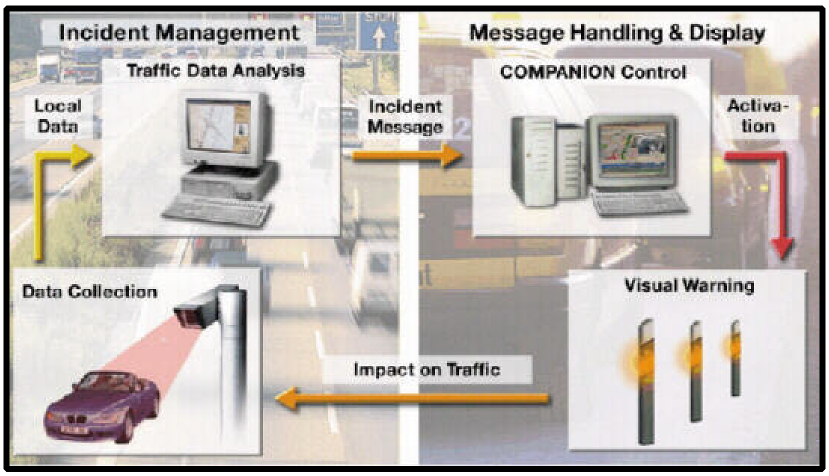

Figure 2-13. Flowchart of COMPANION System Detection and Warning Process.[36,37]

Italian median installation German outside shoulder installation

Figure 2-14. Pictures of COMPANION System Installations in Italy and Germany.[36, 37]

Mobile Traffic Jam Warning Systems: There are several other types of queue warning systems deployed on German autobahns. Two systems developed by GreenWay Systeme are installed on approaches to construction zones to advise motorists of traffic queues.[38] Another system is deployed to warn drivers of the truck and heavy-vehicle border queues on the approach to a border crossing to Poland.

The first construction-based system is located on Autobahn 3 in a construction zone near the Hosbach junction. The second construction-based system is installed on Autobahn 9 near the Greding junction. Both of these applications utilize a mobile traffic jam warning system (MTJWS). All system components (detectors and variable message signs) have an independent power supply by photovoltaic. Active infrared detectors positioned on the side of the road measure traffic queue data (Figure 2-15). The traffic condition information acquired by the system detectors is processed in the central module, converted to signal commands according to a predefined control matrix and then directed to the displaying modules. Finally, road users are dynamically informed about the current traffic conditions on the road ahead (e.g., length of the queue) by sets of VMSs positioned to the left and right of the road, respectively (Figure 2-16). A picture of the border queue warning system on Autobahn 12 is provided in Figure 2-17.

Other Queue Warning Techniques: Since there is no speed limit on most of the German autobahn facilities, the potential for catastrophic rear-end collisions at the back of a queue is enhanced compared to roadways with some form of speed control. One technique used in Germany is the use of red banners with the message **STAU** to warn motorists of stopped traffic ahead. These banners are carried on helicopters and aircraft and are also unfurled from bridge structures when an incident or other unexpected event is producing a significant queue.

Figure 2-15. Infrared Detection Station in Germany.[38]

Figure 2-16. Mobile Traffic Jam Warning System on Autobahn 9.[38]

Figure 2-17. Mobile Traffic Jam Warning Sign near the Germany/Poland Border.[38]

German officials have equipped several other roads with advance motorway control, including queue detection and warning systems. Autobahn 100 in Berlin is one of the busiest motorways. Almost 19 km (11.8 miles), the Autobahn 100 loops around the entire western section of downtown Berlin. The Siemens corporation has recently installed several components that provide motorists with advance warning of slow and/or stopped traffic ahead.[39] The detection portion of the Autobahn 100 system utilizes video cameras for queue detection. The queue warning components include small VMS with flashers (mounted both roadside and in the median — Figure 2-18), variable speed limit signs (flip-panel technology — Figure 2-19), and lane control signals (Figure 2-20).

Figure 2-18. Small Roadside VMS on Autobahn 100 in Germany.[39]

Figure 2-19. Variable Speed Limit Sign on Autobahn 100 in Germany.[39]

Figure 2-20. Bridge-mounted Lane Control Signals on Autobahn 100 in Germany.[39]

The Siemens corporation has also installed advanced technologies on the Autobahn 9 and Autobahn 92 motorways on the north side of Munich.[40] In addition to some of the components pictured in Figures 2-18, 2-19, and 2-20, the system near Munich also utilizes overhead gantries with VMSs to warn motorists of queues ahead (Figure 2-21). This system also detects queues using video-based technology.

Figure 2-21. Overhead Gantry with Multiple VMSs on Autobahn 92 near Munich.[40]

Figure 2-22 provides a graphical representation of a QWS with multiple queue warning signs and overhead detection (NOTE: translations – STAU = queue, triangle with exclamation point = danger, and Staugefahr = queue danger). Figure 2-23 shows this system deployed in the field with a variable prism panel sign with the congestion warning displayed and solar panel, and a variable prism panel sign with neutral display without the solar panel.

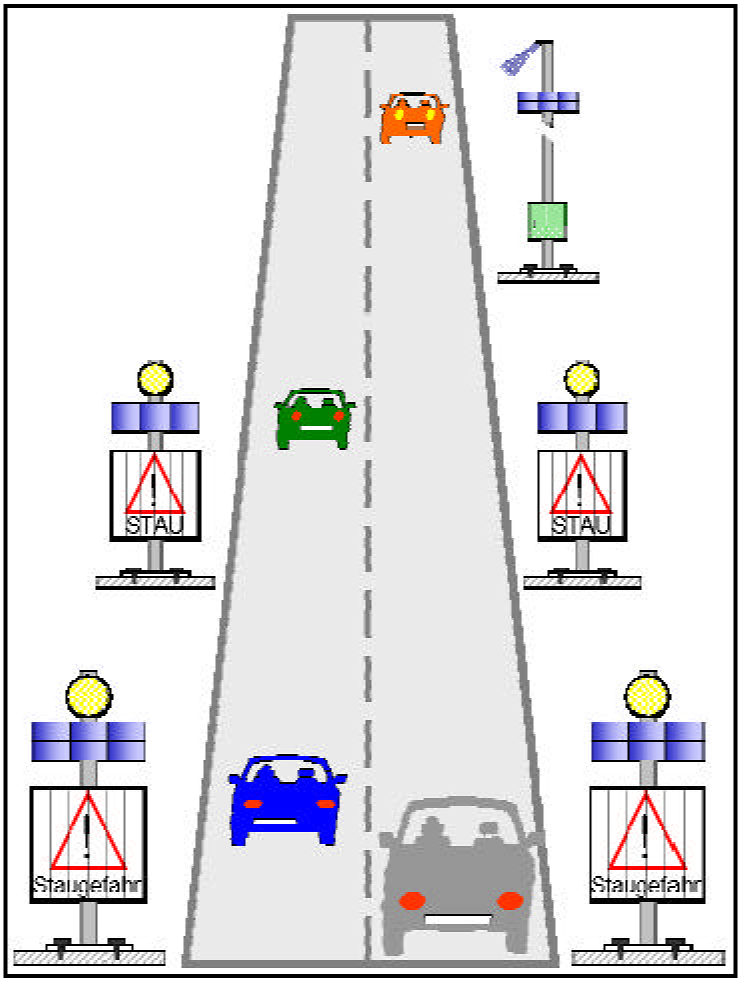

Figure 2-22. Graphical Depiction of Queue Warning System in Germany.[38]

Figure 2-23. Variable Prism Panel Signs Used for Queue Warning in Germany.[38]

7) Japan

The Metropolitan Expressway Public Corporation (MEPC) of Japan deployed a Congestion Tail Display (CTD) system in April of 1996. A paper by Kujirai and Matano introduces the CTD system and reports the results on accuracy of system's congestion tail (i.e., back of queue) data.[41]

Nearly half the total number of collisions on the Metropolitan Expressway, a high-volume roadway in the city of Tokyo with a number of blind curves, were rear-end collisions, most of which were attributable to congestion. Of these collisions, the number of injuries and fatalities resulting from rear-end collisions at the tail of congestion was more than twice that caused by all other types of collisions occurring on the expressway. The MEPC installed information display boards to inform drivers of the tail position of congestion ahead. The CTD system provides drivers with real-time information on the distance to the tail position of the congestion queue in units of 100 m (328 ft). MEPC personnel installed a total of 10 congestion tail information display boards by June 1998.

The CTD system performs the congestion analysis with data from ultrasonic vehicle detectors located in pairs at 300 m (984 ft) intervals (Figure 2-24). In the CTD system, traffic data are collected and provided at one-minute intervals. Thus, one-minute average speed and occupancy data are primarily used for congestion judgment. Previous investigations revealed that the propagation speed of the congestion tail on the Metropolitan Expressway was about 18 km/h / 300 m/min (11.2 mph / 984 ft/min). These data were used to determine CTD system settings.

The CTD determines the contents of information to be displayed based on whether a vehicle's encounter distance with the tail of congestion falls within a specified distance range. Figure 2-25 shows a conceptual diagram of how the CTD system calculates the encounter distance. If vehicles are within the specified encounter distance, congestion display boards are activated with messages that read **Congestion X m Ahead** and **Beware of rear-end collision** using both text and graphics. If the encounter distance is outside the distance range for display or no congestion exists, the CTD issues a command to enable a speed warning to drivers. In this case, the text **Speed Down** is displayed together with graphics.

Kujirai and Matano performed an evaluation of congestion tail information and average speed data used for congestion tail determination by comparatively verifying the data recorded in the CTD processor against the actual traffic conditions obtained through video. The evaluation revealed the correlation coefficients for the 10-second average speed data (0.90), the congestion tail point information (0.94), and the encounter distance information (0.84). Correlation is a relationship in which two variables increase or decrease together with a considerable amount of uniformity. Correlation coefficient is a measure that indicates the strength of the correlation between two variables. A correlation coefficient value equal to one indicates the highest level of correlation for the two variables. If the sample size is 100 or more and the correlation coefficient is 0.8 or more, this means the two variables have an extremely high significance. In the Kujirai and Matano study, all of the calculated correlation coefficients exceeded the 0.8 threshold indicating that the CTD system was very accurate. Kujirai and Matano also determined that the total number of rear-end collisions slightly decreased (3.6%) in 1996 after the CTD system was introduced.

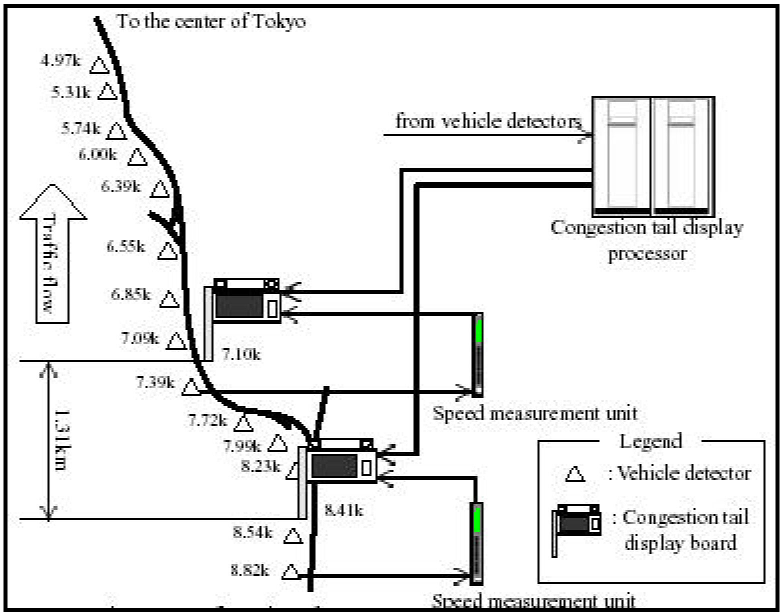

Figure 2-24. Configuration of CTD System and Its Terminal Arrangement.[41]

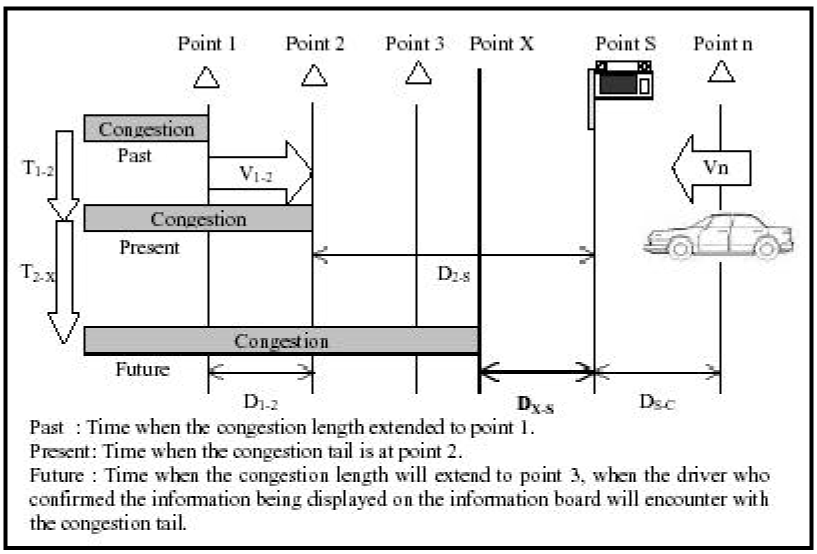

Figure 2-25. Conceptual Diagram of Encounter Distance Calculation.[41]

8) Netherlands

The Netherlands has been very active in evaluation studies of queue warning systems. A 1998 report by Hogema and Gobel describes a driving simulator experiment that researchers performed to evaluate the effect of VMS distance in an Automatic Incident Detection (AID) system on driving behavior.[42] AID is a traffic management system that provides maximum speed information to drivers with the goal of slowing traffic when approaching a traffic queue further downstream. In theory, AID should allow drivers to make an earlier and more gradual speed reduction when approaching the tail of a queue. Hogema and Gobel determined if the expected effects on driver behavior occurred and also evaluated how distance between VMSs affected drivers.

In a simulated motorway environment, participants of the experiment were randomly confronted with a stationary traffic queue. Test subjects completed several runs without, and several runs with the AID system. Hogema and Gobel varied the VMS distance (300, 700, and 1500 m) (984, 2297, and 4921 ft) and the prevailing traffic conditions. In runs with AID, subjects first passed a VMS displaying a 70 km/h (44 mph) speed limit followed by a VMS showing 50 km/h (31 mph) before reaching the tail of the queue.

The results showed that the AID system produced the intended changes in driving behavior when approaching stationary traffic queues. With AID, participants started reducing their speed farther from the tail of the traffic queue and also had smaller maximum deceleration profiles. Furthermore, Hogema and Gobel determined that the AID system results in an increase of the minimum time-to-collision (TTC) in the phase up to the final approach part of the maneuver.

When comparing how drivers approached the queue in the separate VMS distance conditions, the behavior found with 1500 m (4921 ft) VMS was somewhat less desirable than with 700 m (2297 ft) or 300 m (984 ft). When, as in this experiment, the AID only activates two signs upstream of the queue's tail, the 700 m (2297 ft) VMS distance is preferable over the 300 m (984 ft) VMS distance. Hogema and Gobel concluded that in order to benefit from an AID system with small (300 m / 984 ft) VMS spacing, more than two signs upstream of the queue should be activated.

TROPIC Queue Pictogram Study: The European DG-VII project TROPIC (Traffic Optimization by the Integration of Information and Control) is performing studies to increase the knowledge on VMS in order to expand the implementation and achieve consistent applications, especially on the Trans-European Road Network. One of the TROPIC studies involved comparison of pictograms (i.e., electronic pictures displayed on VMS) for warning motorists of an upcoming queue.[43]

9) Norway

The Public Roads Administration (PRA) in Oslo has established a system for automatic queue detection and warning.[44] The objective of the system is to avoid situations that can lead to collisions by decreasing vehicle speeds before reaching the traffic queue. The information about queues is given to drivers by VMS. The Oslo system utilizes video detectors for queue detection. When pre-set limits of speed and occupancy are exceeded, a queue warning is issued. The system is fully automated and no operator is necessary.

The SINTEF Civil and Environmental Engineering group performed an evaluation of the Oslo QWS and presented the results at the 8th ITS World Congress in Sydney, Australia.[45] SINTEF researchers divided the evaluation into two parts: (1) behavior of drivers when they are warned about queue situations; and (2) how well the system warns about queue situations.

The Oslo QWS utilizes eight cameras and video detectors on the E18 highway outbound from the central portion of the city. On this section of road, queues normally occur in the afternoon when people are going home from work. Two or more cameras and video detectors are used to detect queues for each of the four VMSs along this stretch. Each VMS has a camera placed directly adjacent to it and also one right after it. In Oslo a queue is detected when:

- The speed is below 30 km/h (19 mph).
- The zone occupancy is higher than 30%.
- The limit for speed and zone occupancy is exceeded for more than 15 seconds.

The PRA designed the system so that queue detection is cancelled when the speed of traffic is higher than 30 km/h (19 mph) or the zone occupancy is lower than 30% for more than 20 seconds. A queue warning is issued only when there is a queue present immediately after passing the VMS. In other words, there is no queue warning when the queue starts before or adjacent to the VMS. The driver is at that time already in queue and does not need to be warned about queues ahead. Also, if a queue is detected at one or more of the cameras that are placed after the VMS, and not at the camera adjacent to the VMS, a queue warning is displayed at the VMS.

Figure 2-26 provides an example of the typical queue warning VMS used in the Oslo QWS. The left panel of Figure 2-26 shows the sign with the queue warning and flashers activated. The right panel of Figure 2-26 shows the sign without any queue warning.

Figure 2-26. Oslo Queue Warning Signs.[44]

The SINTEF researchers studied speed and zone occupancy levels to see if the present queue detection levels were correct and determined that the number of registrations (i.e., queue detections) was the least when the zone occupancy was between 40 and 60%. This study also indicated that the road capacity was exceeded at a speed of about 30 km/h (19 mph) and zone occupancy of 50%. The speed queue detection level seems to be correct; however, SINTEF concluded that the zone occupancy level should be raised to 50%.

SINTEF researchers evaluated driver behavior under free flow traffic conditions. The research team manually turned off and on the queue warning sign to provoke changes in behavior from the drivers. Speed measurements, via radars placed 100 m (328 ft) and 50 m (164 ft) in front of the sign and 50 m (164 ft) after the sign, and registrations of vehicle brake lights were done to evaluate the effect of the warning on the driver. The research team also recorded this data using a video camera so the brake light registrations could be validated later back in the office.

As expected, the speed at the first radar did not change much when the queue warning was activated. The data showed that speed differentials were higher on radars two and three. SINTEF researchers concluded that the speed differentials of 2.9 and 5.2 km/h (1.8 and 3.2 mph) were both significant to a 90% confidence interval. Figure 2-27 shows the speed measurement data with and without the queue warning activated.

The brake registration data showed that in the periods with no queue warnings, only 1.5% of the drivers used their brakes. When a queue warning was active, 12.6% of drivers used their brakes. This difference is significant within a 90% confidence interval. The brake light registration data are provided in Figure 2-28.

The SINTEF evaluation concluded the following:

- Queue warnings have some positive effects on the speed and braking characteristics of drivers.
- The video detectors in the Oslo QWS detected queues fairly well; however, some short queue warning durations were the result of slow-moving heavy vehicles.

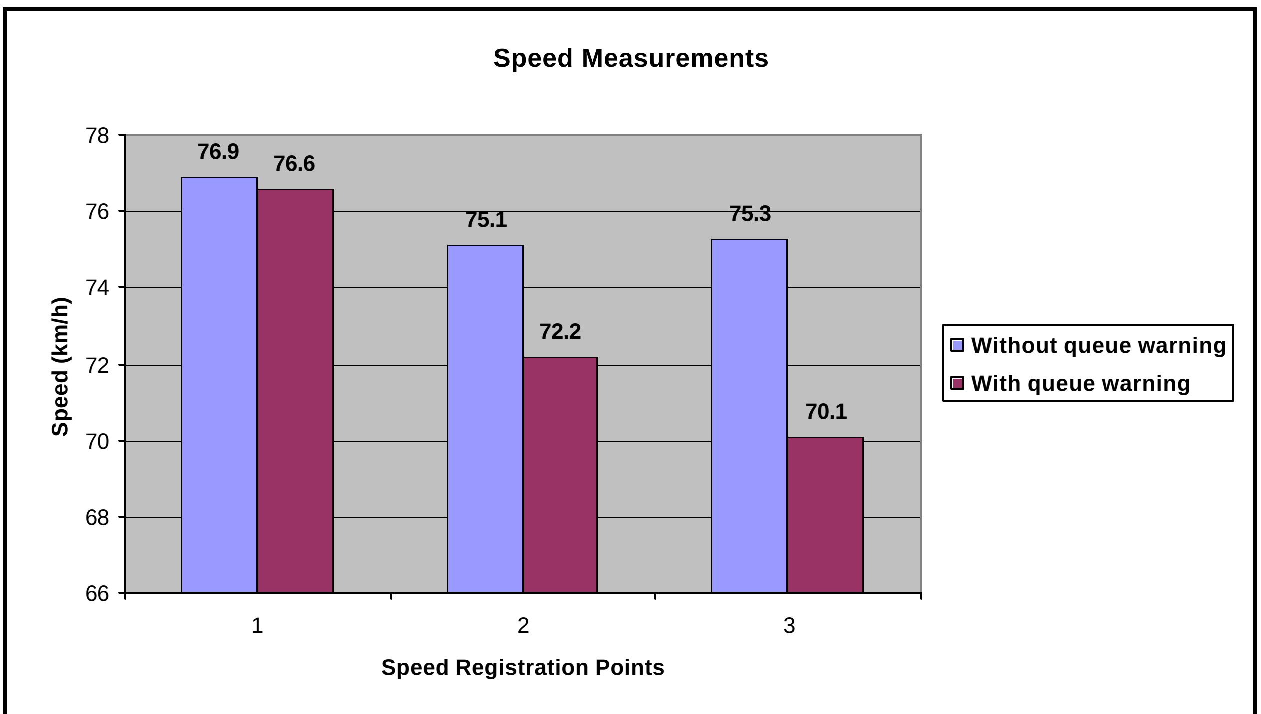

Figure 2-27. Oslo Speed Measurements with and without Queue Warning.[45]

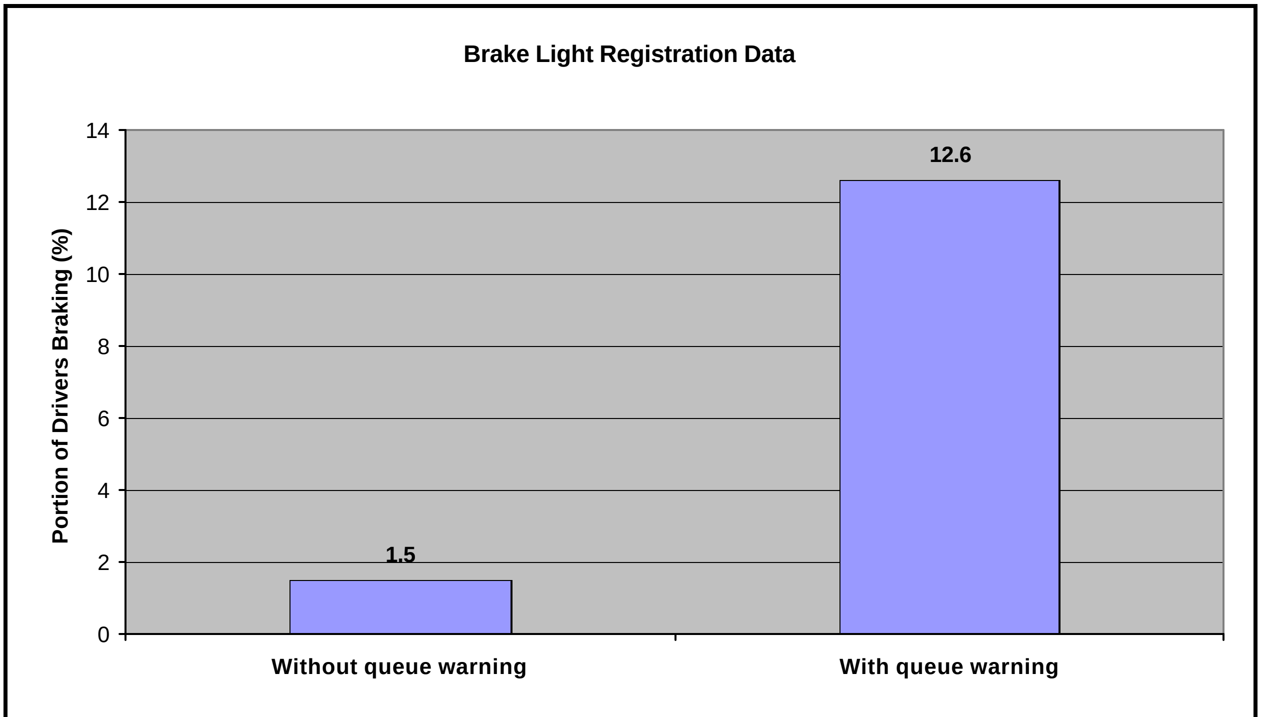

Figure 2-28. Oslo Brake Light Registrations with and without Queue Warning.[45]

10) Turkey

Over the last five years the Turkish General Directorate of Highways (TGDH) has implemented several intelligent transportation system projects.[46] Using products manufactured by engineers at the Ortana Corporation, TGDH personnel have deployed systems capable of providing advance warning of stopped traffic to drivers on motorways.[47] TGDH officials have installed three different Ortana products on Turkish motorways for this purpose:

a) Doppler Radar Speed Warning System – This system is used at the critical point of motorways (i.e., roads with high collision rates, high prevailing traffic speeds, etc.). The radar-based system measures the speed of passing vehicles and then informs drivers of their speed via light emitting diode (LED) displays. Some systems use flashers to warn drivers exceeding the speed limit. Figure 2-29 shows a picture of a Doppler Radar Speed Warning System on a Turkish motorway.
b) Variable Traffic Sign – This is a smaller version of a variable message sign. Variable Traffic Signs (VTSs) are similar to lane control signals that are deployed in the United States. On Turkish motorways these signs can display two types of messages:
    i. Lane use:
        - Red X (closed lane)
        - Green down arrow (open lane)
        - Diagonal down arrow (move right or left)
    ii. Warnings:
        - Speed limits: 40, 60, and 80 km/h (25, 37, and 50 mph) limits
        - Attention signage

Figure 2-30 provides an example of a typical VTS approaching a tunnel entrance.

c) Mobile Variable Message Sign – This system is trailer-mounted and is used to dynamically warn drivers about traffic conditions (road, weather, etc.). A mobile variable message sign with a queue warning (i.e., three cars inside a triangle) is shown in Figure 2-31. Figure 2-31 also shows a sign with speed limit and text messages.

Figure 2-29. Doppler Radar Speed Warning System on Turkish Motorway.[47]

Figure 2-30. Example of Variable Traffic Sign Display on Turkish Motorway.[47]

Figure 2-31. Mobile Variable Message Sign Trailers on Turkish Motorways.[47]

11) United Kingdom

English Systems: The Highways Agency (HA), the federal transportation agency in the United Kingdom, has an extensive program to improve safety by automatically protecting the back of queues following motorway incidents. Transport 2010, the 10-year plan of the HA, recommends that all congested parts of the motorway network in the United Kingdom will be equipped with Automatic Hold-up and Warning Systems (AHWSs) for back-of-queue protection.[48,49] At present AHWSs are operational on parts of the Motorway 25 (M25) and M60.

The HA systems for queue protection use cantilever VMSs upstream of very slow or stationary traffic to automatically give text messages (e.g., **Congestion - Caution** or **Queue Ahead**), pictograms, and/or advisory speed limits about congestion ahead. The primary goal of AHWS is to reduce secondary collisions, particularly high-speed collisions that produce fatalities, at the back of queues on motorways. Secondary goals include:

- Reduce traffic delays (fewer collisions occur and messages are automatically removed as soon as traffic flow is restored).
- Reduce driver stress, as information about problems ahead is provided.

AHWS utilizes loop detectors embedded in each lane at regular intervals to detect slow and/or stopped traffic.

Figure 2-32 gives an example of the overhead gantries that include both a VMS component capable of displaying text and pictogram messages and electronic advisory speed limit signs over each driving lane. In this case, reduced speed limits are displayed over the driving lanes and a queue warning (pictogram with three cars inside a red triangle) is displayed over the outside shoulder. Furthermore, drivers are told of the approximate location of the queue by providing a crossroad reference (e.g., after J15). The HA also has deployed advisory speed limit signs, called matrix signals, in the median area instead of on an overhead gantry.

Figure 2-32. VMS and Advisory Speed Limit Gantry in the United Kingdom.[8]

Evaluation of Benefits for the English Systems. The HA commissioned the Transport Research Laboratory (TRL) (**http://www.trl.co.uk/**) to study the possible benefits of AID systems.[50] An AID system on the M1 has been operational since 1989. The TRL study examined the benefits of AID in terms of changes in collision frequencies and injury severities, delays to drivers, and police resource requirements.

The AID system on the M1 stretches approximately 83 km (52 miles) from Bedfordshire to Northamptonshire. The AID system obtains real-time information about traffic conditions from buried inductive loops in each lane, with stations spaced every 500 m (1640 ft). The High Occupancy (HIOCC) algorithm processes the data from the loop stations and detects the presence of slow and/or stopped traffic. Queuing or slow-moving traffic is generally caused by an incident (spilled load, breakdown, collision, etc.) or flow breakdown due to demand exceeding capacity (i.e., recurrent congestion). An alert from the HIOCC algorithm initiates the setting of 50 km/h (31 mph) advisory speed limit matrix signs upstream of the tails of traffic queues. The matrix signs are spaced at 1 km (0.6 mile) intervals on this stretch of motorway.

The TRL evaluation of the M1 AID revealed that the system was effective at automatically setting the 50 km/h (31 mph) matrix warning signs upstream of the tail of a queue of slow-moving traffic. The TRL study documented several significant benefits attributable to the AID. In particular, TRL found that the total injury collisions were reduced by 18% when the AID system was operating and a variety of influencing variables were taken into account. Closer investigation revealed that single vehicle collisions were reduced by 29% and multiple-vehicle collisions by 20%. Additionally, the number of injury collision clusters (i.e., two collisions close together in time and space), which account for around 5% of all total injury collisions, was reduced by almost 50% during the period of AID operation. TRL researchers estimated that 24 fatal, 186 serious-injury, and 264 slight-injury collisions were prevented during this period. The TRL research team calculated collision savings of 85,000 pounds per km of motorway per year due to the combined reduction in collision frequencies and severities.

Furthermore, the TRL research team found savings in reduced driver delays to be around 5,000 pounds per km of motorway per year. These savings represented only 6% of the collision reduction benefits. Researchers identified an overall savings of 90,000 pounds per km of motorway per year. Finally, TRL gathered data from police control centers operating both with and without AID and it showed that the installation of an AID system does not reduce the resources required in the control center, or the number of police patrol vehicles.

Scottish System: In January 1998, Scottish transportation authorities deployed and tested a version of the COMPANION system previously documented on a 4 km (2.5 mile) stretch of southbound M90.[51,52] The site consists of 68 COMPANION posts located at 50 m (164 ft) spacing installed along the outside shoulder (Figure 2-33). The M90 is the main route from the north of Scotland to Edinburgh. It experiences recurrent congestion from the Forth River Bridge to Junction 2 and beyond. A sweeping bend to the south along this section also reduces the visibility for drivers.

Figure 2-33. COMPANION System in Scotland.[51]

In addition to the COMPANION infrastructure, this motorway section is equipped with a 5-line by 16-character VMS, located approximately 1 mile north of Junction 2. The site is fully covered by three closed circuit television (CCTV) cameras and has microwave detectors placed every 500 m (1640 ft) to gather vehicle speeds and estimate the prevailing traffic conditions. The COMPANION warning system is activated in two ways:

- Sudden drop activation: activation when vehicle speeds at two adjacent detectors are different by more than 30 mph (Note: vehicle speeds at the downstream detector must have speeds less than 45 mph).
- Gradual reduction activation: activation when speeds at a single detector fall under 20 mph.

The system also uses set criteria for deactivation:

- Sudden drop deactivation: deactivates when speeds have risen above 45 mph.
- Gradual reduction deactivation: deactivates when speeds have risen above 20 mph.
- Queue tracking deactivation: deactivation of downstream activation if the upstream activation speed is within 10 mph of the downstream speed.

Scottish System Costs and Benefits. The COMPANION system costs approximately 100,000 pounds per km to install, including the provision of communications infrastructure. A consulting firm analysis of COMPANION in Scotland and Europe indicated that vehicle speeds were reduced by 10 to 20% as a result of COMPANION activation.[51] In addition, COMPANION has been shown to have a positive influence on collision frequency at one site, reducing the rate from 0.10 to 0.06 injury collisions per million vehicle kilometers traveled. The consultant team recommended that to maximize the benefits of COMPANION, future sites should exhibit secondary collisions caused by a combination of recurrent incidents and poor visibility or geometry. Figure 2-34 provides a flowchart to make site selection for COMPANION installation.

Rural Hazard Warning System: The HA has also deployed vehicle-activated fiber-optic blank-out signs to warn motorists of potential hazards in rural areas. Vehicle-activated signs (sometimes referred to as secret signs) are roadside signs that only target selected drivers.[53] Detectors measure the speed of approaching vehicles. If this speed is in excess of a pre-set threshold, the sign illuminates a message. Therefore, only drivers traveling over a speed that is regarded as suitable for the conditions on that particular stretch of road activate the sign.

The main objective of vehicle-activated warning signs is to alert the targeted drivers to the hazard so that the drivers reduce their speed. The signs have the advantage of being blank (i.e., black background) when not activated, limiting their visual intrusion, which is important in rural areas. Figure 2-35 provides a picture of an activated sign with slow down text message and intersection ahead warning pictogram and also a picture of a blank sign.

Previous research has shown that these signs are effective in reducing both speeds and collisions.[54,55,56,57] Generally, mean speed reductions of about 3 to 6 mph can be expected following the installation of a vehicle-activated sign on the approaches to sharp curves, junctions, or a speed limit change, depending on vehicle flows and previous speeds.

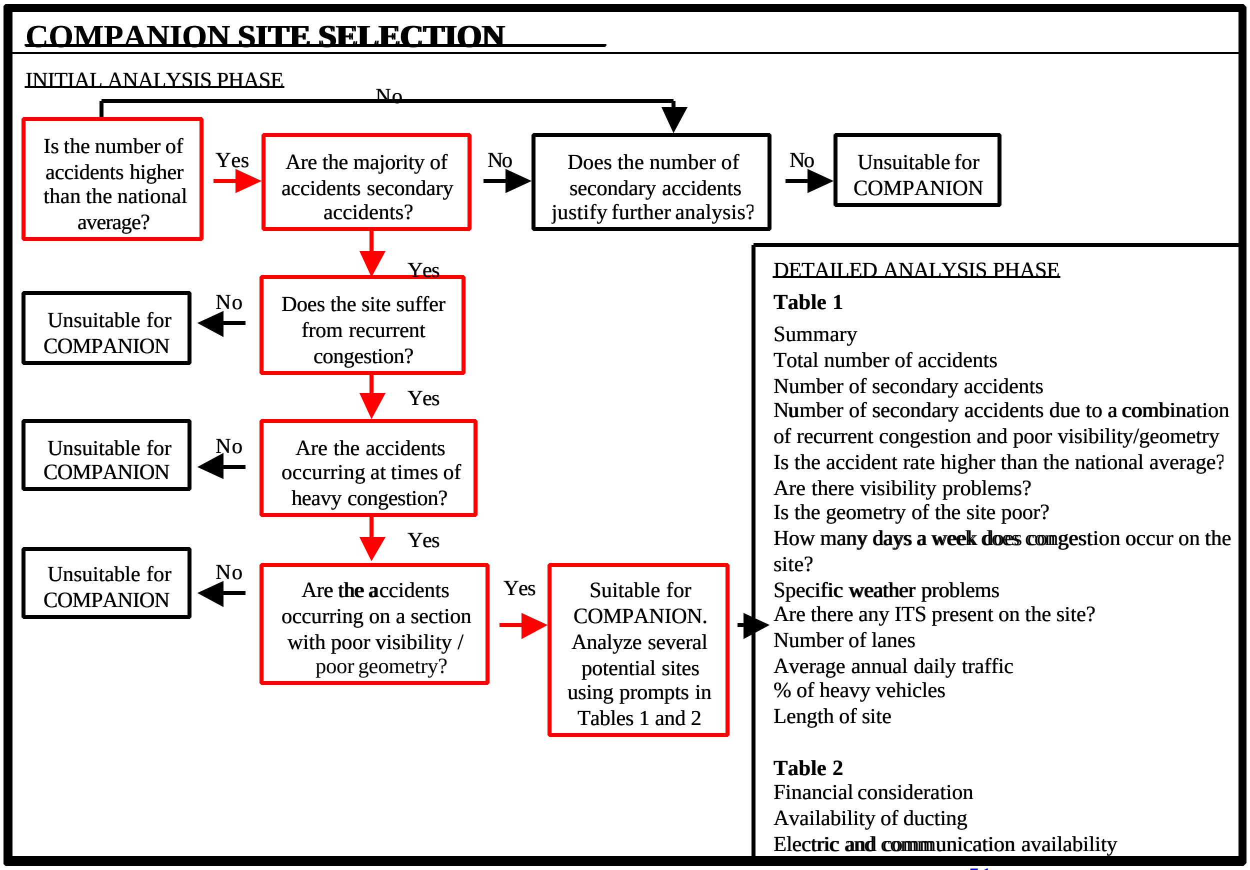

Figure 2-34. COMPANION Site Selection Flowchart.[51]

Figure 2-35. Example of Vehicle-Activated Warning Sign for Rural Application.[53]

A variety of methods have been used to:

- Power the signs/detectors (e.g., main supply line, battery, solar panel, wind generator).
- Determine appropriate threshold speed (e.g., limit, 85th percentile speed, weather/road surface sensor).
- Display timing of message.
- Determine distances between speed measurement position, sign, and hazard location.

Signs using similar technology have also occasionally been used to warn tall vehicles that they are too high to pass under a bridge ahead and to warn vehicles of a queue ahead. The HA is still developing recommended guidelines on the application and operation of vehicle-activated warning signs.

B. State DOT Queue Warning Practices and Techniques

This section summarizes the current practices and techniques being utilized by other state DOTs for detection and warning of slow/stopped traffic ahead. The research team gathered this information from published studies, the Internet, and direct correspondence (e-mail, fax, etc.).

1) California

The California Department of Transportation (Caltrans) has several existing and planned projects related to queue detection and warning. The following subsections briefly describe Caltrans role in an exit ramp spillback problem, a planned queue detection and warning system, use of incident response vehicles, and deployment of an automated fog warning system.

Exit Ramp Spillback: Traffic on southbound IH 15 at Winchester Road, in the city of Temecula, frequently backed up from the exit ramp into the main lanes (Figure 2-36). Caltrans officials became concerned about the unpredictable queues at this location and the 84 collisions that occurred over a 15-month period beginning in January of 2000.[58] A typical collision involved a vehicle traveling at 40 to 45 mph encountering the queue of cars stopped in the exit lane during the afternoon. This scenario, exit ramp spillback, is not uncommon. A paper written by Newell documented the use of loop technology for detecting when the queue from a freeway exit ramp extends onto the freeway main lanes.[59] California Highway Patrol (CHP) officers who investigate these collisions indicate that a common problem is that drivers try to cut into the line of slowed or stopped traffic from the Winchester exit. CHP officials also indicated that all of the tire skid marks around the exit lane were further evidence of the problems at this location. Caltrans has placed a warning sign of slowing traffic ahead north of the typical congestion.

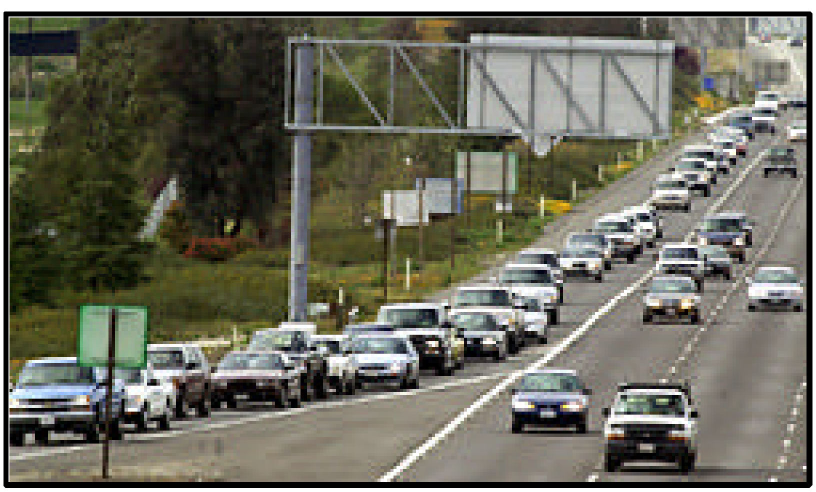

Figure 2-36. Exit Ramp Spillback on Southbound Interstate 15 in Temecula, California.[58]

Planned Queue Warning System: During a task force meeting about using ITS for collision avoidance, Caltrans officials detailed plans for a QWS.[60] The basic problem that precipitated the planning of the QWS was that collision rates on Highway 17 were high compared to other California highways. The highest concentration of collisions occurred within 1 mile on either side of a mountain peak, primarily due to change in grade, horizontal curvature, and limited sight distance. In addition, Caltrans identified that a high percentage of secondary (end-of-queue) collisions were occurring while the primary incidents were in the detection, response, or clearing stages.

The proposed Caltrans pilot project included the following elements:

- Approximately 10 embedded detection loops on 600 foot spacing in each direction of travel
- Two fully programmable VMS in each direction (one already exists in each direction)
- Communications between detectors, controller, and VMS systems
- Hardware to detect moisture and fog
- Software to automatically post messages during inclement weather and congested conditions

Caltrans designed the system to operate by posting messages on the VMS in advance of stopped traffic. The stopped or slow traffic could be a result of collisions or inclement weather (typically rain or heavy fog). The messages let motorists know to slow down to an advisory speed.

Use of Incident Response Vehicles: Caltrans utilizes Freeway Service Patrol/Traffic Management Team (FSP/TMT) vehicles on freeways throughout the state. TMT vehicles are on-call 24 hours a day/7 days a week and are operated by Caltrans Traffic Operations with occasional assistance from Caltrans Maintenance.

TMT trucks assist in locating/identifying incidents, as well as in deploying their variable message signs (mounted to the trucks) to warn motorists of danger or congestion ahead (Figure 2-37). Another role of TMT is to assist in removing debris, help at incident scenes, and provide traffic control support. Finally, TMT trucks are frequently used at the beginning of traffic queues caused by incidents to both provide warning and to report the length of the queue and current queue location to Caltrans Transportation Management Centers (TMCs).[61]

An electronic mail correspondence with Tarbell Martin, Chief of the Caltrans District 11 TMC in San Diego, provided additional information on how TMT vehicles are utilized for queue monitoring and management on freeways.[62] TMT units were used for five days during the week of the Northridge Earthquake in January 1994. Their purpose was to guard the severely damaged IH 5/IH 14 interchange in the upper San Fernando Valley north of Los Angeles. During that week all six freeways approaching the interchange had at least one of the San Diego-based TMT trucks deployed giving the message **SLOW TRAFFIC AHEAD PREPARE TO STOP** on their VMS. The units stayed approximately one-quarter mile behind the end of the queue. As a result, there were no secondary collisions in the queued traffic approaching the interchange during that weeklong period. The San Diego TMT does not handle recurrent commuter congestion, only incidents or incident generator locations.

Figure 2-37. Picture of Caltrans TMT Vehicle with Slow Traffic Ahead Message Displayed.[62]

Caltrans Automated Warning System: Caltrans District 10 has experienced a high number of multi-vehicle collisions, many with fatalities and attributable to seasonal fog and dust-related events that cause visibility problems. In 1990, motivated by the widening of State Route 120 (SR 120), Caltrans developed a multi-sensor automated warning system as a mitigation measure for incidents in this high-volume corridor. This system development concluded in the Phase I implementation of the Caltrans Automated Warning System (CAWS) in November 1996. The system includes 36 speed monitors, nine weather stations with visibility detectors, and nine VMSs used for providing warning to drivers. The District 10 personnel control CAWS with a network of three computers housed at the TMC. Caltrans completed the Phase I deployment under budget at a total capital cost of $2.5 million.

The primary objective of CAWS is to detect the presence of reduced visibility and/or congested traffic on the freeway, and to warn drivers in advance of such conditions. Particular emphasis is on is the situation where there is slow or stopped traffic ahead that drivers might otherwise not be aware due to reduced visibility. Researchers at California Polytechnic State University at San Luis Obispo performed an evaluation of the system.[63] The evaluation report contained only preliminary information on the system benefits in terms of improved safety (e.g., reduced collision rates, lower approach speeds, and larger vehicle headways). The evaluation is ongoing and further information will be in subsequent reports and on the Caltrans web site.

A Caltrans press release for the Operation Fog program provided additional information about how CAWS operates.[64] The system automatically informs drivers, via the VMS, of speeds that would be safe for roadway conditions ahead. When visibility is 0 to 100 ft, the message **Dense Fog Ahead** appears to alert the motorist of conditions ahead. When visibility drops to 201 to 500 ft, **Foggy Conditions Ahead** is displayed. When traffic speeds are 11 to 35 mph, the message **Slow Traffic Ahead** is shown. When vehicle traffic speeds drop between 1 to 10 mph, the message **Stopped Traffic Ahead** is programmed to appear on the VMS (Figure 2-38). In the event of a collision during foggy conditions, speed messages override the fog messages. Caltrans TMC operators can manually override the system as necessary for highway emergencies, advisories, construction, and maintenance work.

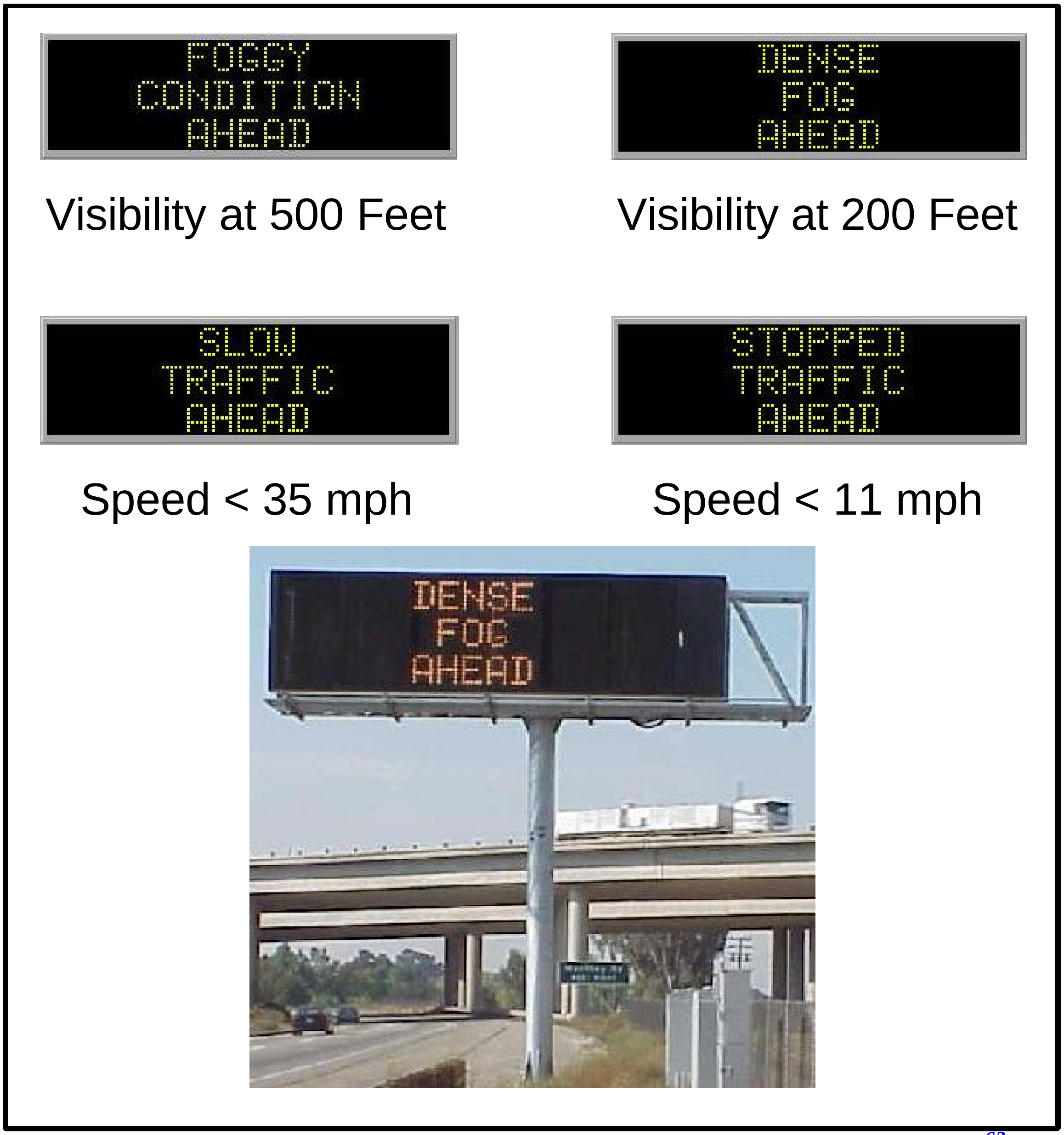

Figure 2-38. Caltrans Automated Warning System Example Sign Messages.[63]

CHP Enforcement Practices: The CHP also has several enforcement practices and methods related to slowing down traffic as it approaches a queue.[65,66] One practice, called *PACE*, is implemented when fog visibility is less than 500 ft. Officers utilize flashing lights to group traffic and lead vehicles at a safe pace through major routes trying to keep traffic speeds at a level during these conditions that minimizes collisions and maximizes safe travel time.

Another practice used by the CHP to slow traffic is called a *Traffic Break*. Every day on California freeways there are objects that wind up in the lanes of traffic. Removing these objects from the road is part of normal CHP routine. There are several ways this can be accomplished. First, an officer can wait for a natural break in traffic and then retrieve the object or push it out of the lanes. On most major urban freeways, a sufficiently long natural break is very rare. In these cases, officers create their own *Traffic Break*. With one officer standing by at the scene of the obstacle, another officer will get on the freeway at a point before the scene of the problem. The officer will turn on the patrol car emergency lights, sometimes activating the siren, and then start moving in the direction of the obstruction. The officer will start to zig-zag back and forth across all lanes of traffic to get the attention of all of the vehicles behind the patrol car. This zig-zagging motion is intended to keep all vehicles behind the CHP vehicle. When convinced that all of the vehicles have seen the patrol car, the officer will slow down. This slowing will create a gap between the vehicles traveling behind the CHP vehicle, and those traveling at normal speeds in front of the patrol car. Normally, the officer will then use the radio to give the officer at the scene of the problem a description of the last car traveling at regular speeds. When the last car goes by, the officer at the scene will then either run out into the lanes to remove the item, push the disabled vehicle out of the way, or instruct the driver of a vehicle facing the wrong way that it is safe to make a U-turn.

A final method used by CHP to slow motorists is called the *Round Robin*. Quite often, at the scene of a major collision or when something happens that blocks most of the lanes of the freeway, traffic will rapidly queue. There have been many secondary collisions in the queue caused by the original problem. When a CHP patrol car arrives at the scene, the officer will notice the situation that is causing the problem. Then, based on an assessment of how long it will take for the roadway to be cleared and how much traffic has backed up, the officer may request a *Signal Alert* (i.e., any unplanned event that blocks a portion of the roadway for more than 30 minutes) to be issued or request help from other CHP officers. One of the ways an officer can reduce the odds of a collision occurring in the traffic queue is to slow the approaching traffic. This goal can be accomplished by a traffic break. Sometimes, however, a single traffic break may not last long enough for a complicated situation. In this case, the officer at the scene may request that other officers perform a *Round Robin* that is a continuing series of traffic breaks designed to slow traffic. Other officers may go as far as several miles to start a traffic break. The officers slow traffic, and keep it slow, until passing the problem and then go back and do it over.

2) Florida

To help motorists deal with the long-term construction project on IH 95 in Palm Beach County, the Florida DOT is deploying a $26 million temporary traffic management system.[67] The system will include 19 portable trailers equipped with cameras, speed sensors, and VMSs that provide incident/delay warnings. Florida DOT expects the system to be in place by August 2002.

An interview with Ms. Tahira Faquir, Traffic Operations Manager of Florida DOT District 4, provided additional information on the IH 95 traffic management system.[68] The total cost of the system, including design, procurement, deployment, and maintenance, is $26 million spread over eight years. The equipment vendor, ADDCO, is supplying their Smartzone and Brick VMS products. This project is somewhat different than traditional ITS deployments in that it is a temporary and portable system with no construction being performed. Communications to the field equipment is via wireless applications (Cellular Digital Packet Data [CDPD] and spread spectrum). There will be 13 hubs that feed the data received from the wireless communications into T1 lines that bring the data back to a temporary TMC. All system components will be on trailers or temporarily mounted for the duration of the IH 95 construction project. Florida DOT is leasing rather than purchasing all of the equipment in order to have flexibility in updating the technology as it changes, as well as the ability to increase or decrease the number of system components without having to re-procure.

Florida DOT has also installed QWSs at north Florida agricultural inspection stations on IH 75, IH 95, and most recently on IH 10.[69] These sites are installed to detect when the queue of trucks stopped for agricultural inspection at these locations are about to back up into the through lanes on the Interstate highway. Before the queue reaches the Interstate, signs with yellow flashers are activated in advance of the inspection station advising trucks to bypass the station. The flashers remain activated until the queue at the station has dissipated enough to safely accept more trucks.

3) Georgia

In-Vehicle Safety Warning System: Researchers at the Georgia Tech Research Institute (GTRI) are developing a radar detector with the capability to display safety warning messages to motorists.[70,71] The Safety Warning System™ (SWS) is an in-vehicle safety warning and signing system that utilizes microwave transmissions to alert drivers in real-time to:

- Hazardous road conditions (e.g., collisions ahead)
- Approaching police/emergency vehicles equipped with an SWS mobile transmitter

GTRI performed an evaluation of the performance of the SWS and its feasibility in 1995. The SWS consists of three primary elements:

- SWS receiver element capable of text or audio warning messages to the driver
- SWS mobile transmitter element that sends the warning message to the receiver (designed for mounting on police and emergency vehicles, slow moving vehicles, school buses, wide loads, highway construction vehicles, and other potential hazards)
- SWS fixed site transmitter element deployed along the side of the highway or on a bridge or sign structure over a highway

The SWS can display any one of the 64 pre-programmed warning messages to the driver. GTRI researchers tested the SWS technical performance with controlled propagation conditions and also with highly variable propagation conditions in the highway environment. Using the worst-case test results produced during highway environment testing, GTRI found the data showed that the system is capable of providing advance warning of a highway hazard to a driver. GTRI researchers considered this result promising because previous driver performance studies from technical literature have indicated that a driver with advance warning is able to stop a vehicle in a shorter distance than a driver who has not received advance warning.

Fog Detection and Warning System: One of the Georgia DOT Research and Development Program's most innovative contribution has been the installation of a Fog Detection Warning System on a high-volume stretch of IH 75 in South Georgia.[72] The system, developed jointly by Georgia DOT and GTRI, serves as a model for automated visibility monitoring programs in other states where fog, snow, or dust create hazards for travelers. Using a network comprised of 19 sensors, 5 sets of traffic speed monitoring loops, weather instruments, and an on-site central computer, the IH 75 system continuously monitors visibility conditions and controls 4 VMSs along a 12-mile section of roadway where dense fog is commonplace. When the system detects a visibility problem, it automatically notifies the proper authorities by telephone and posts appropriate information on the VMSs. The signs, in turn, warn drivers of the specific hazard, advise of reduced traffic speeds when appropriate, and provide detour information if necessary. The system is designed to automatically change messages or a DOT official can change messages in the field. A dial-up system provides law enforcement and DOT personnel with remote access to the information gathered by the system. Using computer networks, officials can monitor visibility levels, traffic speeds, and prevailing weather conditions. The fog warning system uses commercially available optical fog sensors. Each fog sensor contains a light source and a receiver unit that are aligned at a slight angle to one another. Under clear conditions, the beam of light produced by the source will miss the receiver; however, the presence of fog particles in the air scatters the beam and reflects light back into the receiver. The receiver then measures the amount of light it is receiving and calculates the extent of visibility impairment. The Georgia study also includes measured traffic speeds during various fog conditions and a comparison of the visibility sensor readings with human observations.

4) Hawaii

An Internet search about exit ramp spillback produced a link to an article detailing a multi-vehicle collision on the H-1 freeway in Hawaii.[73] The collision involved a westbound truck on the H-1 freeway losing control and sideswiping multiple vehicles approaching the Makakilo exit ramp. Traffic on this exit ramp frequently queued back onto the freeway during morning and afternoon peak hours. This situation is particularly hazardous because drivers going around a curve at a high rate of speed often do not see the stopped traffic until the last second and sometimes have to quickly stop. The collision involved 11 vehicles and produced 1 fatality and 12 injuries to the vehicle occupants. Figure 2-39 provides a picture and diagram of the collision site. At the time of the collision, the exit ramp was being renovated partly to prevent queues extending onto the freeway.

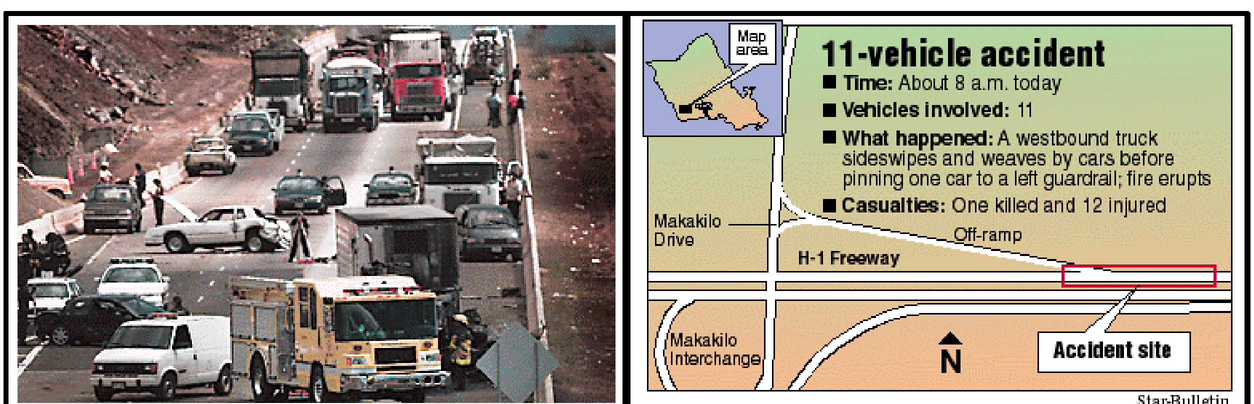

Figure 2-39. Exit Ramp Spillback Incident on H-1 Freeway in Hawaii.[73]

5) Illinois

Interstate Construction Zone System: The Internet search also produced a link to a Herald News newspaper article regarding a system deployed in an IH 55 construction zone to warn motorists of slow/stopped traffic situations.[74] The Illinois DOT received requests from the coroner's office and local residents to install electronic signboards around either side of the construction project at the bridge over the Des Plaines River to warn drivers of potential construction zone queues. Illinois DOT officials responded to these requests by installing solar-powered, trailer-mounted VMSs around the construction area, with two each in the north and southbound sides placed about two miles on either side of the work zone.

Exit Ramp Queue Warning System: The Illinois Tollway Authority (ITA) implemented an exit ramp queue warning system to alert northbound traffic of queuing and congestion on the exit ramp from the Tri-State Tollway to eastbound Grand Avenue.[75] ITA officials completed the exit ramp QWS on May 15, 2001. In addition to the QWS, work in this location included bottleneck improvement on the existing shoulder on the northbound Tri-State Tollway exit ramp to eastbound Grand Avenue. The ITA converted the shoulder into a 12-ft auxiliary lane and built a new 10-ft shoulder to help prevent traffic from queuing back onto the Tollway (Figure 2-40). The system detection of queuing on the ramp is based upon travel speeds on the ramp, with a threshold set for activating the warning system. When speeds on the ramp decrease to this level or below, the detector activates flashing beacons on two signs located just north of Washington Street and just south of Belvidere Road. Figure 2-41 shows one of these warning signs, which has an orange legend with black text on the bottom that reads **CONGESTION AHEAD – RAMP CONGESTION WHEN FLASHING**. The flashing beacons are clearly visible for a minimum distance of one-quarter mile when illuminated and will flash at a rate of 50 to 60 times per minute, with the lights flashing alternately.

Figure 2-40. Picture Showing the Tri-State Tollway Bottleneck Improvement Conversion to a 2-lane Exit at Grand Avenue.[75]

Figure 2-41. Grand Avenue Congestion Ahead Warning Sign.[75]

6) Indiana

Exit Ramp Queue Warning System: The Indiana DOT addressed a long-standing safety problem at the State Road 131 exit on northbound IH 65.[76] Installation of a special warning system has improved the motorist safety in this area. Indiana DOT engineers in the ITS section evaluated the interchange and developed the special warning system to improve safety.

Because of the heavy traffic volume exiting northbound IH 65 at SR 131, traffic on this ramp can at times queue back onto the northbound lanes of IH 65. During these situations, through traffic is obstructed and a high-speed differential between traffic in adjacent lanes is also produced. The Indiana DOT placed a warning sign south of the exit advises motorists to watch for slowed traffic ahead. This sign, 18 ft wide by 9 ft tall, has a yellow background with black text that reads **WATCH FOR SLOWING TRAFFIC**.[77] A second sign equipped with flashing yellow lights advises motorists to use an alternative exit when the SR 131 exit is congested. This sign, 19 ft wide by 6 ft tall, has a yellow background with black text that reads **USE ALT 131 WHEN FLASHING**. When the QWS detects slowed or stopped traffic on the ramp, the system activates the yellow warning lights on the second sign. Motorists can then follow the alternate SR 131 exit route north on IH 65 to IH 265 westbound with an immediate exit to IH 65 southbound returning to the southbound SR 131 exit. Indiana DOT officials considered this warning system and alternative routing as temporary remedies for the IH 65/SR 131 interchange reconstruction. A preliminary evaluation of this system showed the following collision statistics:

- In 1997 there were 55 collisions at the SR 131 exit – 19 resulting in injuries and 1 fatality.
- In 1998 there were 43 collisions at the SR 131 exit – 16 resulting in injuries and 2 fatalities.
- In 1999 there were 26 collisions at the SR 131 exit – 2 resulting in injuries and no fatalities.

The activation of the QWS in April of 1999 has reduced the number of collisions 42% (28 collisions between May and December 1998 compared to 16 collisions in the same period in 1999).

7) Minnesota

Queue Warning System Operational Test: A consulting firm assisted the Minnesota DOT with the deployment of an operational test during the summer of 1996.[78] The test was on an urban interstate at a freeway lane drop at a major interchange with a state highway that is one of the most heavily traveled routes to several recreational areas in central Minnesota. In the past, congestion along this route occasionally caused traffic to queue back onto the Interstate highway. The Minnesota DOT expected the reconstruction of the state highway to make the traffic conditions substantially worse. Collision studies revealed that the congestion in this area caused some rear-end collisions at the lane drop (the 60 mph speed differential between the lane drop and the adjacent through lanes is an opportunity for serious collisions). Therefore, since there was no way to eliminate the congestion due to the reconstruction, Minnesota DOT officials deployed a dynamic queue monitoring and advance warning system.

The Minnesota QWS deployed for the operational test consisted of optical vehicle detectors to identify the formation and length of queues in the lane drop, static warning signs with wig-wag flashers, and a VMS placed in advance of the end of the queue to warn drivers of the unexpected stopped condition ahead. The consultant designed the system so that the flashers and VMS would be operational only when there was stopped traffic detected in the lane drop.

Smart Work Zone: As part of the statewide ITS program, the Minnesota DOT sponsored an operational test of the Portable Traffic Management System (PTMS) in a work zone setting in cooperation with product vendors.[79] The overall goal of the test was to provide useful real-time information to motorists about traffic conditions on the approach and within the work zone. The basic purpose of providing the real-time information at work zones is to improve safety for motorists and construction personnel and to minimize the motorist delay. The FHWA, who sponsored the ITS operational test, required an independent evaluation by SRF Consulting Group, Inc.

The PTMS application is now known as the Smart Work Zone. The Smart Work Zone integrates traffic management technologies into a comprehensive traffic control system. The Smart Work Zone provides data such as speed, volume, and incident detection so that decisions can be made by DOT personnel and relayed to the traveling public. The system consists of four subsystems:

- Vehicle detection/surveillance
- Traffic control center
- Driver information
- Communications

A typical Smart Work Zone deployment consists of portable skids containing various subsystems that work as nodes. The nodes are placed in strategic locations and linked together by spread spectrum radio. The nodes can include both vehicle detection and driver information capabilities. The vehicle detection/surveillance subsystem (VDSS) consists of video cameras placed at strategic locations. The portable machine vision provides data such as volume, speed, incident detection, and vehicle intrusion into the work zone. The data from the VDSS can be transmitted to a TMC. If information is relayed, operators can review the data and implement traffic control changes to improve traffic flow through the work zone. These traffic control changes are basically messages to motorists on full-size portable and smaller-size portable VMSs. If desired, the traffic information can also be made available online. The communications subsystem relies on spread spectrum radio, cellular phone, and Integrated Services Digital Network (ISDN).

Summary of Smart Work Zone Traffic Impacts: The list below summarizes the SRF Group's evaluation of the Smart Work Zone traffic impacts:

- There was a significant increase in the traffic volume that moved through the work zone when the PTMS was in operation (3.6% higher in the morning peak period and 6.6% higher in the afternoon peak period).
- There was a significant decrease in the traffic volume that exited IH 94 to Highway 280 in the afternoon peak period (5.3% lower). This decrease is likely due to increased driver confidence because of the real-time traffic information provided by the PTMS.
- The PTMS decreased the variability in speed for traffic traveling within the work zone by over 70%, which suggests improved safety.
- The PTMS decreased the average speed for traffic approaching the work zone by 9 mph. This speed reduction suggests a safety improvement as approaching vehicles slowed sooner.

A recent newspaper article documented the deployment of a Smart Work Zone system.[80]

8) Missouri

An Internet search revealed a link to a page with pictures of freeway signs throughout the state of Missouri.[81] Two pictures of signs that warn of congestion were on this site. Figure 2-42 shows a sign in St. Louis on northbound IH 270 approaching the IH 70 interchange. This sign has an orange background with black text that reads **CONGESTION AHEAD – NEXT 2 MILES**. The sign also has flashing amber lights mounted on the top left and right corners. Figure 2-43 shows a sign located in the Grandview Triangle interchange in the south Kansas City metropolitan area. This sign has an orange background with black text that reads **CONGESTION AHEAD**. The sign also has a flashing amber light centered on the top of the sign and is solar-powered.

Electronic mail correspondence with Daniel Bruno, Traffic Operations Engineer in District 6 of the Missouri DOT, revealed additional information about the sign pictured in Figure 2-42.[82] Mr. Bruno is a member of the Missouri DOT statewide sign manual group and typically gets involved in some form or another with most of the unique signing issues. Mr. Bruno provided background information into the selection of the **CONGESTION AHEAD** message, the need for the special warning sign, and results of a collision study at this St. Louis location.

Figure 2-42. Congestion Ahead Warning Sign in St. Louis, Missouri.[81]

Figure 2-43. Congestion Ahead Warning Sign in Kansas City, Missouri. [81]

Without the necessary funding to create an advanced system capable of monitoring traffic flow and producing alerts accordingly, the Missouri DOT was faced with placing a permanent warning sign that alerted motorists to a temporal condition (i.e., dependent on time of day). There is a danger associated with alerting motorists to a condition that is rarely present. In this case, congestion was present during a large portion of the day, well outside of the normal rush hours. Missouri DOT officials, concerned about developing a proper message to warn motorists in the IH 270 corridor, selected **CONGESTION AHEAD** as opposed to **BE PREPARED TO STOP** or something similar. The rationale behind the selection of the congestion ahead message was that it gave the motorist information on what they might encounter, rather than what they might need to do. Therefore, if they do not encounter any congestion, no action is necessary.

The Missouri DOT installed the congestion ahead sign and flasher in 1998 as a short-term solution prior to the ITS roll-out in St. Louis called Gateway Guide. The sign is designed to inform out-of-town motorists of the impending congestion that frequently occurs on northbound IH 270. The LED flashers were installed to draw motorist attention to the sign during those times when congestion was most likely to be present. Based on previous studies, as well as field observations, the pre-timed flashers were set to activate during the hours when congestion was typically present. Additionally, a push button was installed for field personnel to use so that the flashers may be activated outside of programmed hours as necessary. The sign and flashers caused a 31% reduction in collisions during the first 3 months after its installation, but that number reduced to around 15% once some motorists became immune to its presence.

In a related matter, the Missouri DOT has another similar installation in St. Louis on westbound IH 270 east of IH 170 in north St. Louis County. The sign reads **LEFT EXIT AHEAD – BE ALERT** and it was installed, along with pre-timed flashers, as a result of a massive multi-fatal collision in 1999. Figure 2-44 shows a picture of this sign (orange background with black text). The sign is intended to warn motorists of routine congestion in the left lanes approaching the left-hand exit. This sign is temporary in nature, as the entire interchange will be reconstructed for two years beginning in late Spring 2002, making all ramps right-hand entry and exit.

Figure 2-44. Left Exit Warning Sign in St. Louis, Missouri.[81]

9) North Carolina

An Internet search revealed a link to the Special Signing Squad page on the North Carolina DOT web site.[83] The Special Signing Squad is a group of experienced personnel established to assist in the development and completion of standard and non-standard signing projects. An electronic mail correspondence with Mr. Mike Reese, Signing Section Engineer with the North Carolina DOT, provided details on the types of static signs in use by the North Carolina DOT for warning motorists of traffic congestion and/or slow traffic ahead.[84]

The first sign used in North Carolina, depicted in Figure 2-45 below, is 10.5 ft wide by 7 ft tall and tells motorists **TRAFFIC CONGESTION AHEAD – WHEN FLASHING**. The top portion of the sign has an orange background while the bottom portion has a yellow background. Other signs utilized by the North Carolina DOT include the W26-1BSP – **SLOW MOVING TRAFFIC** sign and the W26-1ASP – **SLOW MOVING TRAFFIC NEXT X MILES** sign. Both of these are the standard 4-ft diamond-shaped warning signs with orange background and black text. A final sign used in North Carolina to warn motorists of slow traffic ahead is the special Trucker Alert signs developed for IH 95 construction zones. The Trucker Alert signs contain a logo with the text **WORK ZONE – STAY ALERT** and then have text at the bottom that reads **PREPARE FOR SLOW MOVING TRAFFIC**.

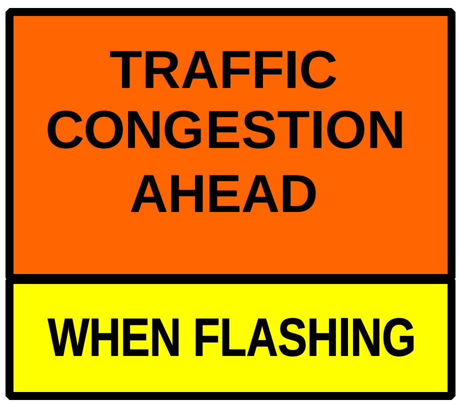

Figure 2-45. North Carolina Traffic Congestion Ahead Special Warning Sign.[84]

10) Pennsylvania

The Pennsylvania DOT faced a daunting task during the rehabilitation of US 22 between Easton and Allentown.[85,86] The four-lane highway carried approximately 85,000 vehicles per day and had several sharp curves that limited the ability of drivers to see if traffic ahead had slowed or stopped. This type of limited sight distance situation has high potential for rear-end collisions, which account for more than 33% of all work zone collisions in Pennsylvania. Pennsylvania DOT officials were determined to keep travelers and construction personnel as safe as possible. Project engineers worked with ASTI Transportation Systems to design a system that would keep drivers informed of traffic conditions on the road ahead 24 hours-a-day, 7 days-a-week. The system, known as CHIPS (Computerized Highway Information Processing System), relies on a queue length detector, one of the products developed within the Strategic Highway Research Program (SHRP).

Using a series of 15 VMSs placed along the roadside before the work zone, CHIPS alerts drivers if traffic ahead has slowed/stopped, or if a lane has been blocked by an incident. The system also provides information on the estimated length of any delays. The VMSs change in response to signals from the eight queue length detectors placed along US 22. The portable detectors shoot an infrared beam across the traffic lanes and measure how long it takes a vehicle to pass through the beam. If this measurement exceeds a preset threshold, the detector indicates that traffic has slowed down or stopped. The detectors send this information to the CHIPS central computer, located in a nearby Pennsylvania DOT field office, which then activates the appropriate message on all of the VMS. The system uses radio signals rather than cellular telephones to produce more reliable communications. Cellular phone networks are often congested during incidents and peak traffic periods.

Pennsylvania Turnpike Automated Warning System: The Pennsylvania Turnpike installed a state-of-the-art automated traffic speed flow monitoring and warning system between Mileposts 191.2 and 197.5 in September of 1999.[87] Turnpike officials believe this system will help better manage and monitor traffic speeds and flows during a major reconstruction project and also will alert customers about traffic conditions. Real-time information will be relayed to motorists via four Highway Advisory Radio (HAR) stations broadcasting on 530 AM and also via 12 VMSs. In large part, information on the VMS reflects data relayed from six speed-monitoring devices. Messages will vary based on certain threshold readings of the average speed of vehicles traveling the Turnpike on that section. Turnpike officials designed the VMSs to display the following messages based on speed ranges:

- <u>Speed-Based Message #1</u> – **ROADWORK AHEAD: DELAYS POSSIBLE** when the average speed is 40 mph or above.
- <u>Speed-Based Message #2</u> – **ROADWORK AHEAD: SLOW TRAFFIC AHEAD** at speeds of 39 to 25 mph.
- <u>Speed-Based Message #3</u> – **ROADWORK AHEAD: TRAFFIC STOPPED** at 24 mph or slower.

Turnpike officials based messages about incidents on the same average travel speed thresholds:

- <u>Incident Message #1</u> – **ACCIDENT AHEAD: USE CAUTION** at 40 mph or over.
- <u>Incident Message #2</u> – **ACCIDENT AHEAD: SLOW DOWN NOW** at 39 to 25 mph.
- <u>Incident Message #3</u> – **ACCIDENT AHEAD: STOPPED TRAFFIC** at 24 mph or slower.

11) Tennessee

In December 1990, a chain-reaction collision on IH 75 in southeastern Tennessee involving 99 vehicles prompted the design and implementation of a fog detection and warning system.[88] The system covers a 19-mile stretch of IH 75 including a 3-mile, fog-prone section above the Hiwassee River and 8-mile sections on either side.

The Tennessee DOT and Tennessee Highway Patrol (THP) have access to a central computer system that manages data from 8 fog detectors and 44 vehicle speed detectors. With continuous monitoring of these data, the computer system predicts and detects conditions likely to produce fog, and alerts managers when established threshold criteria are met. THP personnel visually verify on-site conditions. The system has built-in response scenarios based on the field sensor data. Operational techniques include advising motorists of prevailing conditions via flashing beacons mounted on top of 6 static signs, 2 HAR transmitters, and 10 VMSs. The system also includes 10 Variable Speed Limit (VSL) signs and can restrict vehicle movements to the affected section of highway by utilizing automated ramp gates.

TMC personnel select pre-programmed VMS messages (Table 2-1), pre-recorded HAR messages, and appropriate speed limits (i.e., 50 mph or 35 mph) based upon response scenarios proposed by the system. Under the worst-case scenario (i.e., visibility less than 240 ft), the THP activates the eight ramp gates to close IH 75 and detour traffic to US 11.

Table 2-1. Tennessee Fog Detection and Warning System VMS Messages.[88]

Conditions	Displayed Messages
Reduced Speed Detected	Flashing **CAUTION** with **SLOW TRAFFIC AHEAD**
Fog Detected	Flashing **CAUTION** with **FOG AHEAD TURN ON LOW BEAMS**
Speed Limit Reduced	Flashing **FOG AHEAD** with **ADVISORY RADIO TUNE TO XXXX AM**
	Flashing **FOG AHEAD** with **REDUCE SPEED TURN ON LOW BEAMS**
	Flashing **FOG AHEAD** with **SPEED LIMIT YY MPH**
Roadway Closed	Flashing **DETOUR AHEAD** with **REDUCE SPEED MERGE RIGHT**
	Flashing **I-75 CLOSED** with **DETOUR TO US 11**
	Flashing **FOG AHEAD** with **ADVISORY RADIO TUNE TO XXXX AM**

According to THP collision data, over 200 collisions, 130 injuries, and 18 fatalities have occurred on this highway section since the interstate opened in 1973. Since the fog detection and warning system began operating in 1994, Tennessee DOT officials have determined that safety has been significantly improved and no fog-related collisions have occurred.

12) Virginia

Weigh Station Traffic Queue Warning System: The Virginia DOT has developed and installed a system that detects vehicle queues at truck weigh stations.[89] The traffic queue warning system was necessary due to the increasing number of trucks needing to be processed through Virginia DOT's weigh stations and because existing methods required DOT personnel to manually activate open/close signs to prevent traffic queues from backing up onto the freeway main lanes. The system is designed to help facilitate efficient and safe movement of trucks through Virginia DOT weigh stations and to provide an automated means to assist station personnel with traffic management. The system automatically closes the weigh station to additional traffic when the single lane within the weigh station is full. When the traffic clears and room for more trucks is again available, the system opens the station. This system is designed to enhance safety while allowing weigh station staff to focus their attention on other activities. The initial system deployment at two weigh stations costs $25,000. Virginia DOT plans to install the traffic queue warning system at eight additional weigh stations throughout Virginia.

13) Washington

Exit Ramp Queue Warning System: The Washington State DOT has installed a congestion notification system for truckers traveling to the Port of Tacoma.[90] DOT officials installed video detection on the main exit ramp serving the Port of Tacoma to detect queues on the ramp. When a queue is detected, an alarm is triggered in the Olympic Region TMC and an operator activates the flashing lights on a sign that tells truckers to use another approach to the Port. The Washington DOT has received funding to expand the congestion notification system to three other ramps that serve the Port of Tacoma.

Traffic Warning System Near Elementary School: The King County DOT recently deployed a new traffic warning system at a high-accident section of roadway near Panther Lake Elementary School. King County engineers installed a new warning sign with flashers in February of 2002 near the intersection of Southeast 208th Street and 105th Place Southeast.[91] The warning sign is hung on a span wire above the lanes of Southeast 208th Street. The sign text reads **PREPARE TO STOP – WHEN FLASHING** and has a pictogram of a hill with a car on it and two cars stopped on the other side. Figure 2-46 provides a picture of the warning sign.

Motorists approach this intersection after cresting a hill, and sometimes they are surprised to see a long queue of traffic stopped for the traffic signal at 105th Place — a cross street serving as the sole access point for the elementary school. In the past, drivers frequently did not allow themselves enough time to safely stop and were involved in rear-end collisions with the waiting vehicles. The new traffic warning system alerts motorists traveling east on 208th Street of traffic signal changes and queues of traffic ahead. An electrical controller at the intersection monitors the stopped traffic and controls a flashing sign located over the hill and about 700 ft west of the intersection. When activated, the sign alerts motorists to the stopped traffic ahead. Figure 2-47 shows the view of a motorist after going over the crest of the hill on the approach to the intersection with 105th Place Southeast.

14) West Virginia

The West Virginia Department of Transportation recently implemented its first advance fog warning system on IH 64 in the Nitro-St. Albans area.[92] The $89,000 project, under contract to Nu-Metrics, Inc. of Pennsylvania, utilizes sensors located 1 mile east and 1 mile west of the IH 64 Kanawha River bridge near the St. Albans interchange.

The system is designed to detect fog with special sensors that can then activate flashers to warn motorists to slow down and exercise caution. The system also includes an alarm and video camera component so that traffic engineers in the West Virginia DOT headquarters can get a visual confirmation of the fog conditions. In an additional effort to combine tasks and provide cost savings, West Virginia DOT planners installed in-pavement sensors to detect the volume and speed of traffic for use for purposes other than just traffic management.

Figure 2-46. Picture of King County Queue Warning Sign near Elementary School.[91]

Figure 2-47. View on Top of Crest of the Hill on Southeast 208th Place.[91]

C. Texas DOT Queue Warning Practices and Techniques

This section documents the existing practices and techniques being utilized by TxDOT for detection and warning motorists of slow and/or stopped traffic ahead. The research team gathered this information from Internet searches, direct correspondence, and field observations.

1) San Antonio Area

The TransGuide intelligent transportation system has been in operation in the San Antonio metropolitan area since July 1995.[93] The initial concept of operations for TransGuide did not include congestion management, defined as a proactive transfer of information to the traveling public regarding non-incident related traffic conditions. Shortly after TransGuide became operational, TMC personnel implemented congestion scenarios. These scenarios display messages on VMSs prior to areas of heavy congestion. The message displayed is typically **CONGESTION AHEAD - USE CAUTION**. TransGuide operators have observed a smoother flow of traffic in areas of recurring congestion when the congestion scenarios are running.

The messages originally included an approximate distance ahead that the driver could expect to slow down due to congestion. TransGuide operators discontinued this practice due to the dynamic nature of congestion requiring constant modification of the message. The TransGuide system was initially deployed in the downtown area of San Antonio. The beginning or ending of a congestion queue was in the area covered by TransGuide, but rarely both the beginning and ending. With the expansion of TransGuide on IH 10 and IH 410, it is now possible to observe in many cases both the start and end of the queue. The system can inform the traveling public of the start and end of the queue using VMSs. Figure 2-48 provides queue messages. The top panel shows a typical congestion message, and the bottom panel shows a typical message with travel time information. Due to the dynamic nature of congestion, operators must closely monitor the queue and modify messages when necessary. The existing scenario process has been enhanced to allow easier modification of the congestion limits. The Southwest Research Institute recently upgraded the scenarios to allow VMS and lane control signal modification while a scenario is running, so modification is now a relatively quick process. TransGuide has also used messages (e.g., **CONGESTION AHEAD - FROM WURZBACK - TO CROSSROADS** and **USE CAUTION - MINIMIZE - CHANGING LANES**) advising motorists to minimize lane changes while approaching congested areas.

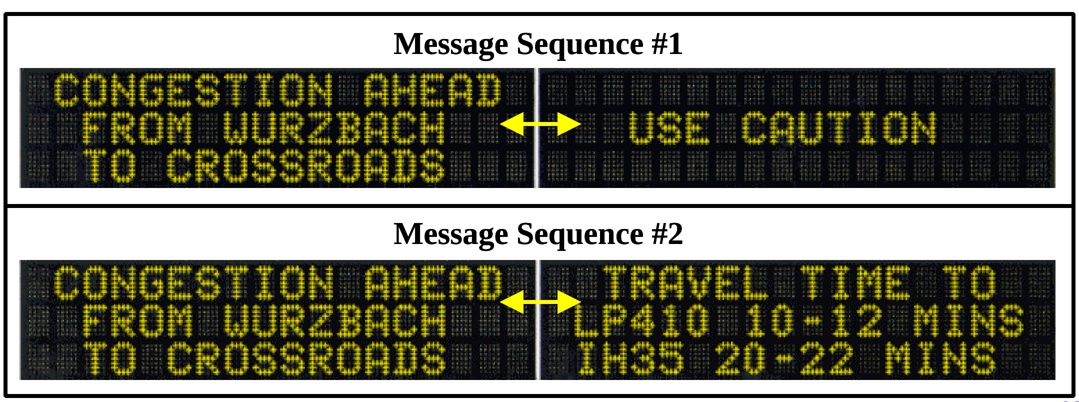

Figure 2-48. San Antonio TransGuide Congestion Warning Example Messages.[93]

2) Fort Worth Area

According to field observations, several techniques are being utilized by the TxDOT Fort Worth District to warn motorists of slow/stopped traffic ahead. The first method involves the use of the large VMSs in the TransVISION system. The second method involves the use of traditional signs at locations with recurrent congestion and some sight distance issues.

Christmas at Hulen Mall: Hulen Mall is located in southwest Fort Worth at the intersection of Hulen Street and IH 20 (also designated as Southwest Loop 820). The exit ramp for westbound motorists comes into the frontage road only 750 ft from the signalized intersection at Hulen. This relatively small storage area, coupled with the high exit volume because of the mall and surrounding developments, creates the potential for traffic queuing back onto the IH 20 main lanes. This potential is enhanced during the Christmas holidays when demand to access the mall property is significantly increased.

Realizing the hazard created by a lane of traffic queuing back onto the main lanes, TxDOT began to utilize the permanent VMSs on westbound IH 20 to warn motorists of the potential queue at the Hulen exit ramp. Figure 2-49 provides a picture taken from one of the TransVISION cameras of the VMS with the Hulen warning message being displayed.[94] TransVISION operators displayed the message **WATCH FOR SLOW TRAFFIC AT HULEN EXIT** at the VMS located at James (2.5 miles from the Hulen exit) and at Granbury (0.5 mile from the Hulen exit). The operators also have the capability to activate yellow flashers on top of the VMSs to attract additional attention to the sign if they verify queue spillback onto IH 20.

Figure 2-49. Warning Message on VMS About Potential Queue Spillback at the Hulen Exit Ramp.[94]

Westbound Interstate 20 Frontage Road at Bryant Irvin Boulevard: The next major interchange on IH 20, located approximately 1.5 miles west of Hulen Street, is Bryant Irvin Road. As was the case at the Hulen interchange, there is considerable development and the corresponding traffic demand at Bryant Irvin Road. In this case, the problem is not exit ramp spillback onto the IH 20 main lanes; rather, there is a driveway just over the crest of the hill on the westbound IH 20 frontage road. TxDOT has addressed this situation by installation of traditional warning signs to alert motorists on both the westbound Bryant Irvin exit and westbound IH 20 frontage road to the potential for slow traffic ahead. Figure 2-50 shows a picture looking west from the IH 20 exit ramp toward Bryant Irvin. The sign in the upper right corner of the picture warns motorists **CAUTION WATCH FOR SLOW TRAFFIC AHEAD**. The line in the picture across the westbound IH 20 frontage road represents the crest of the vertical curve that restricts the sight distance of motorists to vehicles on the other side. Motorists slowing down to make a right turn into this driveway create an additional hazard for high-speed traffic. Another picture, provided in Figure 2-51, shows a view of the westbound IH 20 frontage road looking east from near the signal at Bryant Irvin Road. This view gives further perspective on the rolling terrain and potential for a motorist traveling too fast over the curve to have trouble stopping.

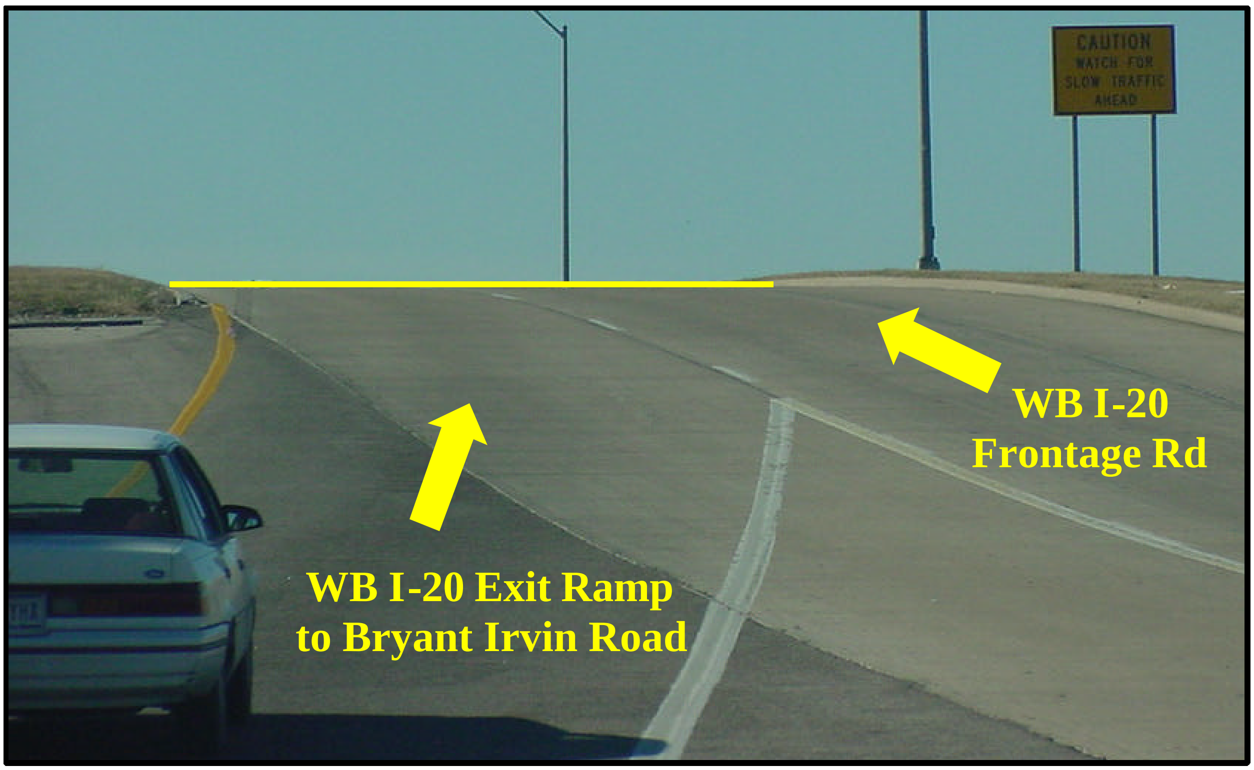

Figure 2-50. Looking West from Westbound IH 20 Exit Ramp to Bryant Irvin Road.

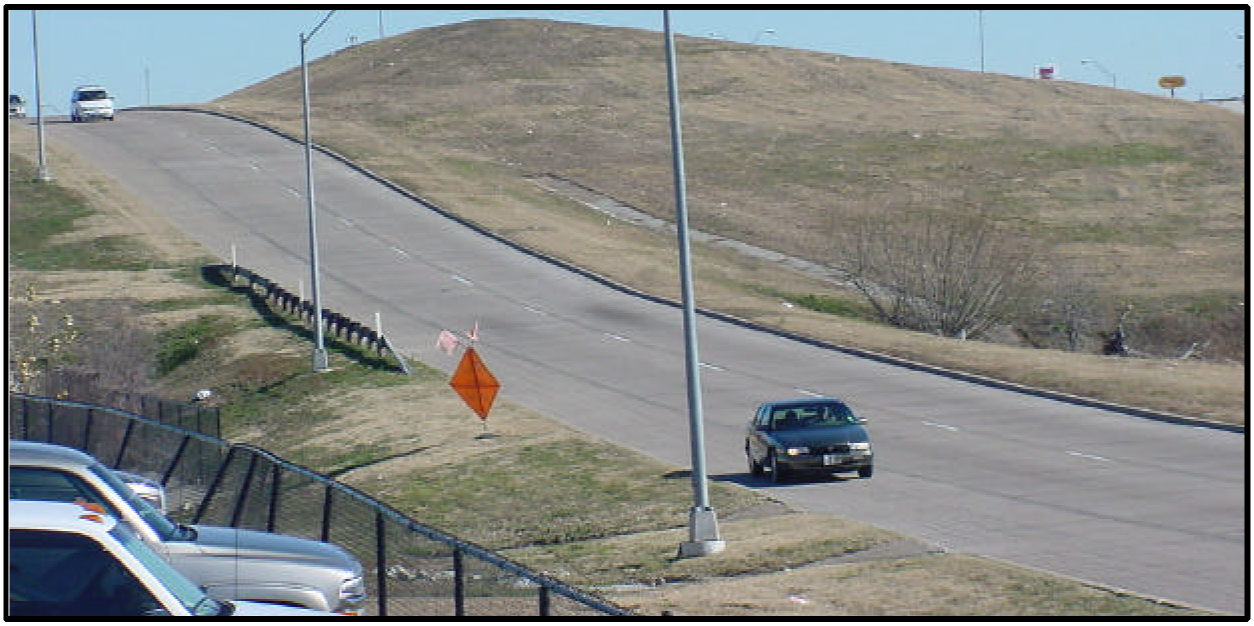

Figure 2-51. Looking East from Near Bryant Irvin at Westbound IH 20 Frontage Road.

Southbound SH 121 at SH 183: A final location where the TxDOT Fort Worth District is providing warning to motorists of slow traffic ahead is on southbound SH 121 at SH 183. This location experiences recurrent congestion and queuing, particularly during the afternoon peak period. Southbound SH 121 has two lanes that connect onto westbound SH 183. Only one of these lanes continues on westbound SH 183; the other is dropped at the Central/Forest Ridge exit. The high volume and lane drop situation create a bottleneck that causes a queue to regularly form. TxDOT addressed this condition by placing a series of warning signs on southbound SH 121 to advise motorists of the potential for slow traffic ahead.

The first set of signs, pictured in Figure 2-52, is located just prior to the Harwood entrance ramp to southbound SH 121, approximately 1.2 miles from the SH 183 merge. These large (estimated as 96 in. by 96 in.) yellow diamond signs have black text that reads **SLOW TRAFFIC AHEAD BE PREPARED TO STOP**. The second set of signs, shown in Figure 2-53, is located just after the Harwood entrance ramp to southbound SH 121, about 1 mile from the SH 183 merge. These yellow rectangular signs (estimated as 48 in. tall by 96 in. wide) have black text that reads **CAUTION WATCH FOR SLOW TRAFFIC AHEAD**. These signs also have yellow flashers mounted on each side that constantly flash throughout the day in a bounce mode. A final warning sign, pictured in Figure 2-54, is located on the right side of southbound SH 121 just before the Murphy overpass (approximately 0.33 mile before the SH 183 merge). This yellow diamond sign, estimated as 48 in. by 48 in., has black text that reads **SLOW TRAFFIC AHEAD BE PREPARED TO STOP**.

Figure 2-52. Southbound SH 121 Prior to Harwood Entrance – Slow Traffic Ahead Warning Signs.

Figure 2-53. Southbound SH 121 after Harwood Entrance – Caution Flashing Warning Signs.

Figure 2-54. Southbound SH 121 near Murphy Overpass – Slow Traffic Ahead Warning Sign.

2.3 EQUIPMENT VENDOR INFORMATION

This section provides some information on vendors that manufacture products and systems related to providing advance warning of slow and/or stopped traffic ahead. The research team obtained the majority of the information in this section from Internet searches, direct correspondence, and conference attendance. Table 2-2 lists the queue warning system equipment vendors identified during the first year and also lists the products and their web site address.

Table 2-2. List of Queue Warning System Equipment Vendors.

Vendor	Product(s)	Web site
ADDCO	Brick – panel VMS Smartzone – work zone system	http://www.addcoinc.com/
American Signal	ITMS – Integrated Traffic Management System	http://www.amsig.com/
ASTI Transportation Systems	CHIPS (Computerized Highway Information Processing System)	http://www.asti-trans.com/
BMW Group	COMPANION roadside hazard warning system	http://www.bmw.de/ (German)
EIS (Electronic Integrated Systems)	RTMS/NEWS	http://www.rtms-by-eis.com/
Georgia Tech Research Institute	Safety Warning System	http://www.gatech.edu/
GreenWay Systeme/PRT	Mobile Traffic Jam Warning System	http://www.greenway-systeme.com/
OMRON	Congestion Tail Display System	http://www.omron.co.jp/
Ortana Corporation	Mobile VMS	http://www.ortana.com/
PDP Associates	Traffic Information and Prediction System (TIPS) Advanced Speed Information System (ASIS)	http://www.PDPassociates.com/
Scientex Corporation	ADAPTIR	http://www.scientexcorp.com/
Siemens	VMS, overhead displays, etc.	http://www.siemens.de/
Traficon	VIP/I Incident Monitor	http://www.traficon.com/

2.4 SUMMARY OF QUEUE WARNING PRACTICES AND TECHNIQUES

This section summarizes the practices and techniques for detection and warning motorists of slow/stopped traffic ahead identified by the research team. Table 2-3 provides a summary of the queue detection and warning practices of international agencies. It includes the country, description of the location, problem type, detection and warning techniques, and a contact person for obtaining further information. Table 2-4 summarizes the queue detection and warning system techniques of transportation agencies in the United States. This table includes the state, description of the location, problem type, detection and warning techniques, and a contact person for requesting additional information.

Table 2-3. Summary of Queue Detection and Warning Techniques of International Agencies.

Location	Problem Type	Detection Technique(s)	Warning Technique(s)	For More Information
		AUSTRALIA		
Melbourne EB off ramp to the Hume Highway	Exit ramp spillback	Embedded loops	Variable speed sign (VSS) and variable message sign (VMS)	Steve Bean VicRoads Steve.Bean@roads.vic.gov.au
		BELGIUM		
Antwerpen E313 freeway	Construction zone queues	Video detection (Traficon)	VMS panels Trailer-mounted VMS	Bart Boucke – Traficon traficon@traficon.com
		CANADA		
Ontario US border crossing near Niagara	Border queues	Microwave radar (EIS–NEWS)	Static signs with flashers – 'PREPARE TO STOP WHEN FLASHING'	Mr. Ken Tai Ministry of Transportation ken.tai@mto.gov.on.ca
Ontario St. Catharine's	Construction zone queues Secondary collisions	Microwave radar	Queue warning signs	Larry Smith, P.E. Ministry of Transportation larry.smith@mto.gov.on.ca
		DENMARK		
Aalborg	Recurrent congestion	Embedded loops	VSS	Finn Krenk – Road Directorate fik@vd.dk
		FINLAND		
Helsinki Western Artery	Fog – visibility Recurrent congestion	Embedded loops	VSS VMS	Matti Kokkinen – Traficon Matti.Kokkinen@Traficon.Fi
		GERMANY/ITALY		
German Autobahns	Incident congestion	Police and/or motorist reports	Helicopter with STAU sign Overpasses with STAU sign Driver warning – use flashers	N/A
A 9 and A 92 near Munich	Recurrent congestion	Video detection	COMPANION posts and VMS panels	H.J. Schultz - Heusch/Boesefeldt info@heuboe.de
A 3 near Hosbach A 9 near Greding A 12 near Poland	Construction (A 3, 9) Border queues (A 12)	Infrared	VMS Mobile traffic jam trailers	Elmar Reisinger – Siemens Elmar.reisinger@mchr1.siemens.de
A 100 in Berlin	Recurrent congestion	Video detection	VMS panels VSS Lane control signals	Frank Stelzner – Siemens Frank.stelzner@lpz.siemens.de

Table 2-3. Summary of Queue Detection and Warning Techniques of International Agencies (continued).

Location	Problem Type	Detection Technique(s)	Warning Technique(s)	For More Information
		JAPAN		
Tokyo Metro Expressway	Recurrent congestion Incident congestion	Ultrasonic detectors @ 300 m (984 ft) spacing	VMS – congestion tail display boards	Makio Komada Omron Technics, Inc. komada@tse.tora.omron.co.jp
		NETHERLANDS		
Netherlands	All types	Embedded loops	VSS VMS	Erich Brunner – PRT e.brunner@prt.at
		NEW ZEALAND		
All throughout the country	Recurrent congestion	No active detection	Static sign with symbol for congestion/queue ahead	http://www.transport.gov.za/ W355 traffic congestion sign
		NORWAY		
Oslo	Recurrent congestion	Video detection (Traficon)	Special queue warning VMS with flashers	Arvid Aakre Norw. Univ. Science & Tech. Arvid.Aakre@bygg.ntnu.no
		TURKEY		
Aydin-Izmir and Istanbul Kurtkoy Airfield motorways	Recurrent congestion Incident congestion Construction zone queues	Doppler radar	Speed warning panels VMS panels Trailer-mounted VMS	Ortana info@ortana.com
		UNITED KINGDOM (ENGLAND + SCOTLAND)		
United Kingdom M1, M25, and M60 roadway facilities	Secondary collisions	Embedded loops	VSS (matrix signals) VMS	Peter York Highways Agency peter.york@highways.gsi.gov.uk
Scotland M90	Recurrent congestion Visibility concerns	Microwave radar	COMPANION posts at 50 m (164 ft) spacing	Colin Hardie & Colin Groves Oscar Faber Consultants http://www.oscarfaber.com/

Table 2-4. Summary of Queue Detection and Warning Techniques in the United States.

Location	Problem Type	Detection Technique(s)	Warning Technique(s)	For More Information
CALIFORNIA				
Temucula IH 15 @ Winchester	Exit ramp spillback	No detection	Static sign with pretimed flashers for PM peak period	Tim Watkins – Caltrans Tim_Watkins@dot.ca.gov
Highway 17	Secondary collisions (near mountain pass)	Embedded loops Fog detectors	VMS	N/A
Statewide	Fog – visibility Incident congestion	Varies – mostly motorist reports	Incident response vehicles with trailer-mounted VMS	Tarbell Martin – Caltrans Tarbell_Martin@dot.ca.gov
State Route 120	Fog – visibility	Embedded loops Fog detectors	VMS with preprogrammed messages	N/A
Statewide	Fog – visibility Incident congestion	Varies – mostly motorist reports	PACE, Traffic Breaks, and Round Robins	Phil Konstantin – CHP philkon@rocketmail.com
FLORIDA				
Palm Beach County IH 95	Construction zone queues	Video detection Radar (ADDCO)	Trailer-mounted VMS	Tahira Faquir – Florida DOT tahira.faquir@dot.state.fl.us
GEORGIA				
IH 75 – south Georgia	Fog – visibility	Embedded loops Fog detectors	VMS with preprogrammed messages Automatic police notification	Marion Waters – Georgia DOT marion.waters@dot.state.ga.us
HAWAII				
H-1 @ Makakilo	Exit ramp spillback	No detection	No warning: now extending ramp spacing to intersection	http://starbulletin.com/98/03/19/news/story2.html
ILLINOIS				
IH 55	Construction zone queues	Radar detection	Trailer-mounted VMS	Pat O'Neill –Will Co. Coroner http://www.patoneil.com/
Tri-State Tollway @ Grand Avenue	Exit ramp spillback	Embedded loops	Static signs with flashers – 'Congestion Ahead: Ramp Congestion When Flashing' Bottleneck improvement	Kenneth Glassman Illinois Tollway Authority Traffic Operations Supervisor kglassman@tollway.state.il.us
INDIANA				
IH 65 @ State Rd 131	Exit ramp spillback	Embedded loops	Static signs with flashers – 'Watch for Slowing Traffic' Bottleneck improvement	Kathy Eaton – Indiana DOT Traffic Field Investigator KAEATON@indot.state.in.us
MINNESOTA				
Central Minnesota	Recurrent congestion (at freeway lane drop) Rear-end collisions	Optical detectors	Static sign with wig-wag flashers and a VMS placed in advance of the end of queue	Howard Preston BRW, Inc. hpreston@hrgreen.com

Table 2-4. Summary of Queue Detection and Warning Techniques in the United States (continued).

Location	Problem Type	Detection Technique(s)	Warning Technique(s)	For More Information
MISSOURI				
St. Louis Northbound IH 270 @ IH 70	Recurrent congestion Rear-end collisions Unfamiliar drivers	No detection – flashers activated by time of day	Static sign with flashers – ‘Congestion Ahead: Next 2 Miles’	Daniel Bruno Traffic Operations Engineer Missouri DOT BRUNOD@mail.modot.state.mo.us
Kansas City Grandview triangle	Recurrent congestion Rear-end collisions	No detection – flasher activated by time of day	Static sign with flasher – ‘Congestion Ahead’	
St. Louis Westbound IH 270 @ IH 170	Exit ramp spillback Rear-end collisions	No detection – timed flashers	Static sign with flashers – ‘Left Exit Ahead: Be Alert’	
NORTH CAROLINA				
Various locations	Construction queues Recurrent congestion Rear-end collisions	Unknown	Several static signs: (1) Traffic Congestion Ahead: When Flashing (2) Slow Moving Traffic (3) Work Zone – Stay Alert: Prepare for Slow Moving Traffic	Mike Reese Signing Section Engineer North Carolina DOT mikereese@dot.state.nc.us
PENNSYLVANIA				
US 22	Construction zone queues Sight distance limitations Rear-end collisions	Queue length detectors using infrared beams	Series of VMSs (CHIPS system)	Frank Simko ASTI Transportation Systems frank@asti-trans.com
Pennsylvania Turnpike	Construction zone queues Rear-end collisions	Radar detector speed devices	Series of VMSs with set messages based on average traffic speed and also HAR	Kathy Liebler, Dir. of Public Info. Pennsylvania Turnpike (717) 939-9551
TENNESSEE				
IH 75 around the Hiwassee River	Fog – visibility	Fog detectors Radar detectors	Series of VMSs with set messages based on weather and roadway conditions	Don Dahlinger Tennessee DOT ddahlinger@mail.state.tn.us

Table 2-4. Summary of Queue Detection and Warning Techniques in the United States (continued).

Location	Problem Type	Detection Technique(s)	Warning Technique(s)	For More Information
TEXAS				
San Antonio TransGuide	Recurrent congestion Rear-end collisions	Embedded loops	VMSs with congestion ahead warning messages	Pat Irwin TxDOT San Antonio District pirwin@dot.state.tx.us
Fort Worth IH 20 @ Hulen Street	Exit ramp spillback	Video detection by TMC staff using cameras	VMSs with 'Watch for Slow Traffic at Hulen Exit'	Wallace Ewell Director of Trans. Operations TxDOT Fort Worth District wewell@dot.state.tx.us
Fort Worth Westbound IH 20 frontage road @ Bryant Irvin	Recurrent congestion Sight distance limitations Rear-end collisions	No detection	Static sign 'Caution: Watch for Slow Traffic Ahead'	
Fort Worth Southbound SH 121 @ SH 183	Recurrent congestion Rear-end collisions	No detection	Series of static signs: 1. 'Slow Traffic Ahead Be Prepared to Stop'; and 2. 'Caution: Watch for Slow Traffic Ahead' (with side-mounted flashers)	
VIRGINIA				
Two truck weigh stations	Spillback at truck weigh stations	Embedded loops	Electronic signs that tell truckers if the station is open	No contact
WASHINGTON				
On IH 5 near the Port of Tacoma	Exit ramp spillback	Video detection	Static sign with flashers that tells truckers to use another ramp to approach the Port	Pete Briglia, ITS Program Manager Washington State DOT briglia@u.washington.edu
King County SE 208th Street	Sight distance limitations Rear-end collisions	Embedded loops	Static sign on span wire: 'Prepare to Stop When Flashing' with hill pictogram	Paulette Norman, County Road Engr. King County DOT Paulette.Norman@METROKC.GOV
WEST VIRGINIA				
IH 64 in the Nitro-St. Albans Area	Fog – visibility	Fog detectors Embedded loops	Sign that warns motorists to slow down and use caution	No contact

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CHAPTER 3. OBSERVATIONAL FIELD STUDIES

During Task 3, researchers conducted observations of freeway congestion. Researchers were especially 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. It is queue growth that is of particular interest, since when queues are growing they are more likely to surprise oncoming drivers than when they are dissipating. Previous research conducted in rural conditions in an Iowa work zone had measured **queues growing at 30 mph, resulting in 65 mph approach traffic encountering conditions comparable to a 95 mph driving speed in terms of rate of closure upon the stopped traffic queue**. It was unclear whether speeds of this type would be encountered under urban conditions, or if rapid queue growth would be repetitive (accordion action) or sustained over periods of time. This section of the report will discuss the purpose of studying queue propagation, the methodology used to conduct the studies, and the research findings.

3.1 PURPOSE

In view of the Iowa research, and the potential impact to issues relevant in identifying appropriate warning and detection systems for providing advance warning to drivers of stopped conditions on the freeway, the researchers decided to study queue propagation speeds under urban conditions. Field observations of queue propagation speed were useful to do the following:

- Determine whether queues were too dynamic to issue location-specific warnings to drivers.
- Determine acceptable sign placement for a variable queue.
- Determine messages/warnings that may be appropriate.
- Assist in determining the applicability of a warning technique to TxDOT.
- Assist in selecting further strategies for testing.

3.2 METHODOLOGY

A. Field Data Collection Locations

The research team, after consultation with the Project Monitoring Committee, selected various field observation sites based upon frequency of congestion due to recurrent overcapacity peak conditions or the presence of construction. In order to facilitate data collection, researchers chose sites in the TxDOT Dallas District so that project personnel could collect data via closed-circuit television cameras available at the DalTrans Traffic Management Center. For this phase of the study, the research team only considered for data collection those freeways with CCTV cameras viewable from the TMC (Figure 3-1).[1] Finally, several members of the research team met with DalTrans operators to review the actual camera views and evaluate the suitability for this type of data collection.

Ultimately, the research team and PMC selected three sites for the observational field studies, as shown with the arrows in Figure 3-1. The three observational field sites are as follows:

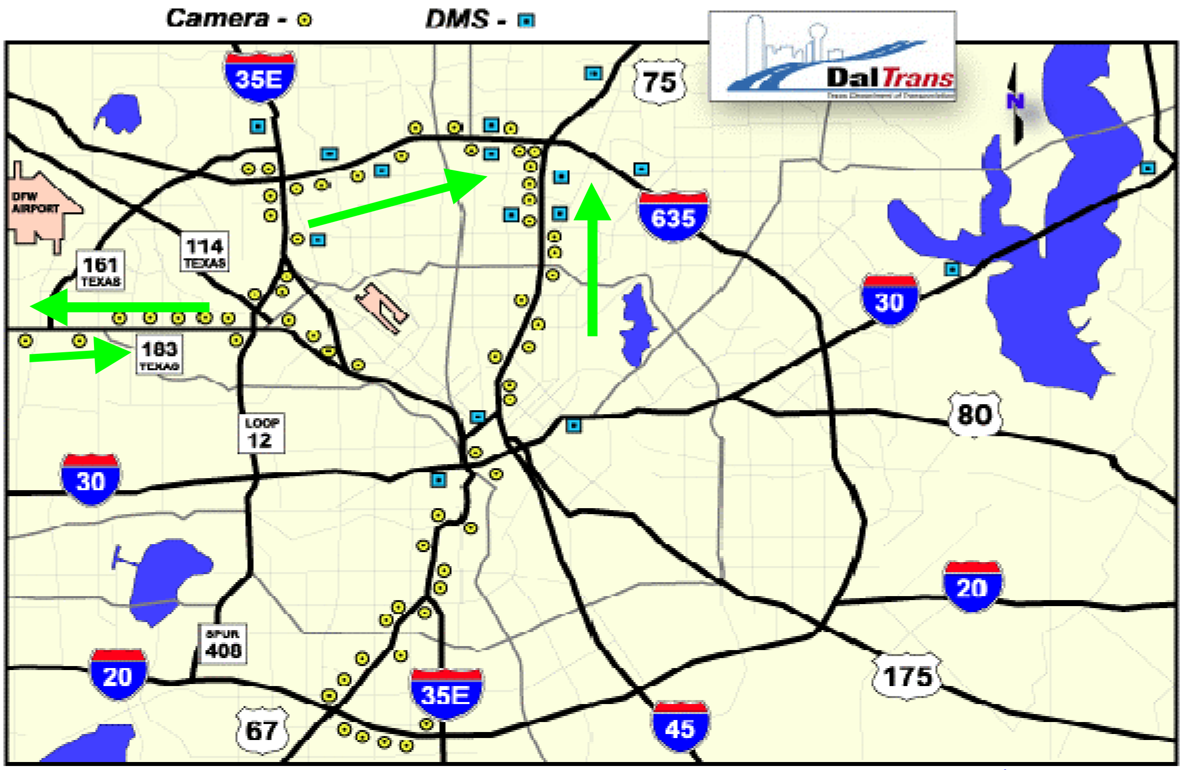


Figure 3-1. Camera and Sign Locations for the Daltrans TMC.[1]

- Site #1 – northbound US 75, PM peak period, approaching the IH 635 interchange (recurrent congestion).
- Site #2 – eastbound SH 183 near Texas Stadium, in the AM peak period, and westbound in the PM peak period (recurrent congestion).
- Site #3 – eastbound IH 635, PM peak period, approaching the US 75 interchange (construction related).

Prior to commencing data collection, researchers developed an observational field test plan and sent it to TxDOT for review. This field test plan:

- Summarized the techniques and locations selected for testing
- Identified the personnel and equipment needed to conduct the field tests
- Determined the types of information to be collected and methodologies selected
- Identified the evaluation strategy for field test results
- Determined any notification and coordination needs with other agencies

B. Data Collection Schedule

The research team began collecting recurrent congestion- and construction-related data in April 2002, and continued for five weeks until early May 2002. All data were collected during the mid-week days Tuesday, Wednesday, and Thursday. All data were collected with dry pavement and no apparent incidents. Researchers conducted a total of 16 observations.

The research team analyzed incident data from a total of six observations: one observation of SH 183 westbound in the PM, three observations of IH 635 eastbound in the PM, and two observations of IH 635 westbound in the AM.

C. Data Collection Strategy

The basic strategy for the collection of the field data was to obtain synchronized videotape of long sections of freeway as queues developed and dissipated, often repeatedly. Then, from these time-stamped tapes, data analysis personnel made comparisons between the location of known objects in the tape and the end of queue, by lane. The analysis personnel noted only the tail of the queue for purposes of this study because once drivers have encountered stop and go traffic, they have effectively been warned that stopped conditions exist on the freeway.

The known objects used to geolocate the tail end of the queues on the videotapes consisted of static freeway features with known station numbers. Thus, distances could be accurately computed as the queues varied over time. These static checkpoint features were usually light poles from the roadway illumination plans, but also included median and side-mount guide signs and, much less frequently, the physical gore of ramps, variable message sign locations, or bridge locations. The researchers were able to exactly locate all of these static features on plan sheets, sometimes after combining different sets of plans for the same freeway section. The data analysis personnel preferred roadway illumination as the checkpoint feature because the short spacing suited data collection needs, and because of the regularity of the installations and the ease of viewing them on the videotape.

For each freeway study site, researchers recorded the maximum number of camera views. This ranged from five to eight CCTV available camera views. In lieu of having each camera view recorded on eight separate video cassette recorders (VCR), DalTrans operators brought the camera images into the TMC and combined the images into "quad screen" views, which show four images on a single screen. Researchers provided tapes for recording the quad screen images. Thus, researchers utilized two synchronized VCRs to capture the concurrent video images. Close coordination with TxDOT engineers and TMC personnel was required to obtain these data, both in the configuration of equipment at the DalTrans TMC and in the selection of optimum camera views.

D. Data Reduction

A member of the research team developed an Excel spreadsheet to facilitate data entry into the computer. The data analysis personnel utilized two televisions and two VCRs. These workers viewed all videotape for queued conditions, and announced the lane and checkpoint location whenever a queue in a lane passed a checkpoint. A third person entered these data and the time into the spreadsheet. Figure 3-2 shows the data reduction personnel performing analysis of one of the observational field study sites.

Figure 3-2. Data Reduction Personnel.

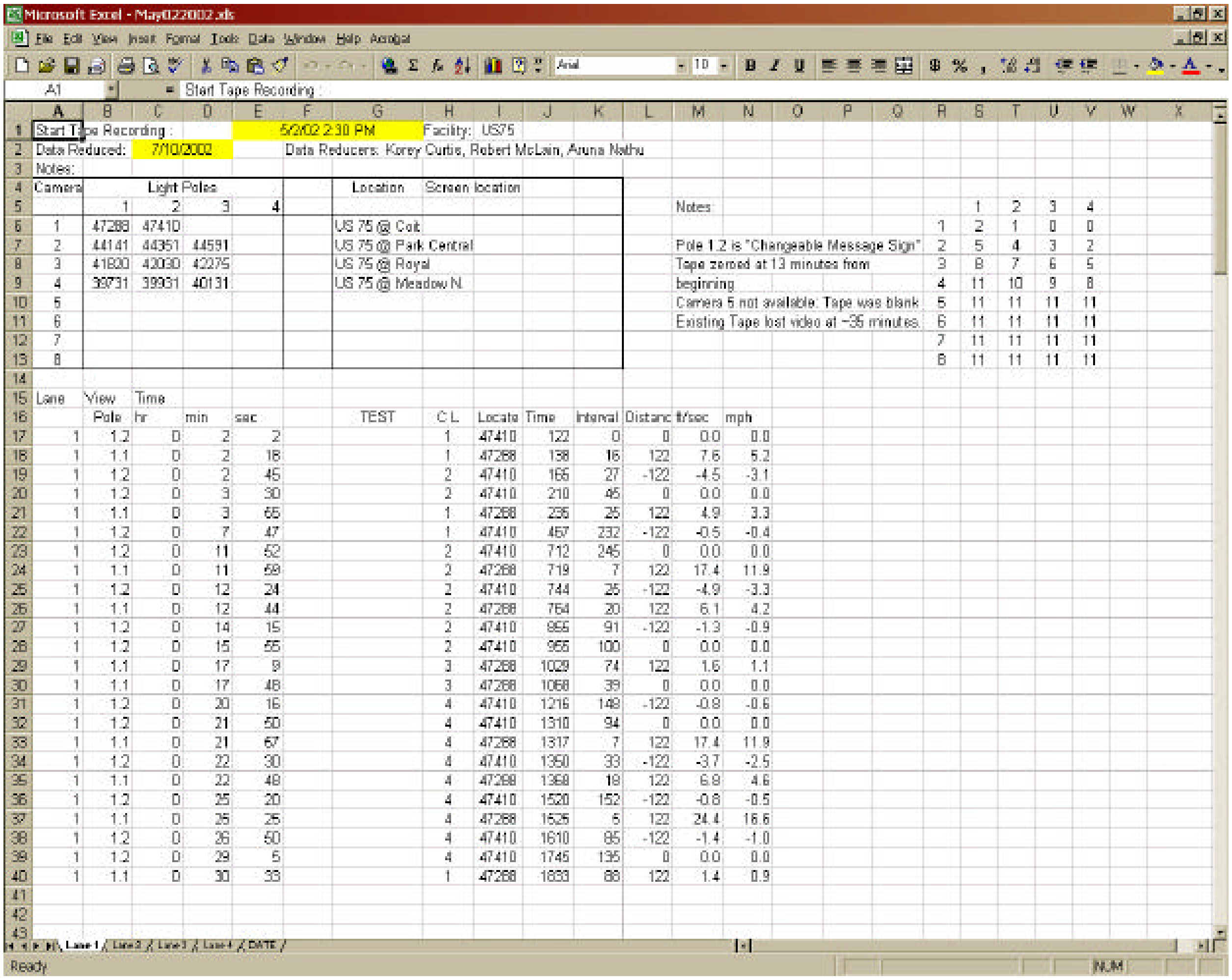
E. Data Analysis

The research team developed a second spreadsheet to facilitate data analysis. This spreadsheet computed the elapsed time and the associated queue propagation, by lane. From this, the spreadsheet also calculated the speed of the queue development in miles per hour. A negative number would indicate that the queue was dissipating, and the speed of that dissipation. For the purposes of this research, the positive values, where the queues were growing, were of particular interest in determining the conditions the drivers were encountering with stopped traffic on freeways. Figure 3-3 shows an image of the Excel spreadsheet used in this analysis, with the last column showing computed speeds in mph for lane 1 (always the inside lane) of US 75.

3.3 FINDINGS

A. Congestion Related to Recurrent Traffic Conditions and Work Zones

Researchers plotted speed versus time of day graphs for data pertaining to the northbound US 75 study site. This information was collected and plotted by lane. For this research study, lane 1 always referred to the inside median lane, with subsequent lanes numbered outward. Figure 3-4 shows an example of this type for northbound PM peak data on US 75 for one of the data collection days. Figure 3-4 shows the variation in observed speeds for queue development for lane 1; Figures 3-5 through 3-7 show the remaining lanes, and Figure 3-8 shows all lanes together.



Microsoft Excel - May022002.xls

Start Tape Recording : 5/2/02 2:30 PM Facility: US75

Data Reduced: 7/10/2002 Data Reducers: Korey Curtis, Robert McLain, Aruna Nathu

Notes:

Camera	Light Poles 1	2	3	4	Location	Screen location
1	47288	47410			US 75 @ Coit	
2	44141	44351	44591		US 75 @ Park Central	
3	41830	42030	42275		US 75 @ Royal	
4	39731	39931	40131		US 75 @ Meadow N.	
5						
6						
7						
8						

Notes:
Pole 1.2 is "Changeable Message Sign"
Tape zeroed at 13 minutes from beginning
Camera 5 not available. Tape was blank
Existing Tape lost video at ~35 minutes.

	1	2	3	4
1	2	1	0	0
2	5	4	3	2
3	8	7	6	5
4	11	10	9	8
5	11	11	11	11
6	11	11	11	11
7	11	11	11	11
8	11	11	11	11

Lane	View Pole	Time hr	min	sec	TEST	C L	Locate	Time	Interval	Distanc	ft/sec	mph
1	1.2	0	2	2		1	47410	122	0	0	0.0	0.0
1	1.1	0	2	18		1	47288	138	16	122	7.6	5.2
1	1.2	0	2	45		2	47410	165	27	-122	-4.5	-3.1
1	1.2	0	3	30		2	47410	210	45	0	0.0	0.0
1	1.1	0	3	65		1	47288	235	25	122	4.9	3.3
1	1.2	0	7	47		1	47410	467	232	-122	-0.5	-0.4
1	1.2	0	11	52		2	47410	712	245	0	0.0	0.0
1	1.1	0	11	59		2	47288	719	7	122	17.4	11.9
1	1.2	0	12	24		2	47410	744	25	-122	-4.9	-3.3
1	1.1	0	12	44		2	47288	764	20	122	6.1	4.2
1	1.2	0	14	15		2	47410	855	91	-122	-1.3	-0.9
1	1.2	0	15	55		2	47410	955	100	0	0.0	0.0
1	1.1	0	17	9		3	47288	1029	74	122	1.6	1.1
1	1.1	0	17	48		3	47288	1068	39	0	0.0	0.0
1	1.2	0	20	16		4	47410	1216	148	-122	-0.8	-0.6
1	1.2	0	21	50		4	47410	1310	94	0	0.0	0.0
1	1.1	0	21	67		4	47288	1317	7	122	17.4	11.9
1	1.2	0	22	30		4	47410	1350	33	-122	-3.7	-2.5
1	1.1	0	22	48		4	47288	1368	18	122	6.8	4.6
1	1.2	0	25	20		4	47410	1520	152	-122	-0.8	-0.5
1	1.1	0	25	25		4	47288	1525	5	122	24.4	16.6
1	1.2	0	26	50		4	47410	1610	85	-122	-1.4	-1.0
1	1.2	0	29	5		4	47410	1745	135	0	0.0	0.0
1	1.1	0	30	33		1	47288	1833	88	122	1.4	0.9

Lane 1 / Lane 2 / Lane 3 / Lane 4 / DATE

Ready

Figure 3-3. Screen Capture of Excel Spreadsheet Used for Queuing Analysis.

Of note in Figure 3-4 is the prevalence of multiple spikes of queue propagation speeds in excess of 20 mph, between about 3:25 to 3:40 PM (about 15 minutes). There is one spike earlier, around 2:45 PM, where the queue propagated at a rate of 27 mph. These changes reflected queue growth of 240 ft within 7 or 6 seconds, respectively, in lane 1. Areas where the line is "flat" reflect areas where, for a variety of reasons, data were not available. The most common reason for the data gaps was that there was no congestion during those timeframes, or that data collection and reduction could not take place during those timeframes because the queue tail was too difficult to geolocate (sometimes due to foreshortened camera views) or because it was not visible on camera. Figure 3-5 shows a spike of over 55 mph in lane 2, where queues grew 245 ft in 3 seconds. Figure 3-8 shows the variability of experiences approaching drivers might have depending upon their time of arrival at the queue tail and their lane of travel.

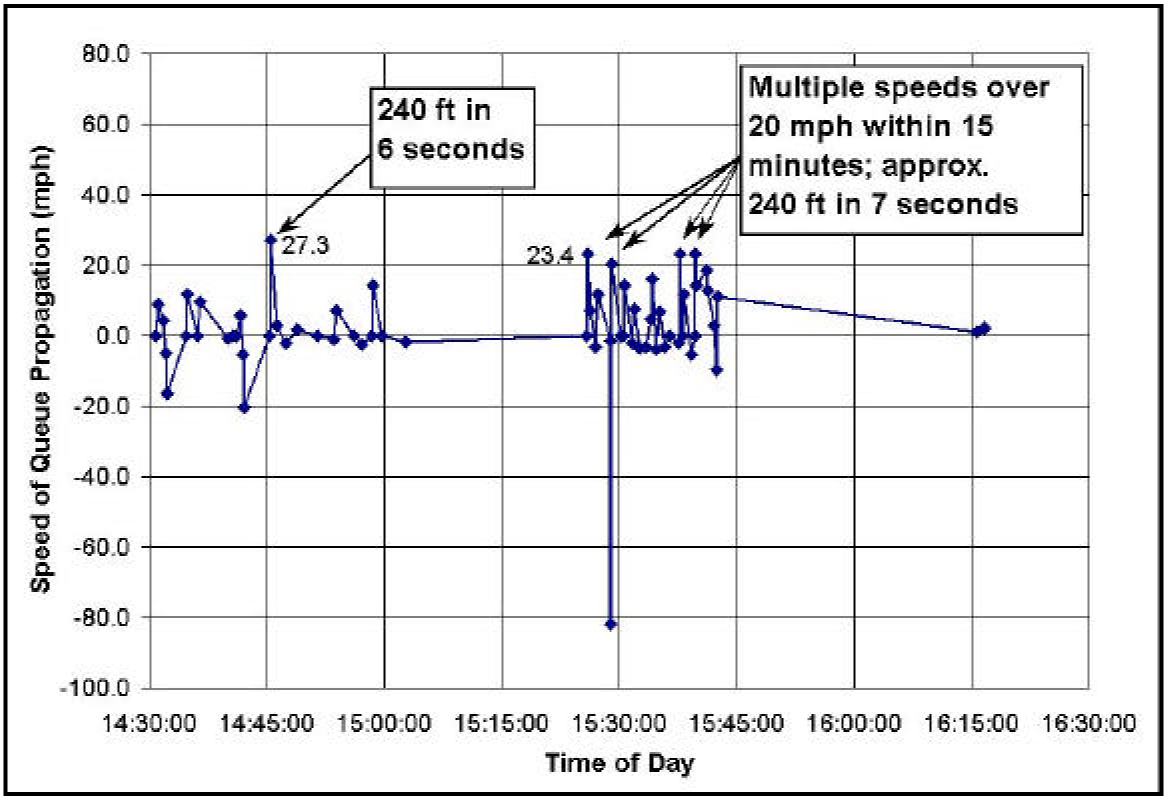


Figure 3-4. US 75 Queue Propagation Data – Lane 1 of 4.

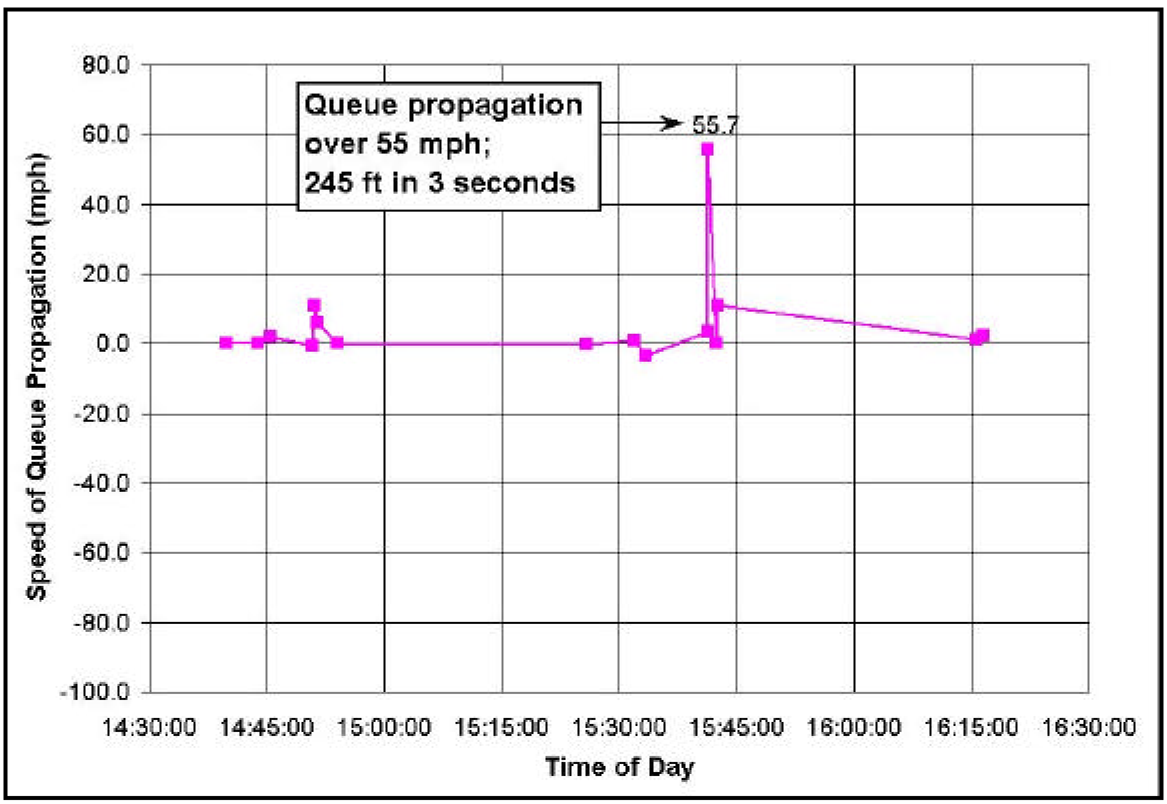


Figure 3-5. US 75 Queue Propagation Data – Lane 2 of 4.

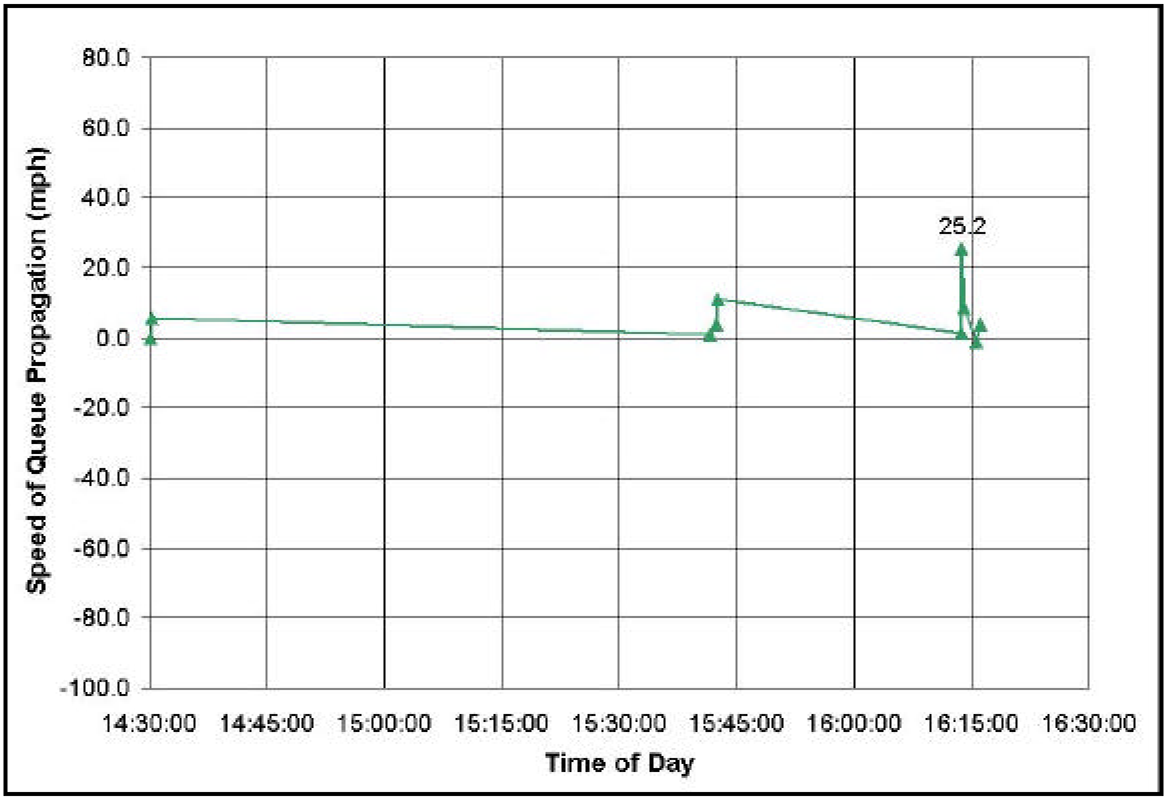


Figure 3-6. US 75 Queue Propagation Data – Lane 3 of 4.

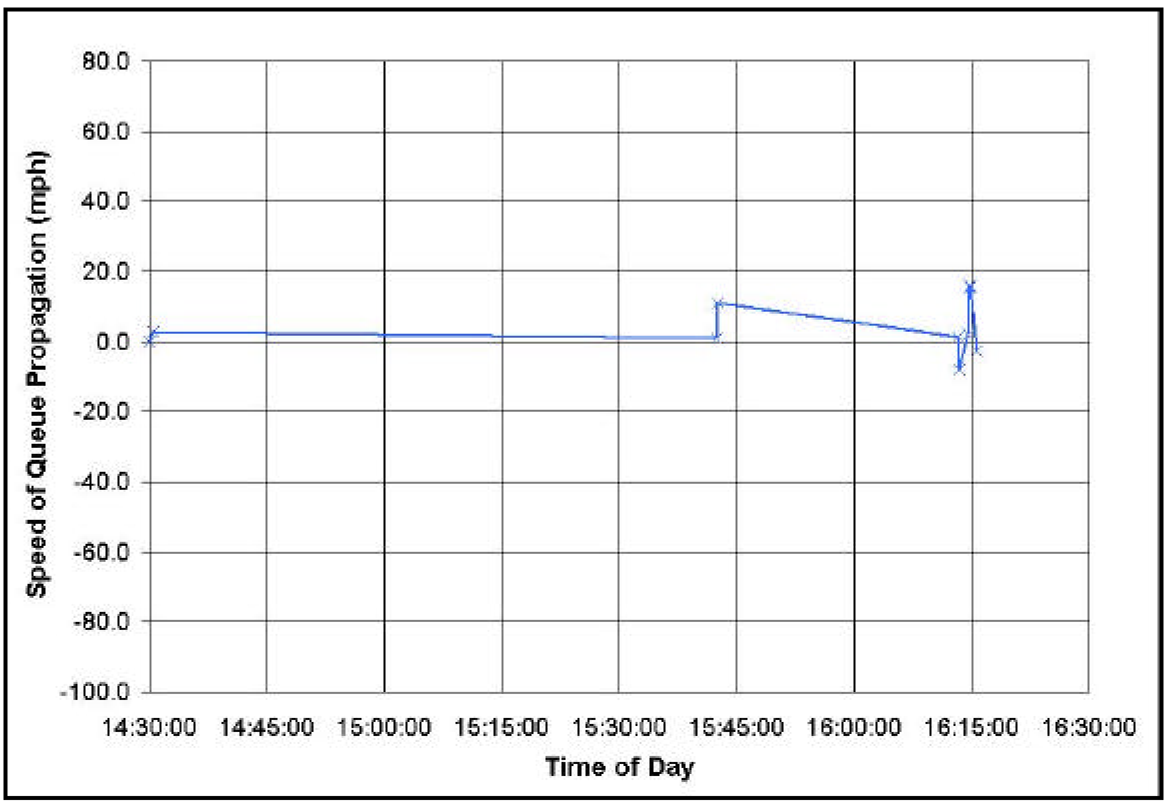


Figure 3-7. US 75 Queue Propagation Data – Lane 4 of 4.

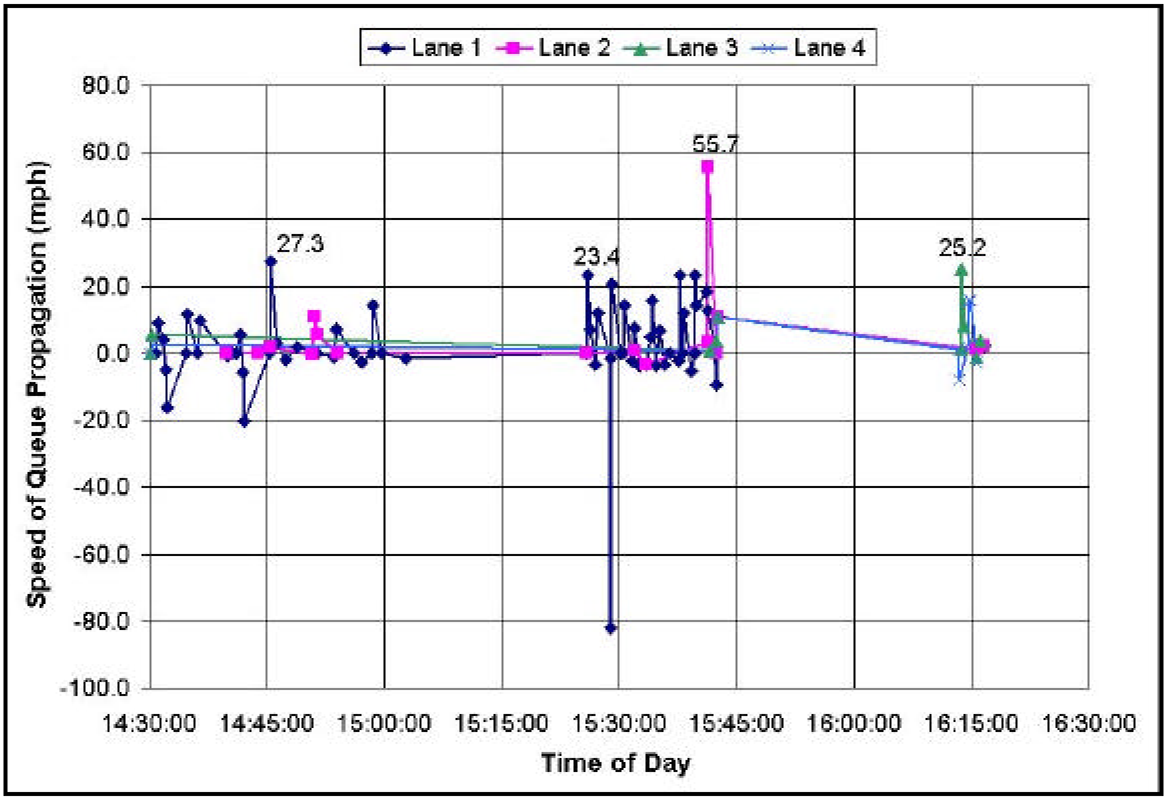


Figure 3-8. US 75 Queue Propagation Data – All Lanes.

Another type of graph, developed for all data collection days and for each of the four study sites, was a graph of growth of queue versus elapsed time. For this type of graph, data points were not shown if the speeds were less than 5 mph, to enhance the clarity of the graph. These data were not of particular interest for the purposes of this study, since they showed very slow queue propagation or queue dissipation. Figure 3-9 shows a graph of recurrent congestion- and construction-related data points in a format that has segments of the graph allocated to various speed ranges. This format concurrently indicates on which freeway the data were collected. Duplicated data points are not shown, but may exist "underneath" shown data points; thus, a frequency distribution is not determinable by looking at these data. However, since data collection was limited to sites in Dallas and to fairly small timeframes, the purpose of the data collection was to determine conditions that were typically encountered by urban drivers, and not representative of rare events. These findings probably represent conditions that are frequently encountered by urban drivers. To determine what unusual conditions might occur would take a longer, more detailed study. In Figure 3-9, data show a 27 mph queue propagation along SH 183 that represents a distance of 4694 ft in a period of 115 seconds.

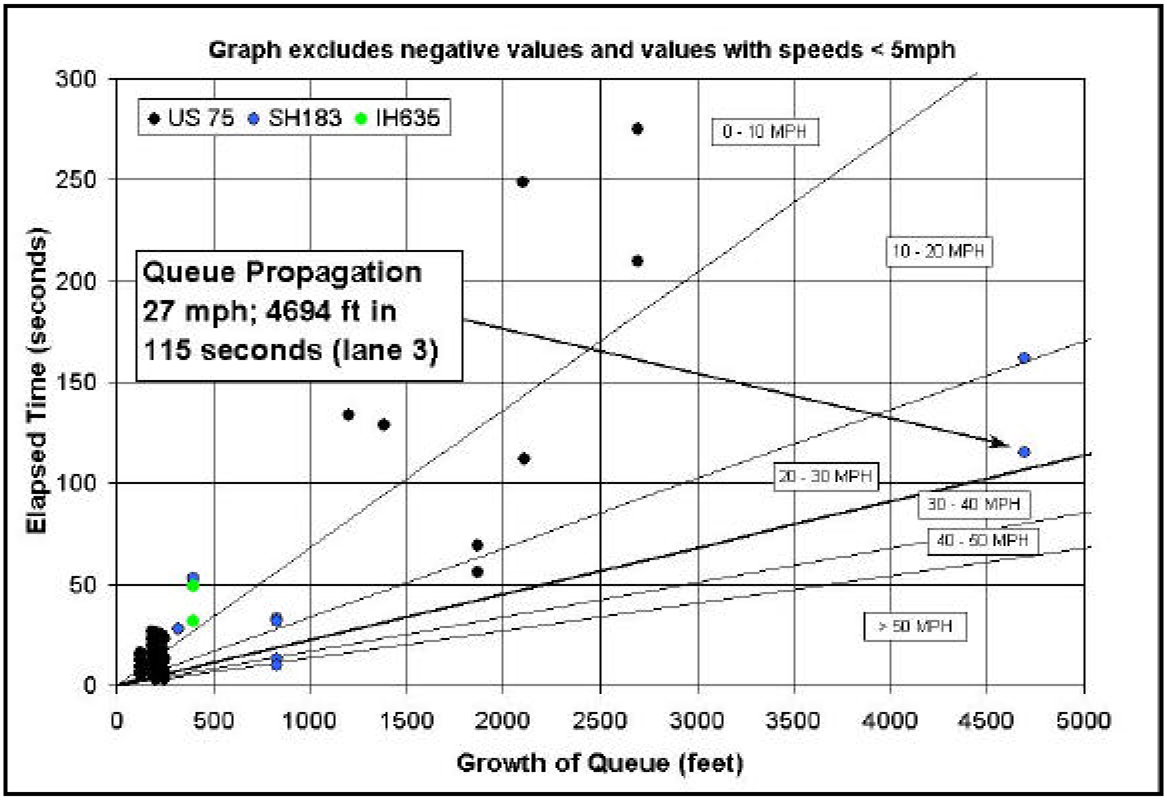


Figure 3-9. Queue Propagation Data for Recurrent Congestion Studies – View 1.

Figure 3-10 shows the same graph truncated to events that occur faster than one minute, and grow less than 1000 ft. This was done to clarify the mass of data points that are difficult to distinguish on the smaller scale. In Figures 3-10 and 3-11, several data points along SH 183 are of particular interest. Figure 3-10 shows a 43 mph queue propagation (which happens to be in all three lanes, although this is not evident from the base graph) that translates into an 830 ft queue growth within 13 seconds. Figure 3-11 shows a similar data point, which relates to a 56 mph queue buildup (two lanes were queued on another data collection day), which translates into an 830 ft queue buildup in 10 seconds. Among data shown in Figure 3-10 are data previously discussed for US 75, notably the instance in which a queue grew at 55 mph (Figure 3-5).

B. Congestion Related to Incidents

The growth of queue versus elapsed time data format was also used to portray incident data, again, plotting only data equal to or in excess of 5 mph. Because no incidents occurred during field observations on US 75, no incident data exist for that location. Looking at the smaller scale graph, Figure 3-12, a sustained queue development of 19 mph is shown on IH 635, with the queue propagating 5047 ft in 181 seconds. Similarly, on SH 183, a queue propagation speed of just over 15 mph is shown growing 2470 ft in 108 seconds. Figure 3-13, for which the scale changes in order to better view data points near the origin, shows a 38.5 mph backup (395 ft in 7 seconds) for SH 183 on a day when there was an incident along the eastbound frontage road. Extra traffic entering the freeway to bypass the frontage road incident led to congestion on the freeway that day.

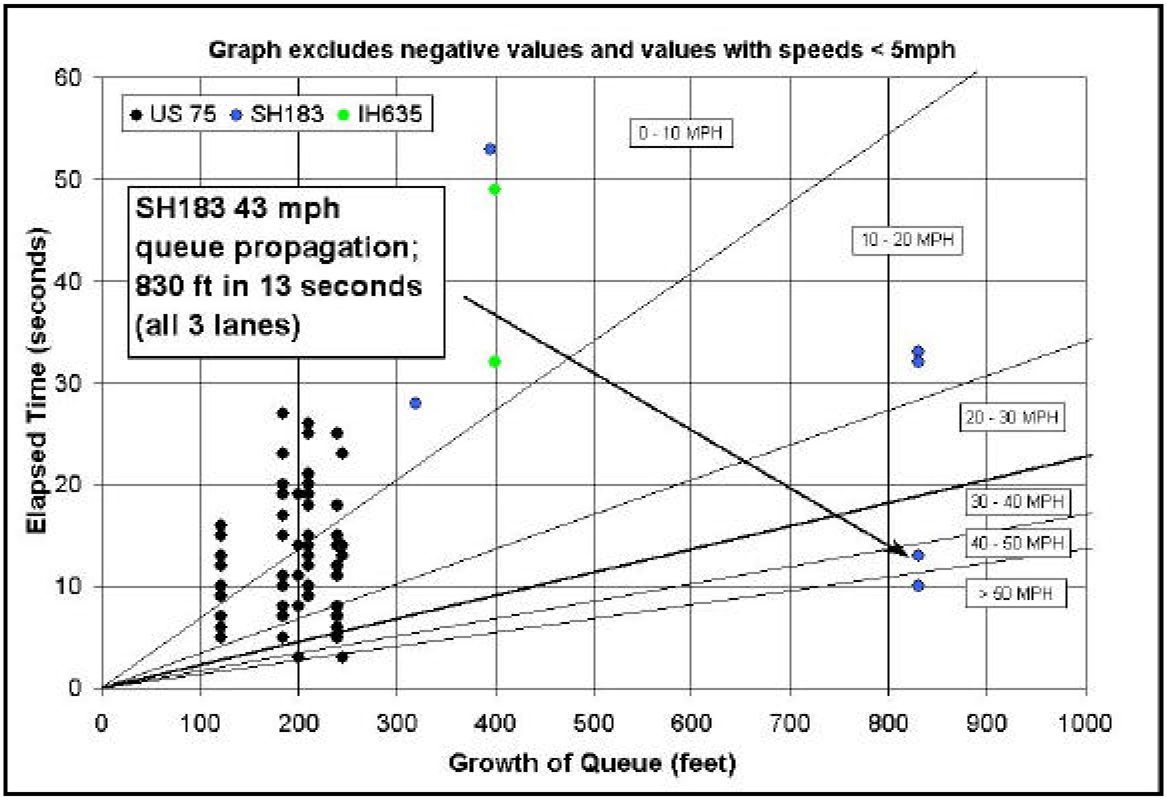


Figure 3-10. Queue Propagation Data for Recurrent Congestion Studies – View 2.

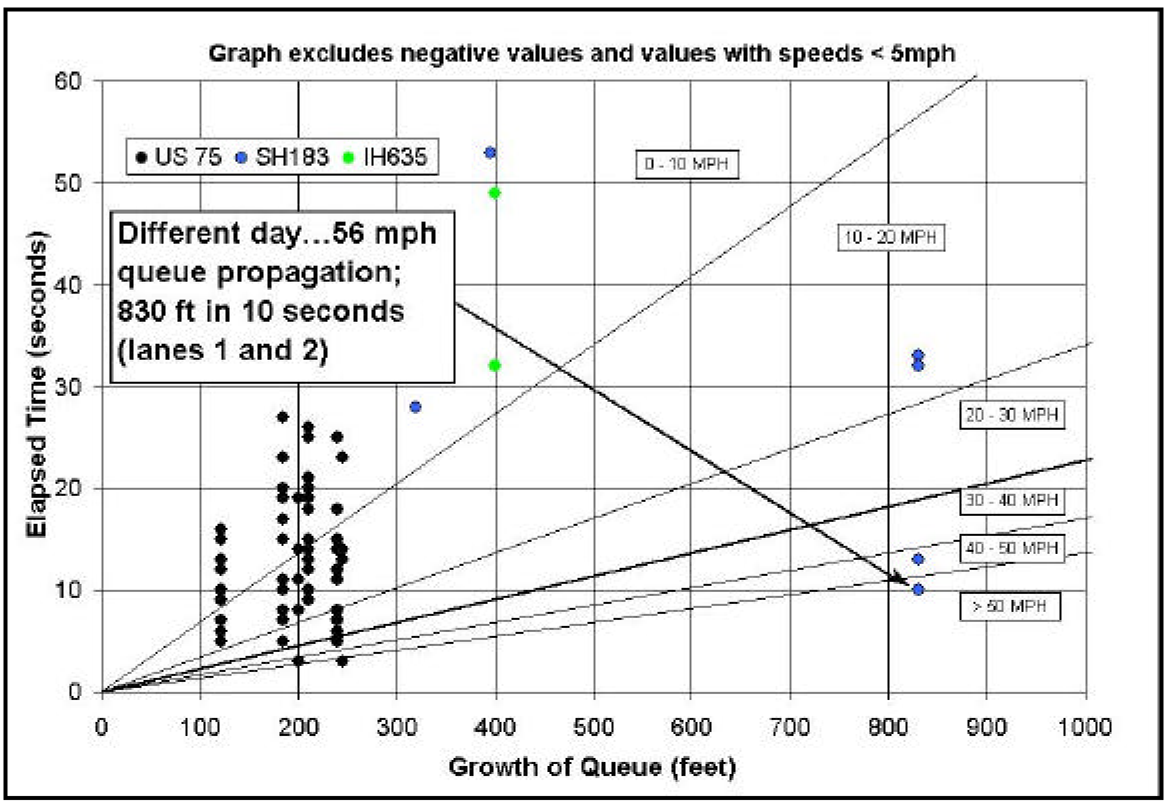


Figure 3-11. Queue Propagation Data for Recurrent Congestion Studies – View 3.

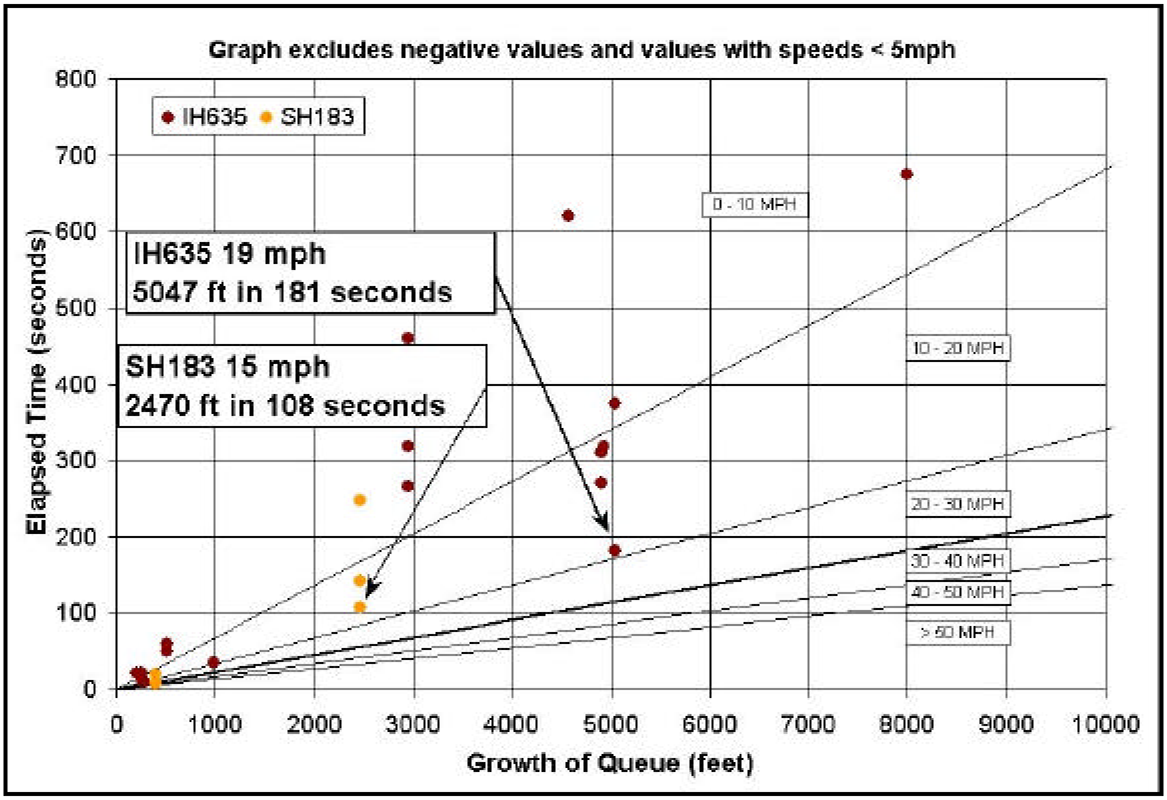


Figure 3-12. Queue Propagation Data for All Incident Studies – View 1.

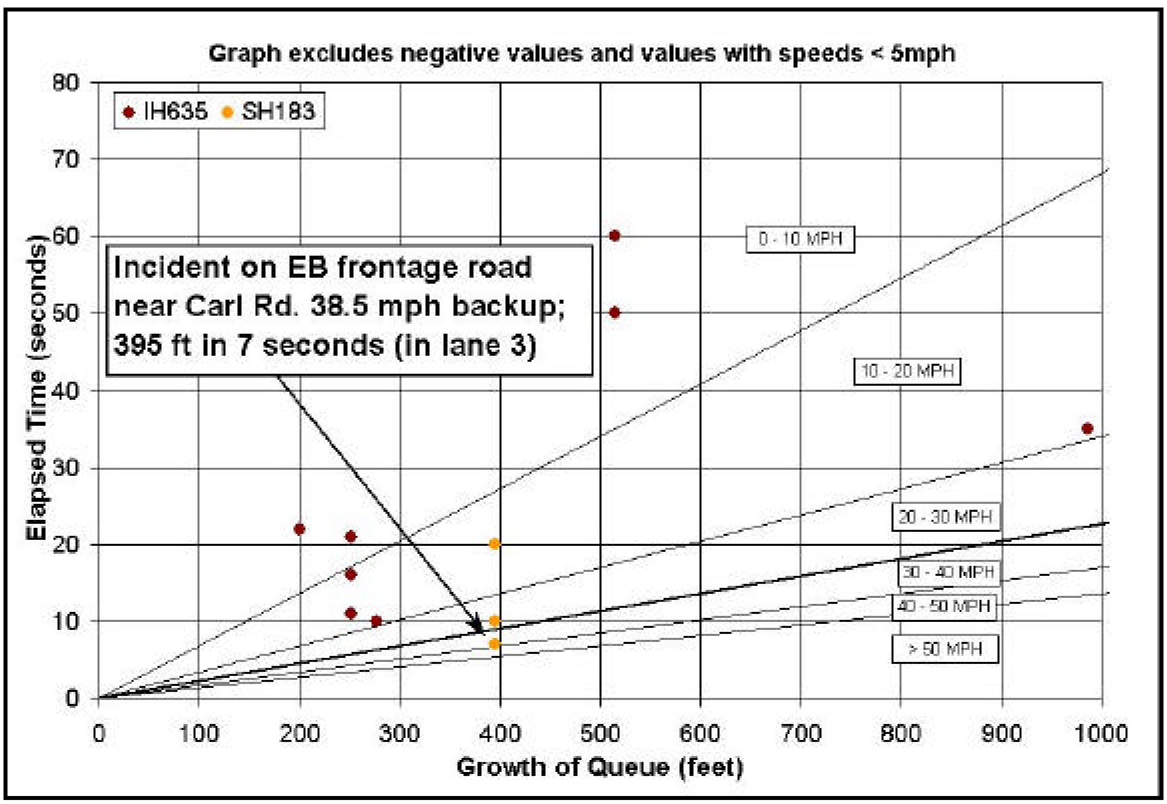


Figure 3-13. Queue Propagation Data for All Incident Studies – View 2.

3.4 SUMMARY OF FINDINGS FOR QUEUE PROPAGATION STUDIES

In summary, researchers have found instances of sustained, repetitive, and excessive queue propagation speeds in these attempts to define the nature of the issue. Additionally, in many instances, multiple lanes were 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, as discussed in greater detail below.

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 made. 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. Additionally, queue development can vary across freeway lanes to preclude accurately providing drivers with distance information to the queue tail, because drivers in any approach lane can read the warning signs, and conditions can vary greatly depending upon the approach lane. Many factors remain to be addressed in future research; however, observations conducted within Task 3 of this project can assist in providing guidance to those testing and implementing and operating systems for advance warning of stopped traffic on freeways.

A. Geometric Issues

Within the project proposal, researchers identified plans to determine, to the extent possible, the impacts that freeway geometry might have on traffic approaching a growing queue. Since it is difficult to capture data at **the exact moments when these two factors interact**, these data were collected anecdotally throughout the first year of research. The following three situations are presented as case studies typical of conditions encountered throughout the year.

1) Case 1

In this instance, researchers were westbound on IH 30 in the city of Grand Prairie, within the TxDOT Dallas District. A queue developed that was not clearly visible due to obstructed sight distance, since an overpass structure was blocking the view (although the freeway would have been visible for a long distance otherwise). Other drivers seemed surprised by the existence of the queue also, since two vehicles in the inside lane (of the three lanes) went into the grassy center median in order to avoid rear-end collisions. This site is depicted in Figure 3-14.

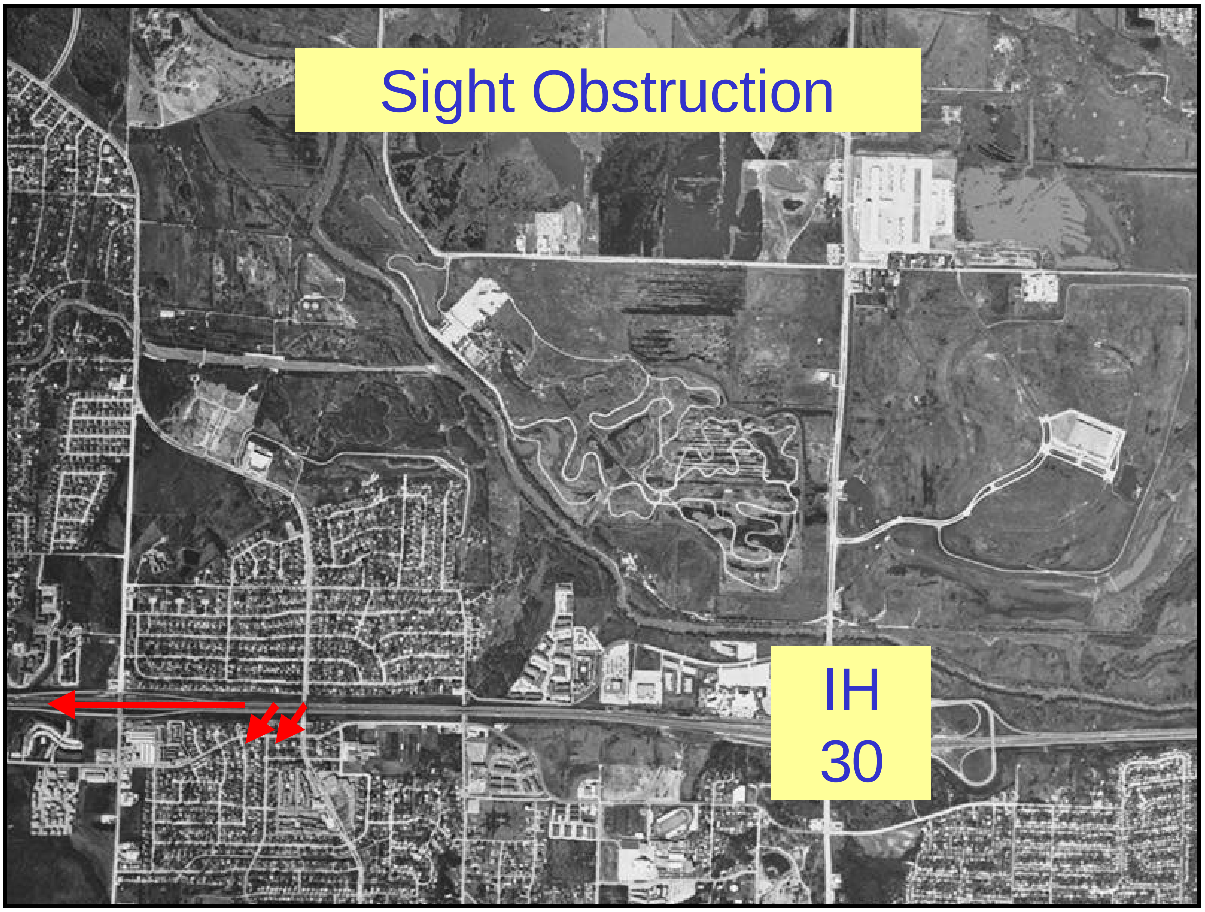


Figure 3-14. Anecdotal Case Study Example #1.

2) Case 2

In this instance, a similar queue created due to a collision was encountered on eastbound IH 20, in the city of Fort Worth within the Fort Worth District. Visibility to this queue was also hindered by the physical structure of the McCart Street overpass. The freeway main lanes go under the McCart Street bridge but then over the nearby railroad track. Despite the lack of visibility, approaching drivers did not seem to be surprised by this queue. This lack of surprise was attributed to the presence and use of the Fort Worth District's freeway lane control signals, which provided drivers advance notice of the closed right two lanes of the four-lane freeway. Drivers had ample time to make adjustments and move out of the lanes, which were closed due to a collision involving the eastbound on ramp from McCart. Figure 3-15 depicts this scenario.

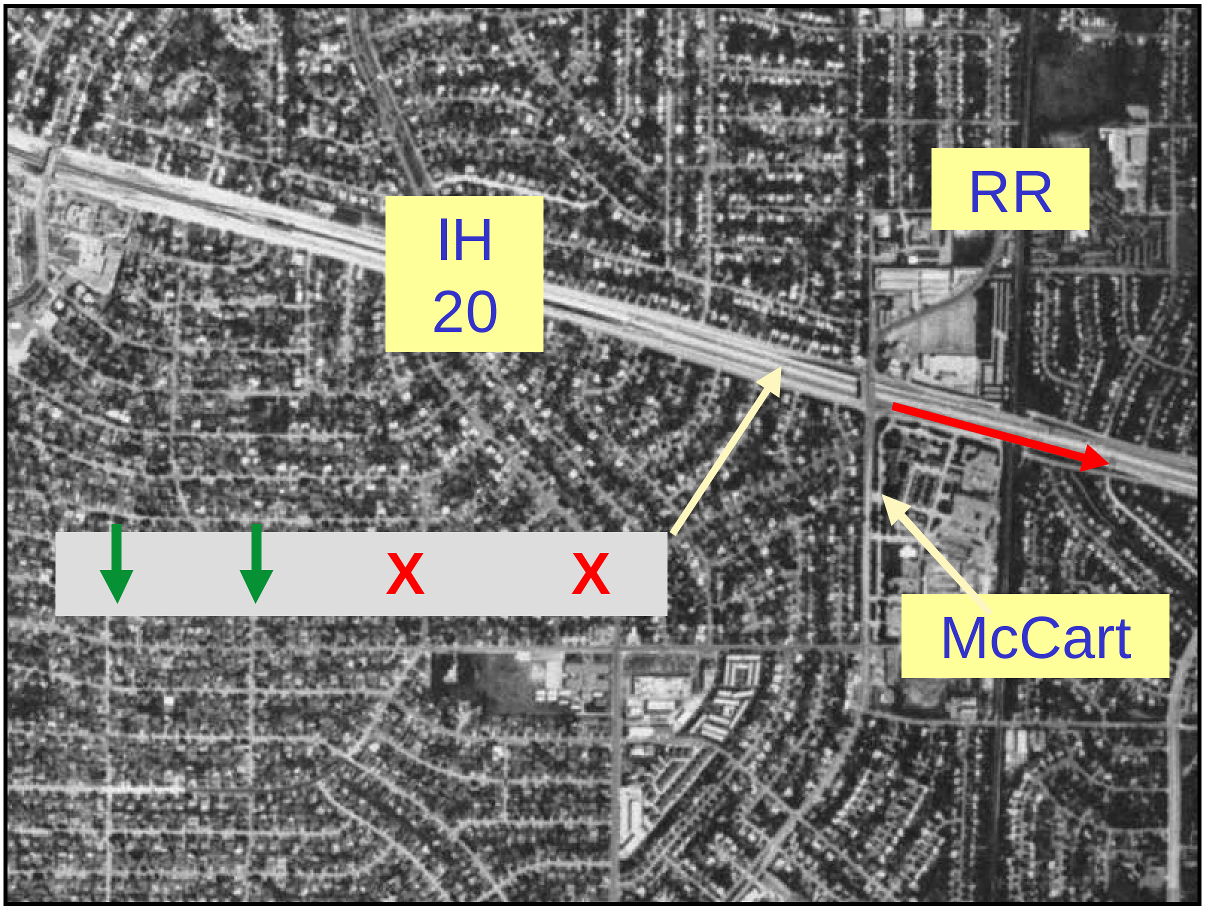


Figure 3-15. Anecdotal Case Study Example #2.

3) Case 3

A researcher observed the final case on southbound IH 20 in Fort Worth, near the merge with southbound US 287. Due to the intense weaving where these two freeways meet, traffic congestion often extends onto the approach legs of the weaving section. Traffic approaching southbound on IH 820 is at-grade, but the main lanes climb over Wilbarger Street and then back to grade in a somewhat pronounced vertical curve. This is immediately followed by a S-shaped horizontal curve, and the queued vehicles were not visible by drivers until they were on the crest of the Wilbarger bridge. A researcher observed two vehicles in the outside lane (of two lanes) diverting abruptly to the outside shoulder to avoid rear-end collisions (Figure 3-16).

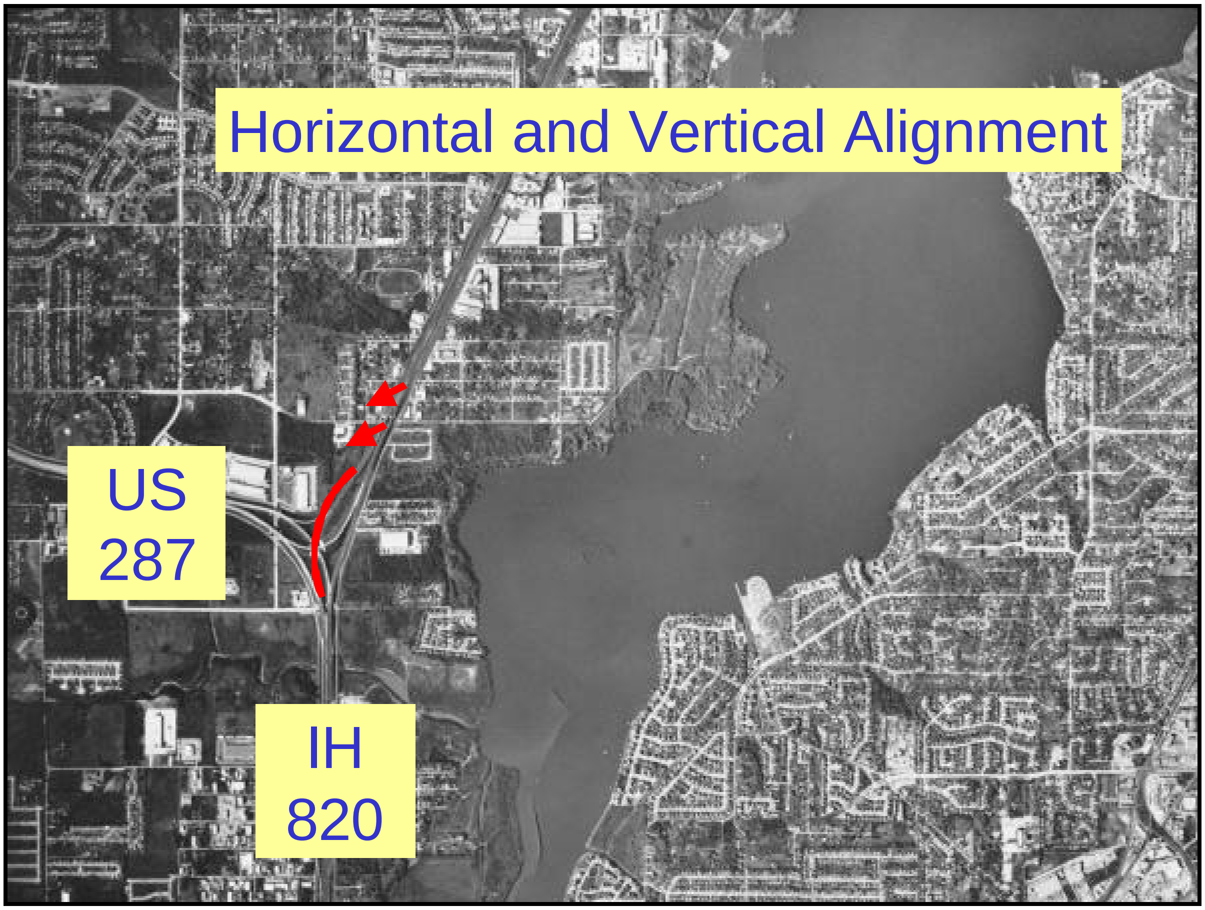


Figure 3-16. Anecdotal Case Study Example #3.

B. Erratic Maneuver Issues and Inappropriate Use of Ramps and Shoulders

The issues of erratic maneuvers and inappropriate use of travel lanes were discussed and quantified within TxDOT-sponsored research conducted by TTI in Research Project 2137-1, led by Dr. Gerald Ullman and entitled "A Review of Traffic Management and Enforcement Problems and Improvement Options at High-Speed, High Volume Work Zones in Texas." Dr. Ullman reported the driving behavior exhibited by vehicles approaching queues, identifying such occurrences as hard braking (when the nose of the braking vehicle visibly dropped), queue jumping (when vehicles perhaps intentionally drove in the closing lane to pass other traffic), lane straddling, and forced merging (when vehicles forced their way into the open lane adjacent to the closed lane). The most prevalent type of erratic maneuver was the forced merge, for both passenger vehicles and trucks. To avoid redundant research and because of the informative and relevant results of Research Project 2137, the research team decided to keep the findings of Project 2137 in mind when proceeding with this project.

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CHAPTER 4. APPLICABILITY OF QUEUE WARNING TO TxDOT

In Task 4, the researchers were to determine the applicability of the reported queue detection and warning practices and techniques to TxDOT. The researchers evaluated each warning strategy by conducting qualitative assessments of three factors:

- Complexity of implementation and operation
- Conformance with current TxDOT standards
- Estimated expense of implementation

4.1 COMPLEXITY OF IMPLEMENTATION AND OPERATION

The research team made an assessment of the complexity of implementation and operation of each of the queue warning techniques identified in Chapter 2. The researchers rated the complexity factor as "Low," "Medium," or "High."

4.2 CONFORMANCE WITH CURRENT TXDOT STANDARDS

The research team also made an assessment as to whether the queue warning practice or technique in question met current TxDOT standards. Researchers indicated the standards assessment with "Yes" or "No" responses, or a question mark symbol if the assessment was unclear.

4.3 ESTIMATED EXPENSE OF IMPLEMENTATION

The research team performed the assessment of the cost for equipment and deployment by comparing the relative cost of the systems to each other. In general, researchers assigned a low cost rating to systems that utilized static signs and standard detection strategies. The research team assigned medium and high cost ratings to systems that involved extensive deployments of high-technology devices. In all cases, researchers made a qualitative judgment as to the relative cost, since actual cost figures were available for only a few of the systems (Chapter 2). The research team assigned the estimated costs for equipment and deployment as low ($), medium ($$), or high ($$$). The research team also assigned a question mark (?) to those systems where there was some uncertainty regarding the estimated cost or whether Texas standards appear to be met.

4.4 TABLES SHOWING APPLICABILITY TO TXDOT

Because of the numerous international and national queue warning techniques reported within Chapter 2, researchers decided to utilize the same organizational and alphabetical format in reporting the applicability of these systems to TxDOT. Table 4-1 lists this assessment for the international queue warning techniques and practices. Table 4-2 provides this assessment for the state DOT queue warning techniques and practices.

Table 4-1. Assessment and Applicability of International Agencies Queue Warning Techniques.

Location	Problem Type	Detection Technique(s)	Warning Technique(s)	Complexity of Implementation & Operation	Meets Standards	Estimated Expense
AUSTRALIA						
Melbourne EB off ramp to the Hume Highway	Exit ramp spillback	Embedded loops	Variable speed sign (VSS) and variable message sign (VMS)	High	Yes	$$$
BELGIUM						
Antwerpen E313 freeway	Construction queues	Video detection (Traficon)	VMS panels and trailer-mounted VMS	High	Yes	$$$
CANADA						
Ontario US border near Niagara	Border queues	Microwave radar (EIS–NEWS)	Static signs with flashers– 'Prepare to Stop When Flashing'	Medium	Yes	$$
Ontario St. Catharine's	Construction queues Secondary collisions	Microwave radar	Queue warning signs	High	No	$$, ?
DENMARK						
Aalborg	Recurrent congestion	Embedded loops	VSS	High	?	$$, ?
FINLAND						
Helsinki Western Artery	Fog – visibility Recurrent congestion	Embedded loops	VSS and VMS	High	?	$$$
GERMANY/ITALY						
German Autobahns	Incident congestion	Police and/or motorist reports	Helicopters with STAU sign Overpasses with STAU sign Driver warning	High Low Low	No No Yes, ?	$$$ $ $
A 9 and A 92 near Munich	Recurrent congestion	Video detection	COMPANION posts and VMS panels	High	No	$$$
A 3 near Hosbach A 9 near Greding A 12 near Poland	Construction queues (A 3, 9) Border queues (A 12)	Infrared	VMS	High	Yes	$$$
A 100 in Berlin	Recurrent congestion	Video detection	VMS panels, VSS, & lane control signals	High	Yes, ?	$$$
JAPAN						
Tokyo Metro Expressway	Recurrent congestion Incident congestion	Ultrasonic detectors @ 300 m (984 ft) spacing	VMS–congestion tail display boards	High	Yes	$$$

Table 4-1. Assessment and Applicability of International Agencies Queue Warning Techniques (continued).

Location	Problem Type	Detection Technique(s)	Warning Technique(s)	Complexity of Implementation & Operation	Meets Standards	Estimated Expense
NETHERLANDS						
Netherlands	All types	Embedded loops	VSS VMS	High	Yes	$$$
NEW ZEALAND						
All throughout the country	Recurrent congestion	No active detection	Static sign with symbol for congestion/queue ahead	Low	No, ?	$
NORWAY						
Oslo	Recurrent congestion	Video detection (Traficon)	Special queue warning VMS with flashers	High	Yes	$$$
TURKEY						
Aydin-Izmir and Istanbul Kurtkoy Airfield motorways	Recurrent congestion Incident congestion Construction queues	Doppler radar	Speed warning panels VMS panels Trailer-mount VMS	High	Yes	$$$
UNITED KINGDOM (ENGLAND + SCOTLAND)						
United Kingdom M1, M25, and M60 roadway facilities	Secondary collisions	Embedded loops	Variable speed signs VMS	High	Yes	$$$
Scotland M90	Recurrent congestion Visibility concerns	Microwave radar	COMPANION posts at 50 m (164 ft) spacing	High	No	$$$

Table 4-2. Assessment and Applicability of United States Agencies Queue Warning Techniques.

Location	Problem Type	Detection Technique(s)	Warning Technique(s)	Complexity of Implementation & Operation	Meets Standards	Estimated Expense
CALIFORNIA						
Temucula IH 15 @ Winchester	Exit ramp spillback	No detection	Static sign with pretimed flashers	Medium	Yes	$
Highway 17	Secondary collisions near mountain pass	Embedded loops Fog detectors	VMS	High	Yes	$$$
Statewide	Fog – visibility Incident congestion	Varies – mostly motorist reports	Incident response vehicles with trailer-mounted VMS	Medium	Yes	$$
State Route 120	Fog – visibility	Embedded loops Fog detectors	VMS with preprogrammed messages	High	Yes	$$$
Statewide	Fog – visibility Incident congestion	Varies – mostly motorist reports	CHP: PACE, Traffic Breaks, and Round Robins	Medium	?	$
FLORIDA						
Palm Beach County IH 95	Construction queues	Video detection Radar (ADDCO)	Trailer-mounted VMS	High	Yes	$$$
GEORGIA						
IH 75 – south Georgia	Fog – visibility	Embedded loops Fog detectors	VMS with preprogrammed messages Automatic police notification	High	Yes	$$$
HAWAII						
H-1 @ Makakilo	Exit ramp spillback	No detection	No warning: now extending ramp spacing to intersection	N/A	N/A	N/A
ILLINOIS						
IH 55	Construction queues	Radar detection	Trailer-mounted VMS	High	Yes	$$$
Tri-State Tollway @ Grand Avenue	Exit ramp spillback	Embedded loops	Static signs with flashers – 'Congestion Ahead: Ramp Congestion When Flashing' Bottleneck improvement	Medium	Yes	$
INDIANA						
IH 65 @ State Road 131	Exit ramp spillback	Embedded loops	Static signs with flashers – 'Watch for Slowing Traffic' Bottleneck improvement	Medium	Yes	$

Table 4-2. Assessment and Applicability of United States Agencies Queue Warning Techniques (continued).

Location	Problem Type	Detection Technique(s)	Warning Technique(s)	Complexity of Implementation & Operation	Meets Standards	Estimated Expense
MINNESOTA						
Central Minnesota	Recurrent congestion @ freeway lane drop Rear-end collisions	Optical detectors	Static sign with wig-wag flashers and a VMS placed in advance of end of queue	High, ?	Yes	$$$, ?
MISSOURI						
St. Louis Northbound IH 270 @ IH 70	Recurrent congestion Rear-end collisions Unfamiliar drivers	No detection – flashers activated by time of day	Static sign with flashers – 'Congestion Ahead: Next 2 Miles'	Low	Yes	$
Kansas City Grandview triangle interchange	Recurrent congestion Rear-end collisions	No detection – flasher activated by time of day	Static sign with flasher – 'Congestion Ahead'	Low	Yes	$
St. Louis Westbound IH 270 @ IH 170	Exit ramp spillback Rear-end collisions	No detection – timed flashers	Static sign with flashers – 'Left Exit Ahead: Be Alert'	Low	Yes	$
NORTH CAROLINA						
Various locations	Construction queues Recurrent congestion Rear-end collisions	Unknown	Several static signs: (1) Traffic Congestion Ahead: When Flashing (2) Slow Moving Traffic (3) Work Zone – Stay Alert: Prepare for Slow Moving Traffic	Low	Yes	$
PENNSYLVANIA						
US 22	Construction queues Sight distance Rear-end collisions	Queue length detectors using infrared beams	Series of VMSs (CHIPS system)	High	Yes	$$$
Pennsylvania Turnpike	Construction queues Rear-end collisions	Radar detector speed devices	Series of VMSs with set messages based on average traffic speed and also HAR	High	Yes	$$$
TENNESSEE						
IH 75 around the Hiwassee River	Fog – visibility	Fog detectors Radar detectors	Series of VMSs with set messages based on weather and roadway conditions	High	Yes	$$$

Table 4-2. Assessment and Applicability of United States Agencies Queue Warning Techniques (continued).

Location	Problem Type	Detection Technique(s)	Warning Technique(s)	Complexity of Implementation & Operation	Meets Standards	Estimated Expense
TEXAS						
San Antonio TransGuide	Recurrent congestion Rear-end collisions	Embedded loops	VMSs with congestion ahead warning messages	Low	Yes	$
Fort Worth IH 20 @ Hulen Street	Exit ramp spillback	Video detection by TMC staff using cameras	VMSs with 'Watch for Slow Traffic at Hulen Exit'	Low	Yes	$
Fort Worth Westbound IH 20 frontage road @ Bryant Irvin	Recurrent congestion Sight distance Rear-end collisions	No detection	Static sign 'Caution: Watch for Slow Traffic Ahead'	Low	Yes	$
Fort Worth Southbound SH 121 @ SH 183	Recurrent congestion Rear-end collisions	No detection	Series of static signs: 1. 'Slow Traffic Ahead Be Prepared to Stop', and 2. 'Caution: Watch for Slow Traffic Ahead' (with side-mounted flashers)	Low	Yes	$
VIRGINIA						
Two truck weigh stations	Spillback at truck weigh stations	Embedded loops	Electronic signs that tell truckers if the station is open	Medium	Yes	$
WASHINGTON						
On IH 5 near the Port of Tacoma	Exit ramp spillback	Video detection	Static sign with flashers that tells truckers to use another ramp to approach the Port	Medium	Yes	$$
King County SE 208th Street	Sight distance limitations Rear-end collisions	Embedded loops	Static sign on span wire: 'Prepare to Stop When Flashing' with hill pictogram	Medium	Yes, ?	$
WEST VIRGINIA						
IH 64 in the Nitro-St. Albans Area	Fog – visibility	Fog detectors Embedded loops	Sign that warns motorists to slow down and use caution	High	Yes	$$

CHAPTER 5. SUMMARY OF INTERIM RESULTS

Phase one of this research project is summarized by tasks in the following sections. Each section lists the major efforts performed and key findings.

5.1 TASK 1: LITERATURE REVIEW

As detailed in this report, researchers conducted a literature review to determine the relevance to advance warning for slow/stopped traffic on freeways. The following subsections summarize some of the significant findings from previous studies.

A. Rear-End Collision Studies

The significant findings of several studies of rear-end collisions on freeway facilities are provided in the following list:

- The most frequent manner of collision in the United States, especially at work zones, is rear-end collisions.[1,2,3,4]
- An University of Alabama study of work zone collisions on Interstates and US Highways in Alabama, Michigan, and Tennessee found that the 'typical' work zone collision involved a male driver, aged 24 to 35, who, while driving in clear weather during mid-afternoon came upon slow/stopped traffic and collided with another vehicle.[5]
- Several studies support the notion that rear-end collisions on freeway facilities are caused by normal speed traffic encountering slow/stopped traffic on main lanes or ramps.[1,3,4]

These findings support the need for advance warning of slow/stopped traffic on freeways so that the frequency of rear-end collisions can be reduced.

B. Driver Behavior Approaching Slow/Stopped Traffic

The key findings related to driver behavior when approaching the end of a traffic queue on a freeway facility are provided in the following list:

- Observational studies conducted in Texas observed between 1 and 16 hard braking maneuvers (significant drop in the vehicle nose) per 1000 approaching vehicles at two work zone sites.[2]
- A Northwestern University study found that approximately 5% of drivers rapidly approached the end of the queue despite advance warnings.[6]
- A Canadian human factors expert has determined that drivers are usually aware that they are closing in on a slower vehicle, however, if there is a large speed differential (over 40 km/h / 25 mph) they often have a very poor perception of just how quickly they are closing in until they get very close or collide with the slower vehicle.[7]

C. Queue Propagation on Freeway Facilities

The research team was not able to find many empirical studies of the speed at which queues propagate backwards on freeway facilities. The following list provides some data on estimates of how fast a queue grows backwards:

- An Iowa study of a rural interstate work zone with lane closures determined rates as high as 30 to 40 mph.[8]
- A study of the Metropolitan Expressway in Japan determined an average speed of approximately 18 km/h (11 mph).[9]
- A study of a short section of the Gardiner Expressway in Canada showed tail end of queue propagation speeds of up to 18 km/h (11 mph).[10]

D. Benefits of Advance Warning of Slow/Stopped Traffic on Freeway Facilities

The research team found several studies that either estimated or have measured the benefits of providing drivers with advance warning of slow/stopped traffic on freeway facilities. The following list provides a summary of these benefits:

- A Daimler-Benz study determined that if passenger car drivers had 0.5 second additional warning time, about 60% of rear-end collisions could be prevented. The Daimler-Benz study also estimated that an extra second of warning time for drivers would prevent about 90% of rear-end collisions.[11]
- A queue warning system in Amsterdam found a 23% decrease in overall collision rates, a 35% reduction in serious collision, and a 46% reduction in secondary collisions at the back of the queue.[12]
- A German autobahn using queue protection and freeway lane control showed a 20% decrease in collision rate.[12]
- A queue warning system in England paid for itself within a year based on the collision savings.[12]

5.2 TASK 2: CURRENT QUEUE WARNING PRACTICES AND TECHNIQUES

The researchers have summarized current practices for advance warning of slow/stopped traffic in use by international DOTs, other state DOTs, and TxDOT.

A. Queue Detection Practices and Techniques

The research team identified the following practices and techniques for the detection of queues (i.e., slow/stopped traffic) on freeway facilities:

- Loop detectors: 5 international agencies and 8 state DOTs in the United States use this form of detection.
- Video detectors: 4 international agencies and 3 state DOTs in the United States use this form of detection.

- Radar-based (microwave or Doppler) detectors: 4 international agencies and 3 state DOTs in the United States use this form of detection.
- Infrared detectors: 1 international agency and 1 state DOT in the United States use this form of detection.
- Ultrasonic detectors: 1 international agency uses this form of detection.
- Optical sensors: 1 state DOT uses this form of detection.

B. Queue Warning Practices and Techniques

Researchers identified the following practices and techniques for providing drivers advance warning of queues (i.e., slow/stopped traffic) on freeway facilities:

a) Variable message signs with the following messages:
    i. Electronic version of the international congestion ahead symbol (three closely spaced cars in a red triangle)
    ii. Text messages such as:
        - **FILE – 500 M / 1000 M**
        - **EXPRESS MOVING SLOWLY BEYOND NEXT TRANSFER**
        - **CONGESTION (DISTANCE IN METERS) AHEAD – BEWARE OF REAR-END COLLISION**
        - **CONGESTION – CAUTION**
        - **QUEUE AHEAD**
        - **SLOW DOWN**
        - **SLOW TRAFFIC AHEAD PREPARE TO STOP**
        - **CAUTION – SLOW TRAFFIC AHEAD**
        - **CAUTION – STOPPED TRAFFIC AHEAD**, etc.

b) Variable speed signs
c) Trailer-mounted and/or portable variable message signs
d) Static signs with the following messages:
    i. International congestion ahead symbol (three closely spaced cars in a red triangle)
    ii. Text messages such as:
        - **PREPARE TO STOP WHEN FLASHING**
        - **CONGESTION AHEAD – RAMP CONGESTION WHEN FLASHING**
        - **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**, etc.

e) COMPANION posts

f) Incident response vehicles with trailer-mounted signs
g) Enforcement vehicles with special driving practices

C. Product Vendors

The research team identified and documented contact information for 13 vendors of queue warning and detection products. Table 2-2 in Chapter 2 of this report summarizes this effort.

5.3 TASK 3: OBSERVATIONAL FIELD STUDIES

For this study, the research team considered three types of traffic congestion:

- Congestion related to recurrent traffic conditions
- Congestion related to work zones
- Congestion related to incidents

The research team conducted observational field studies in order to provide comparative information on topics such as queue formation, including the nature of queuing by lane and length of queue and speed of queue propagation (tracking the speed at which the queue develops). Freeway geometric issues relating to rolling terrain and visibility obstructions such as under and overpasses have also been reported.

In the observational field studies, Chapter 3, researchers have found instances of sustained, repetitive, and excessive queue propagation speeds in attempts to define the nature of the issue. Additionally, in many instances, multiple lanes were impacted. Urban commuters, although generally aware of conditions encountered in their daily travels, might still be surprised by sudden and extensive queue propagation. 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 formation.

5.4 TASK 4: APPLICATION TO TXDOT

In this task, researchers evaluated for applicability to TxDOT the current queue warning practices and techniques identified in Chapter 2. The research team also assessed the potential effectiveness of these practices and techniques in addressing TxDOT concerns relating to advance warning for stopped traffic.

When considering the complexity of implementation and operation, current standards for traffic control and signing, and estimated cost of installment, researchers believe the following techniques have the most promise for application by TxDOT:

- Series of static signs with text message and flashers (similar to TxDOT system already deployed in Fort Worth)
- Series of static signs with international congestion ahead symbol and flashers

- Series of portable variable message signs with messages appropriate to warning drivers of upcoming traffic conditions

The research team plans to test these three techniques in the second-year field testing.

5.5 TASK 5: INTERIM FINDINGS AND PHASE ONE REPORT

The final first-year project task was to summarize the interim findings and prepare the phase one report. Based on the efforts conducted in Tasks 1 through 4, the following sections summarize the research team's interim findings and recommendations.

A. Recommended Infrastructure-Based Warning Strategies

The research team has 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 5-1 provides a summary of the research team's recommended warning strategies for the four major situations that create slow/stopped traffic on freeway facilities.

1) 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.

2) 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.

3) 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.

4) 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 5-1. 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	Queues 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

B. 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 some of the researchers' recommendations for what drivers can do as countermeasures for avoiding 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.

C. General Recommendations

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 made.

- 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.

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CHAPTER 6. FUTURE EFFORTS

Phase two of this research project, as outlined in the project proposal, is provided in the following sections.

6.1 TASK 6: IDENTIFY FIELD TESTING TECHNIQUES AND CONDUCT SITE SELECTION

A. Task 6a: Technique and Location Selection for Field Tests

Using the criteria developed in Task 4 and input from the Project Monitoring Committee, researchers will select a minimum of three advance warning techniques for testing in the field. The research team, after consultation with the project committee, will choose field study sites. It is anticipated that researchers will be able to work with vendors, as necessary, to facilitate field testing and that economies of data collection resources will be obtained by coordinating with TxDOT Transportation Management Centers and other existing facilities to the extent possible.

B. Task 6b: Develop Field Test Plan

The research team will develop a Field Test Plan for conducting and evaluating field studies. The purpose of this Field Test Plan will be to:

- 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 be collected and methodologies selected.
- Identify the evaluation strategy for field test results.
- Determine any notification and coordination needs with other agencies.

6.2 TASK 7: PERFORM FIELD TESTS

Researchers will perform the field tests identified in Task 6 according to the approved Field Test Plan. Elements to evaluate could vary considerably depending upon the techniques and locations chosen for field-testing; however, it is the intent of the research team to collect both qualitative and quantitative measures.

6.3 TASK 8: EVALUATE AND COMPARE FINDINGS FROM FIELD TESTS

The research team will evaluate both the quantitative and qualitative field test measures in order to identify effective techniques for providing advance warning for stopped conditions on the freeway. Researchers plan to conduct this analysis for individual field test results and also comparatively between tested techniques.

6.4 TASK 9: PRODUCE RECOMMENDATIONS, SUMMARY, AND DOCUMENTATION

Within Task 9 researchers will determine research recommendations and findings. Researchers will provide extensive documentation of the research project approach, analysis, evaluations, recommendations, findings, and summary. The Project Research Report and Project Summary Report will be produced. Project products will include both first cut at a Selection Strategy Flowchart, and Guidelines for Implementation of Advance Warning Techniques for Slow/Stopped Traffic.

APPENDIX

OBSERVATIONAL FIELD STUDY GRAPHS

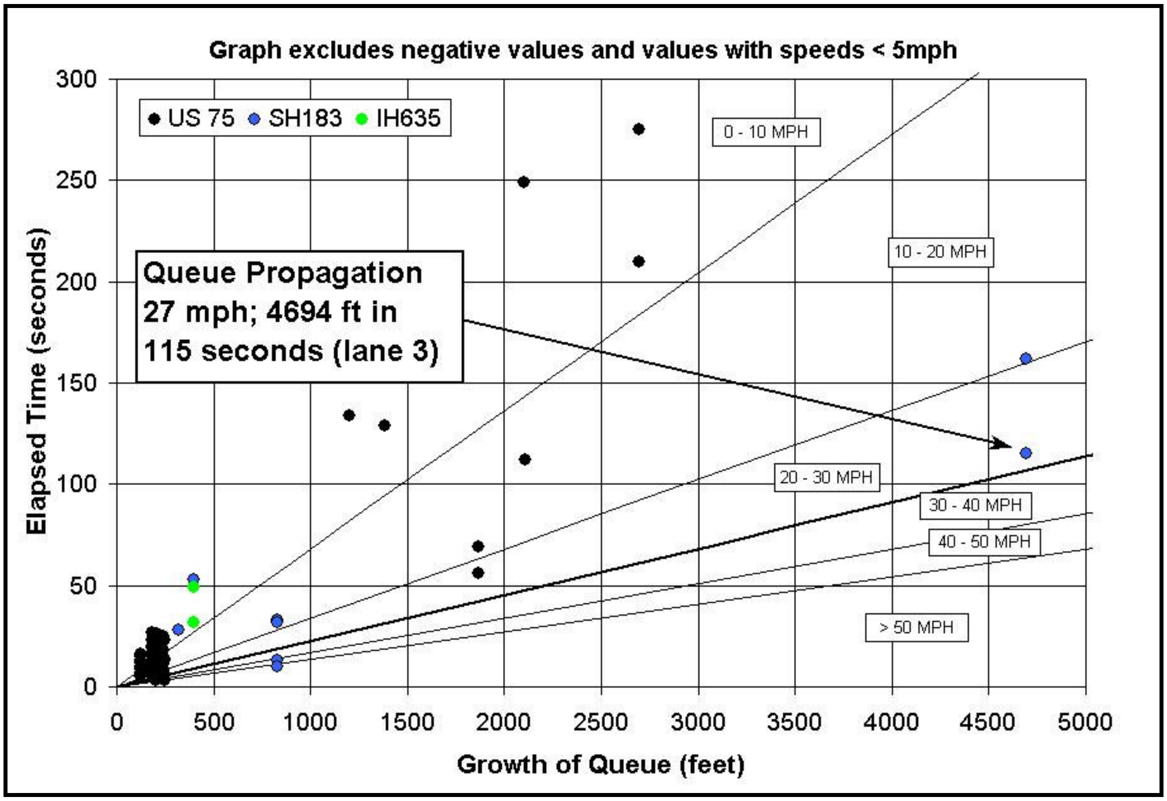

Figure A-1. Queue Propagation Data for Recurrent Congestion Studies – View 1.

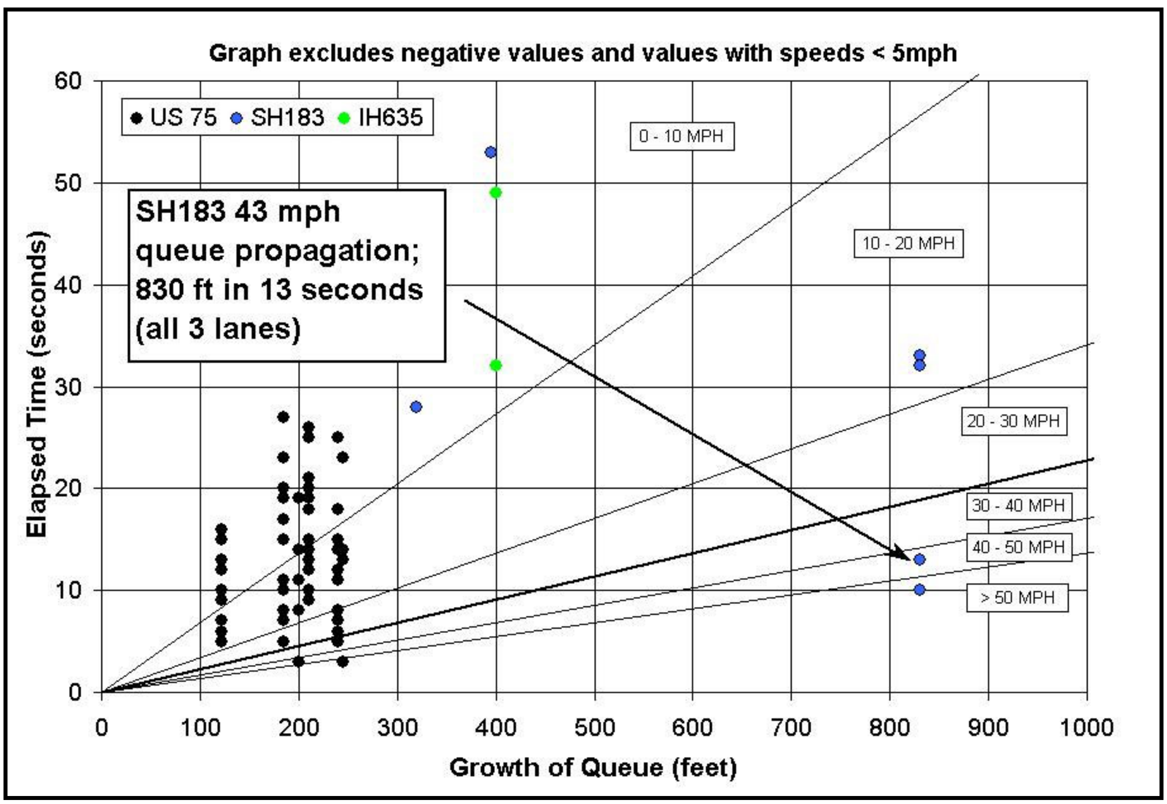

Figure A-2. Queue Propagation Data for Recurrent Congestion Studies – View 2.

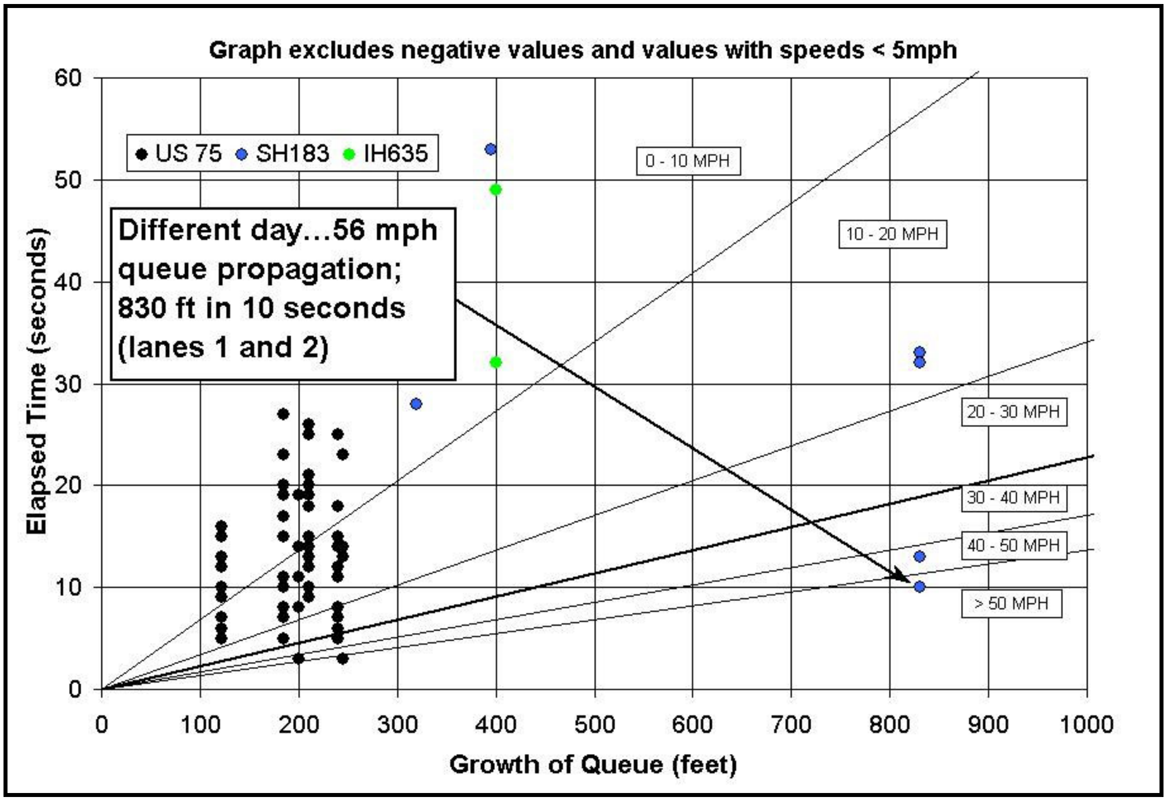

Figure A-3. Queue Propagation Data for Recurrent Congestion Studies – View 3.

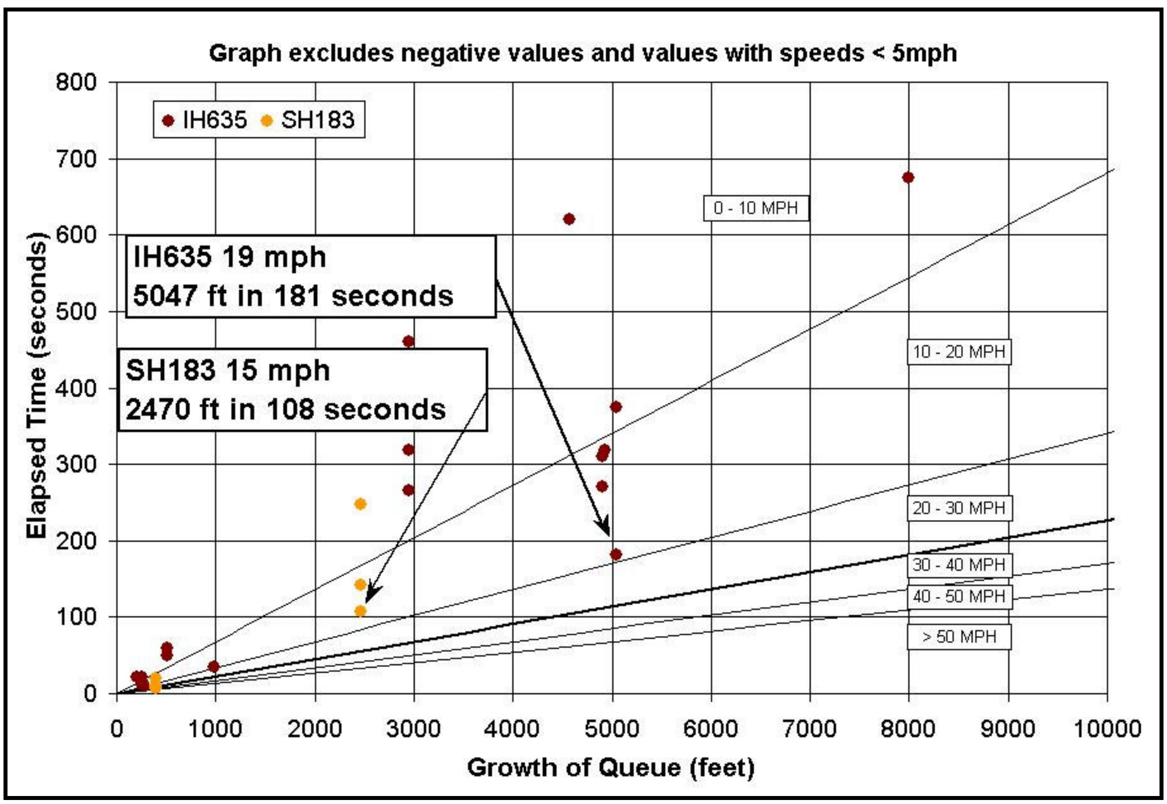

Figure A-4. Queue Propagation Data for All Incident Studies – View 1.

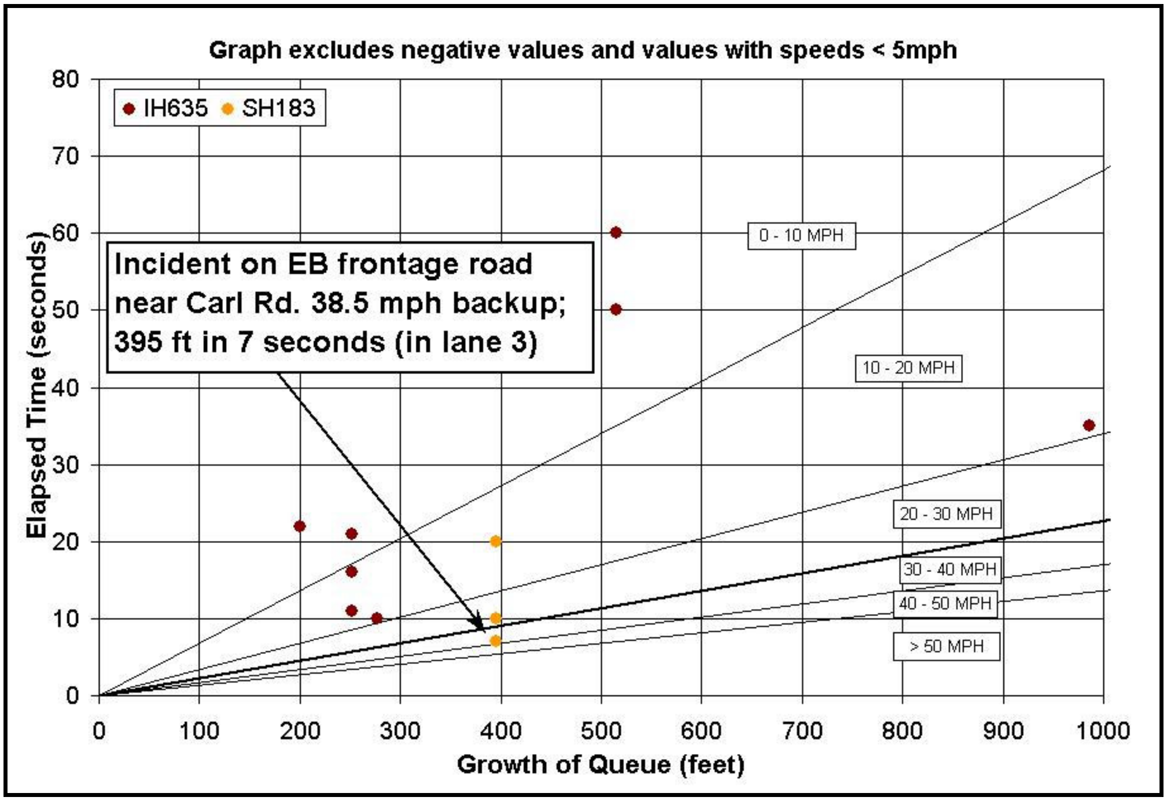

Figure A-5. Queue Propagation Data for All Incident Studies – View 2.

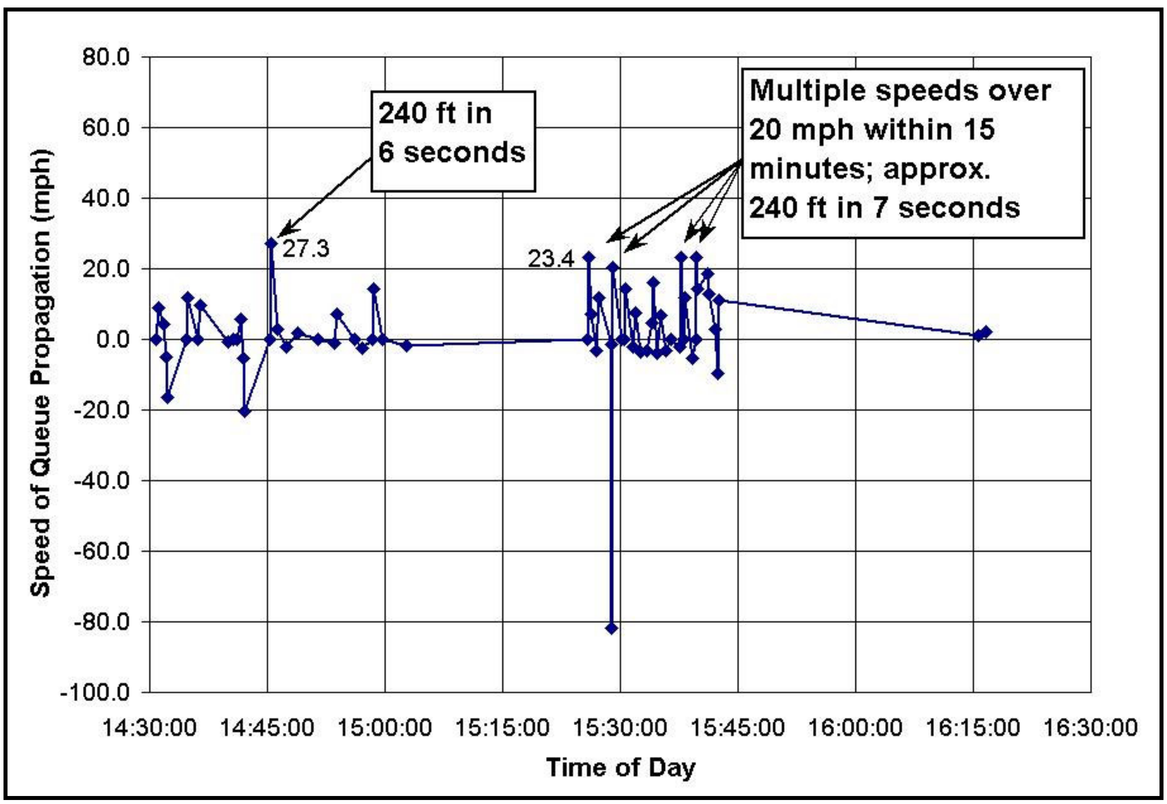

Figure A-6. US 75 Queue Propagation Data for April 23, 2002 – Lane 1 of 4.

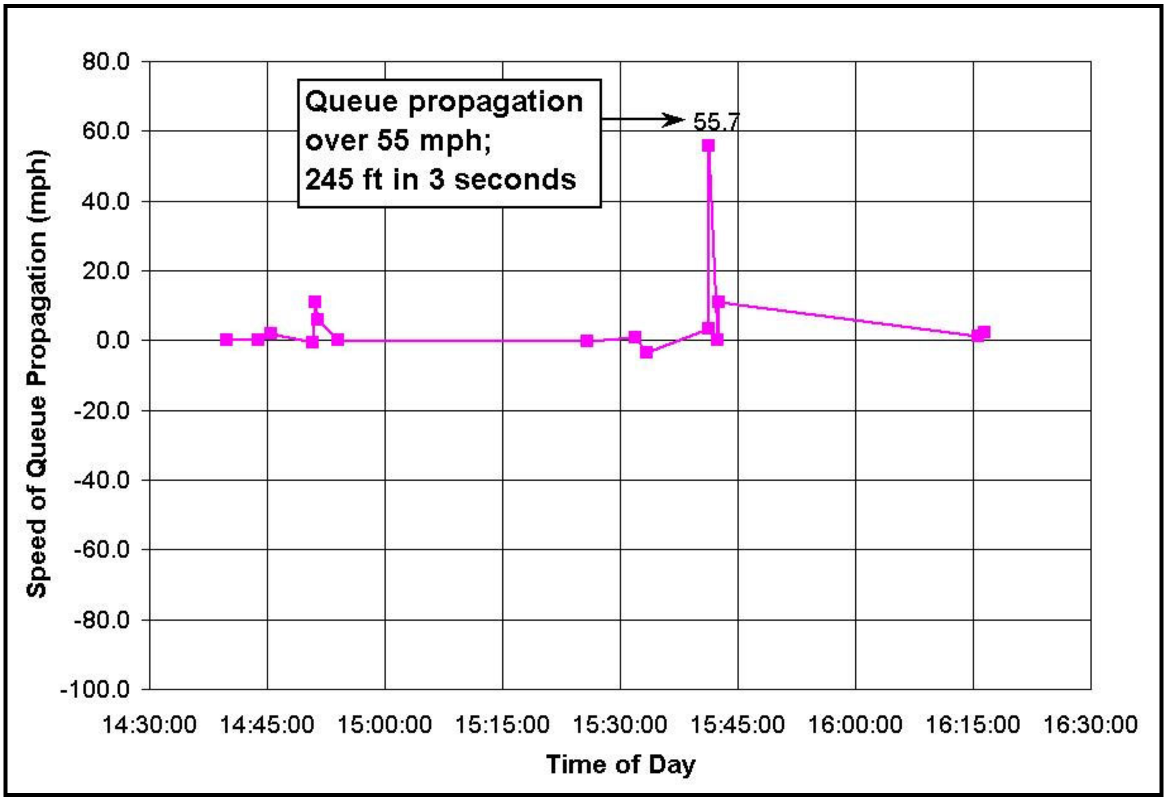

Figure A-7. US 75 Queue Propagation Data for April 23, 2002 – Lane 2 of 4.

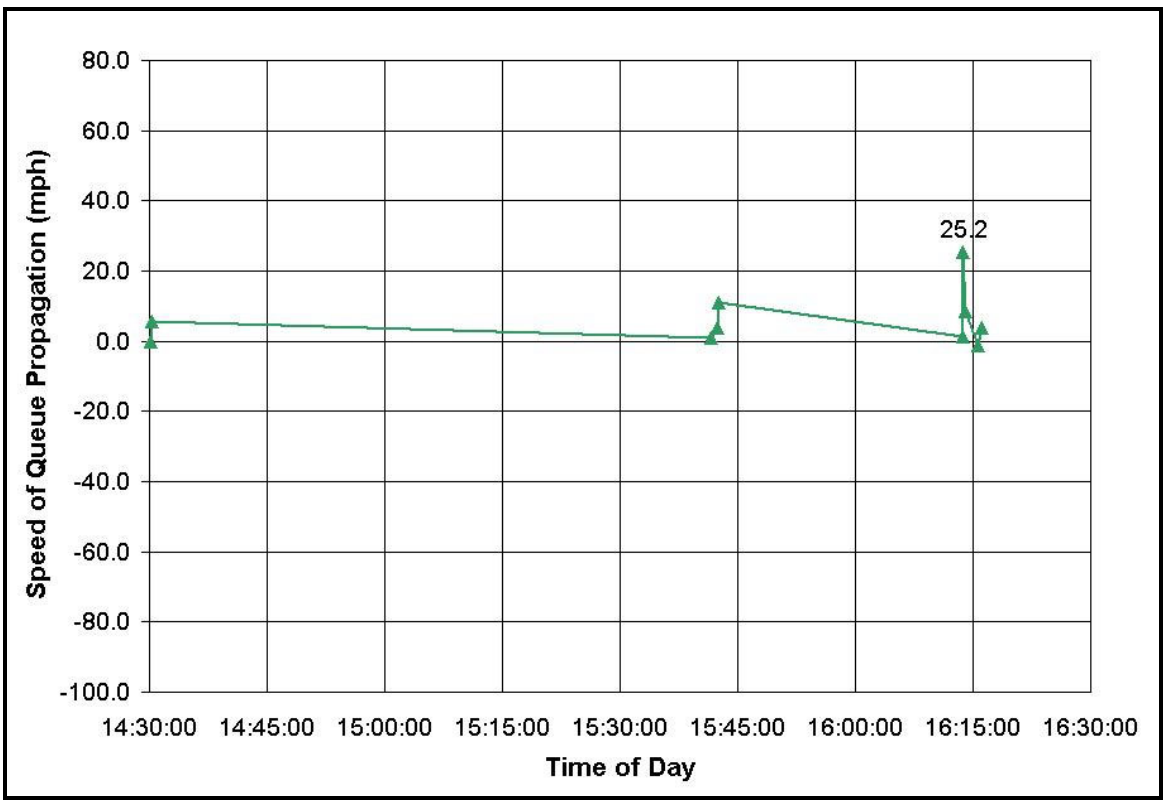

Figure A-8. US 75 Queue Propagation Data for April 23, 2002 – Lane 3 of 4.

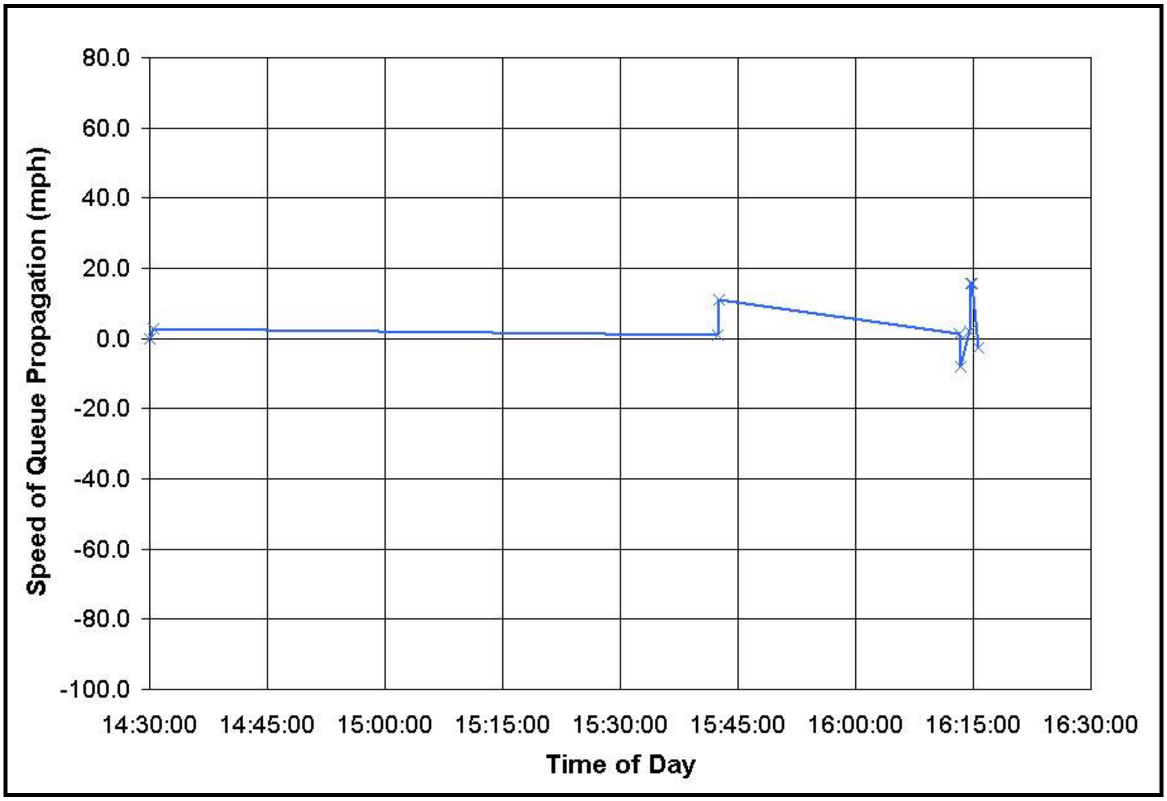

Figure A-9. US 75 Queue Propagation Data for April 23, 2002 – Lane 4 of 4.

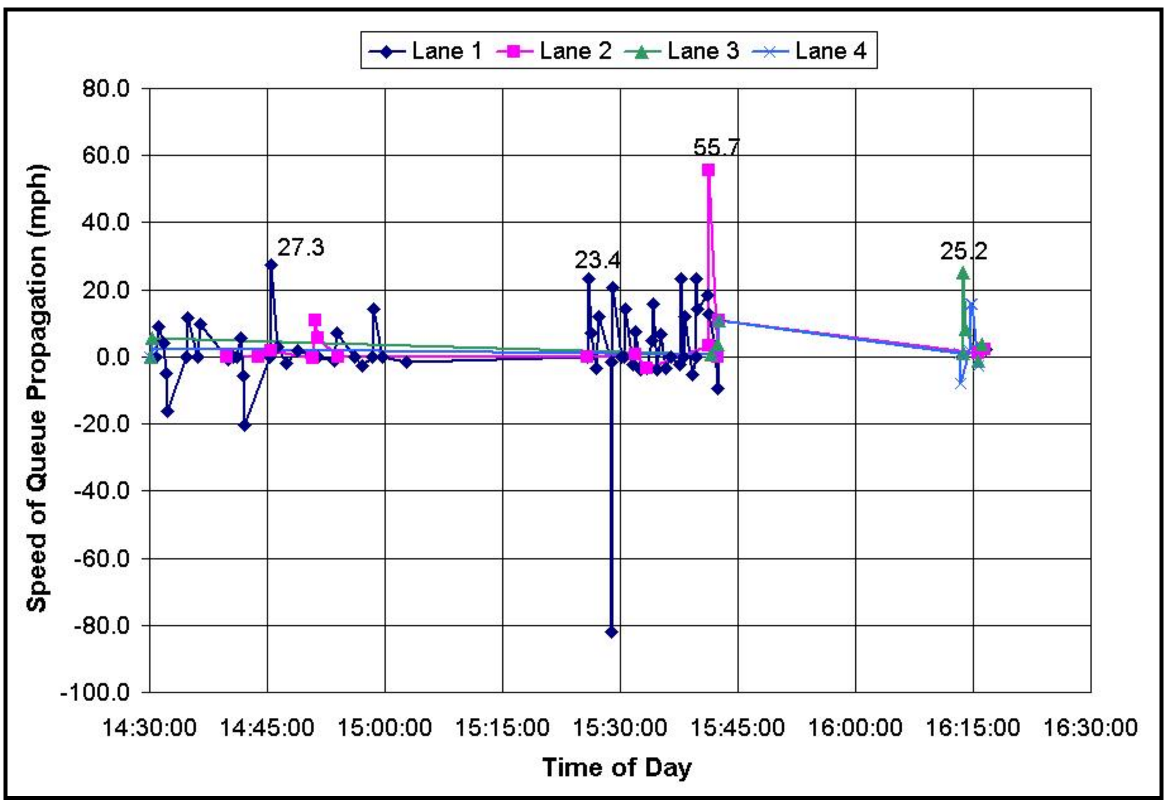

Figure A-10. US 75 Queue Propagation Data for April 23, 2002 – All Lanes.

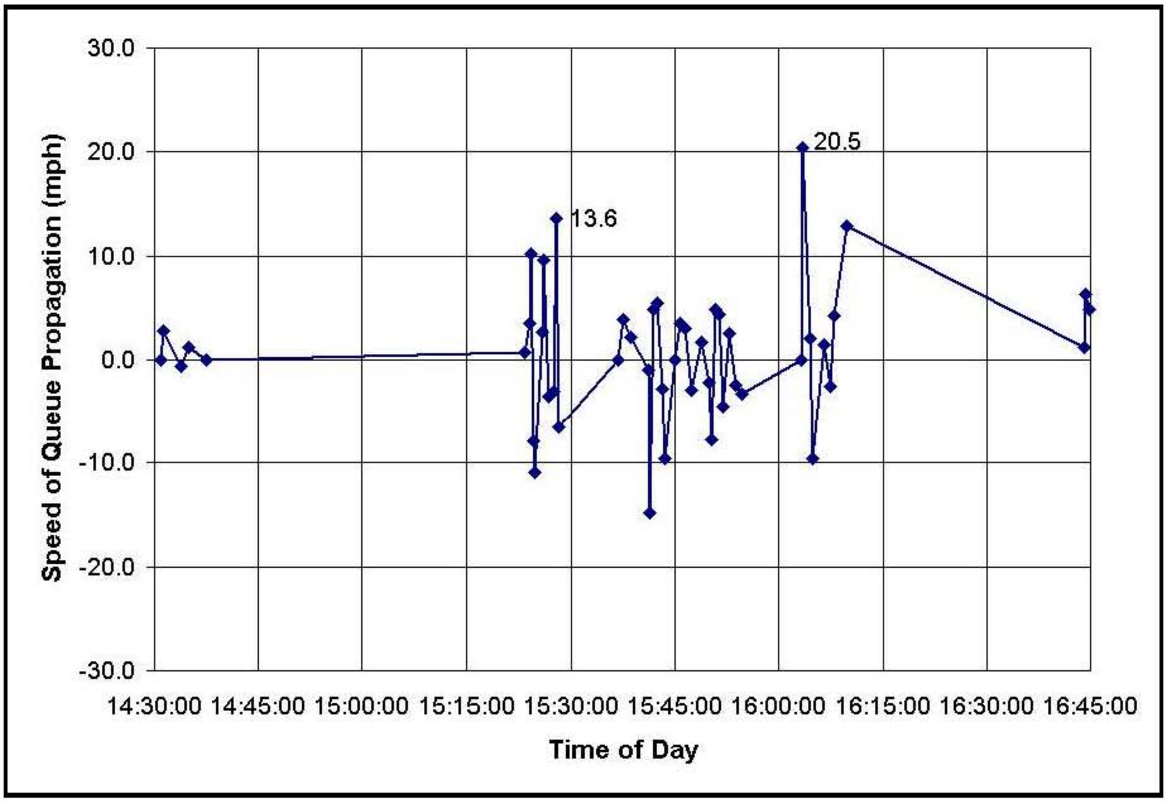

Figure A-11. US 75 Queue Propagation Data for April 24, 2002 – Lane 1 of 4.

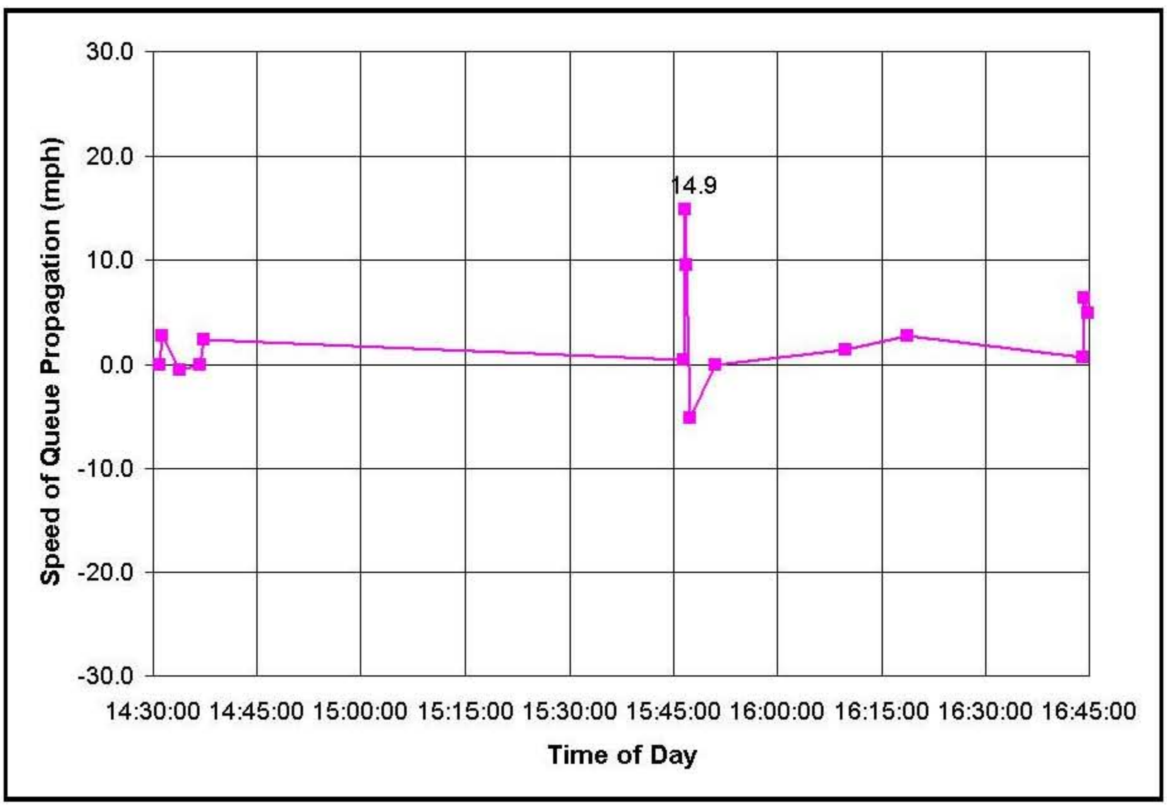

Figure A-12. US 75 Queue Propagation Data for April 24, 2002 – Lane 2 of 4.

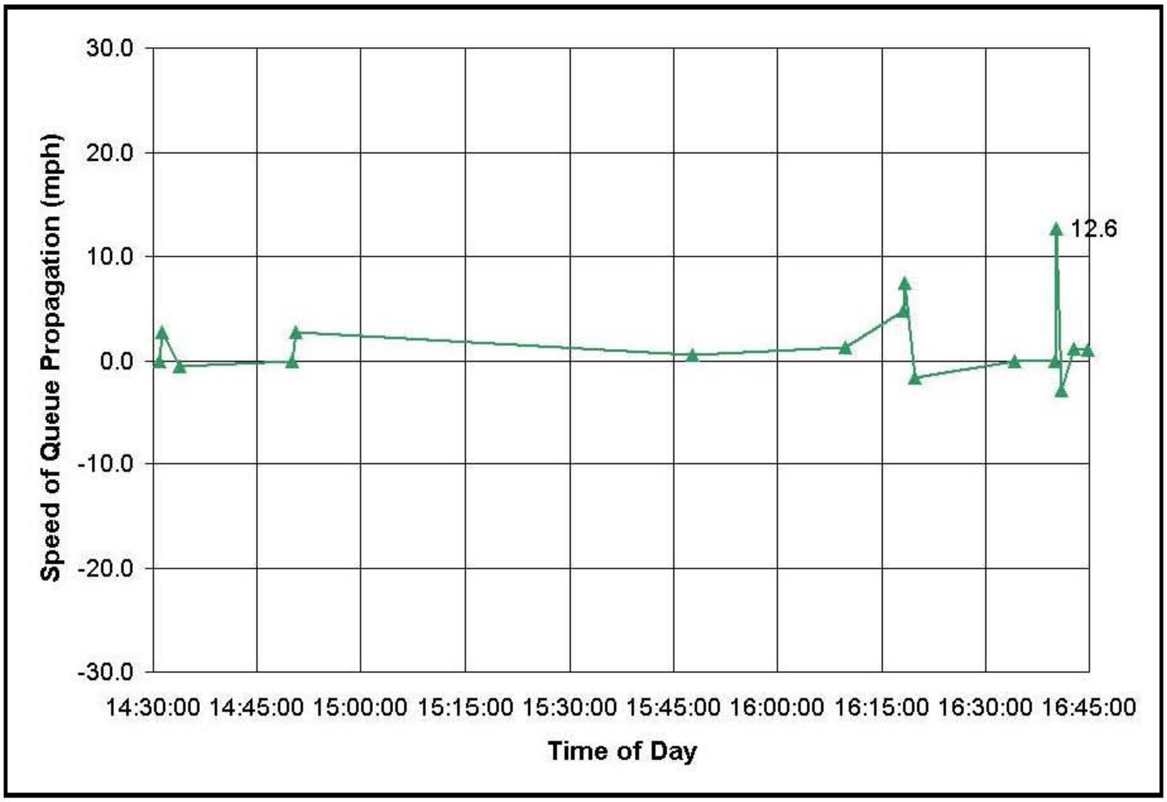

Figure A-13. US 75 Queue Propagation Data for April 24, 2002 – Lane 3 of 4.

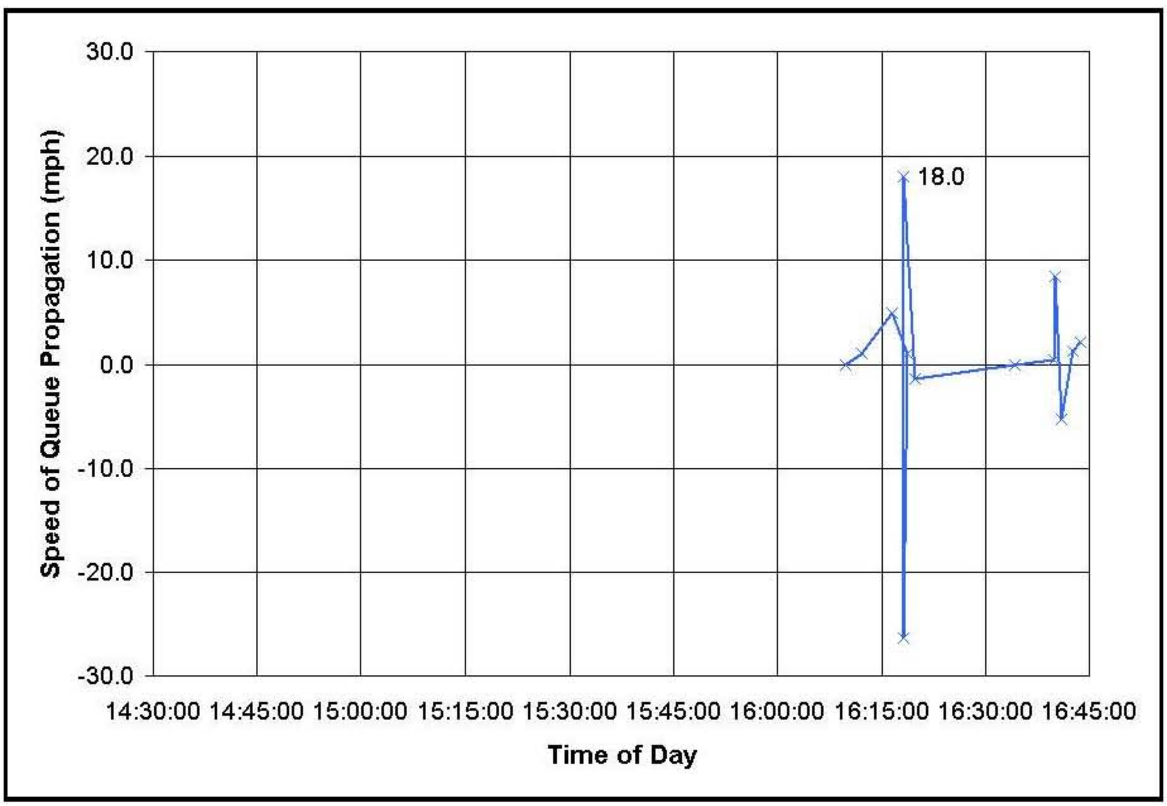

Figure A-14. US 75 Queue Propagation Data for April 24, 2002 – Lane 4 of 4.

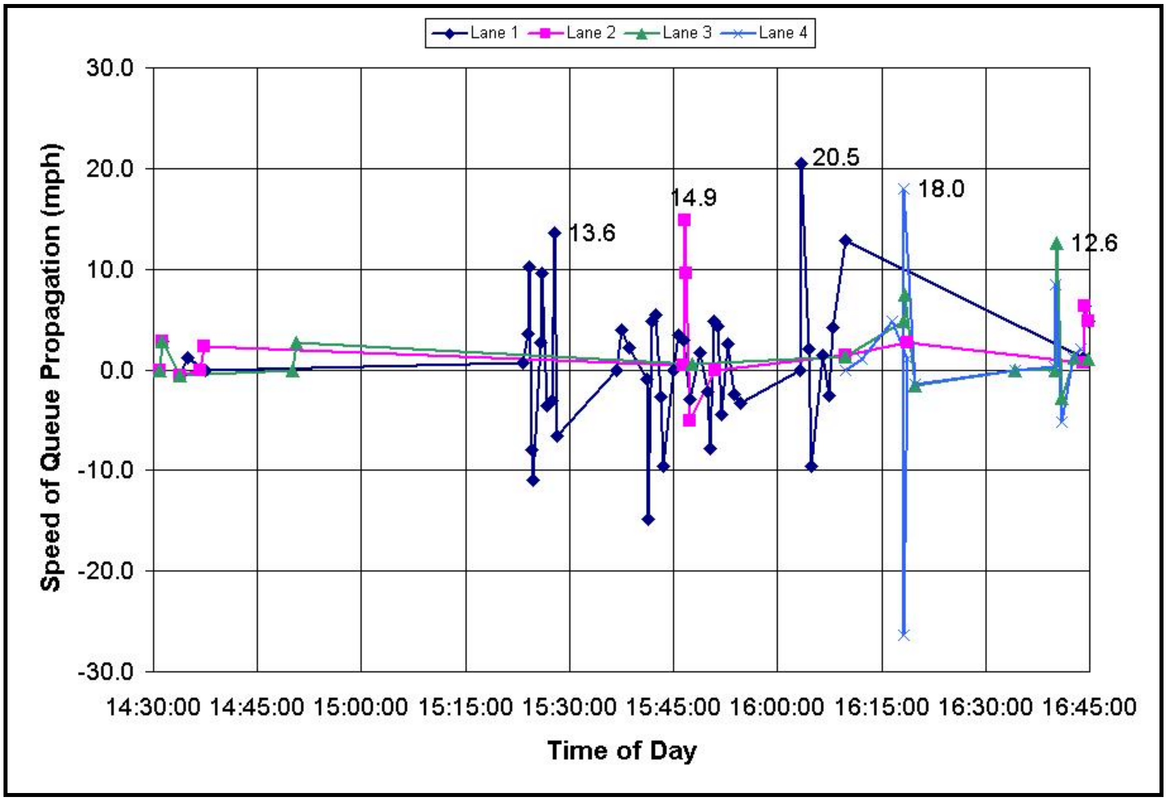

Figure A-15. US 75 Queue Propagation Data for April 24, 2002 – All Lanes.

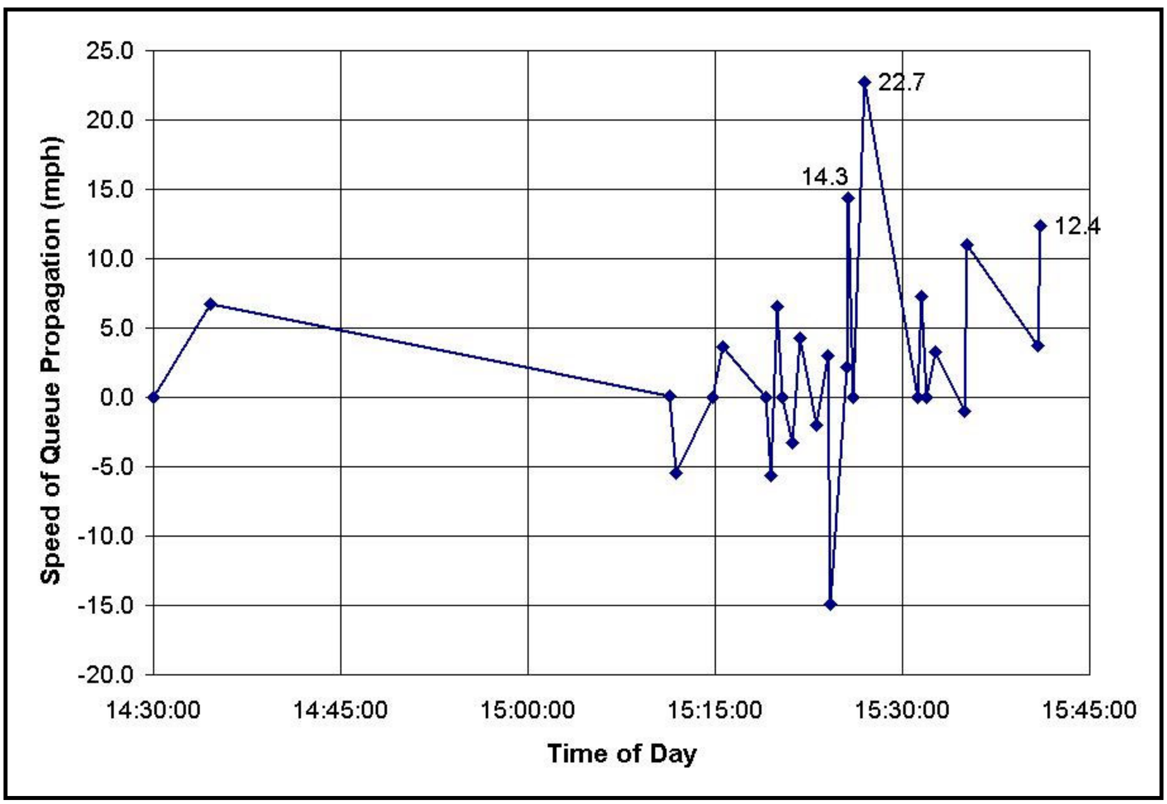

Figure A-16. US 75 Queue Propagation Data for April 25, 2002 – Lane 1 of 4.

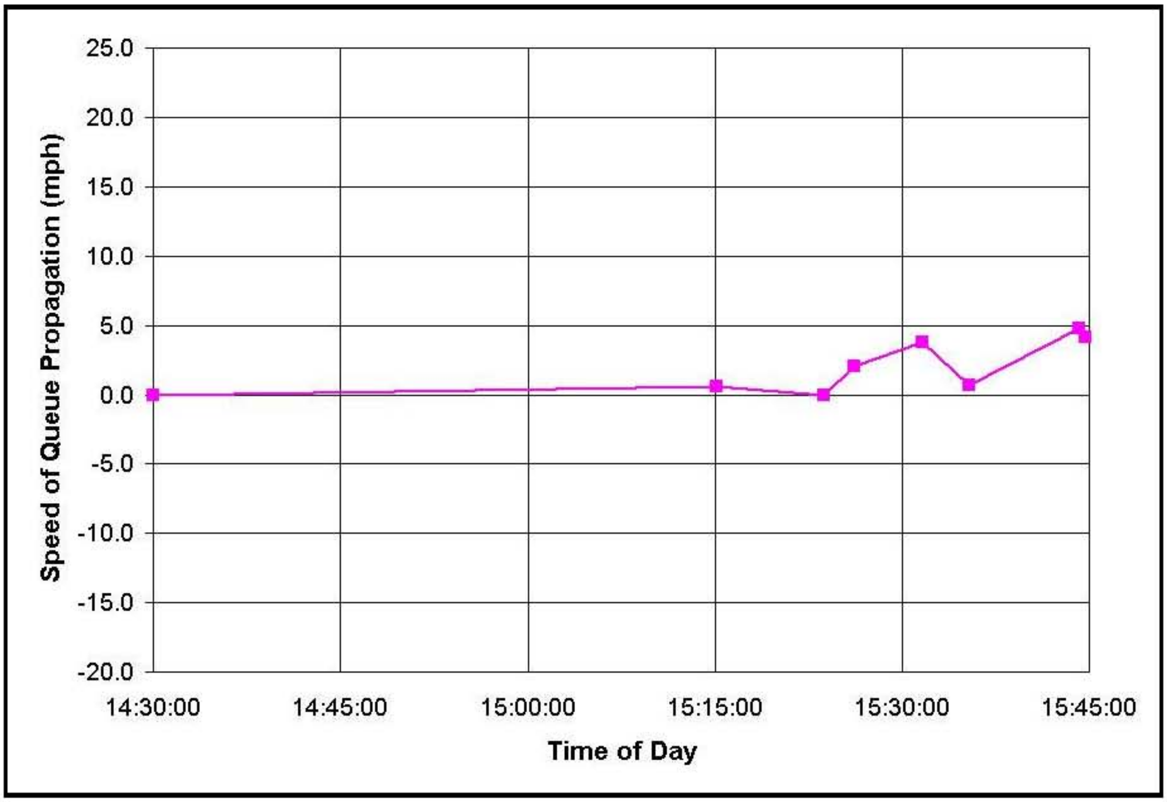

Figure A-17. US 75 Queue Propagation Data for April 25, 2002 – Lane 2 of 4.

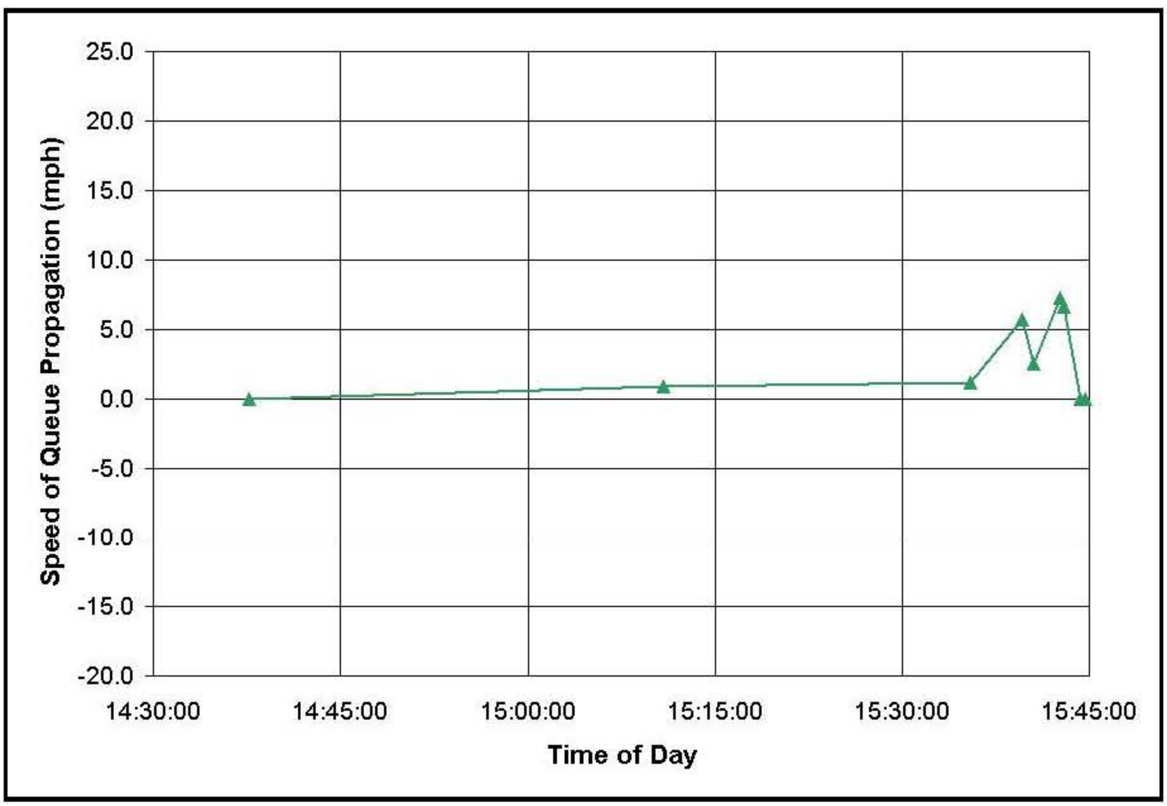

Figure A-18. US 75 Queue Propagation Data for April 25, 2002 – Lane 3 of 4.

Figure A-19. US 75 Queue Propagation Data for April 25, 2002 – Lane 4 of 4.

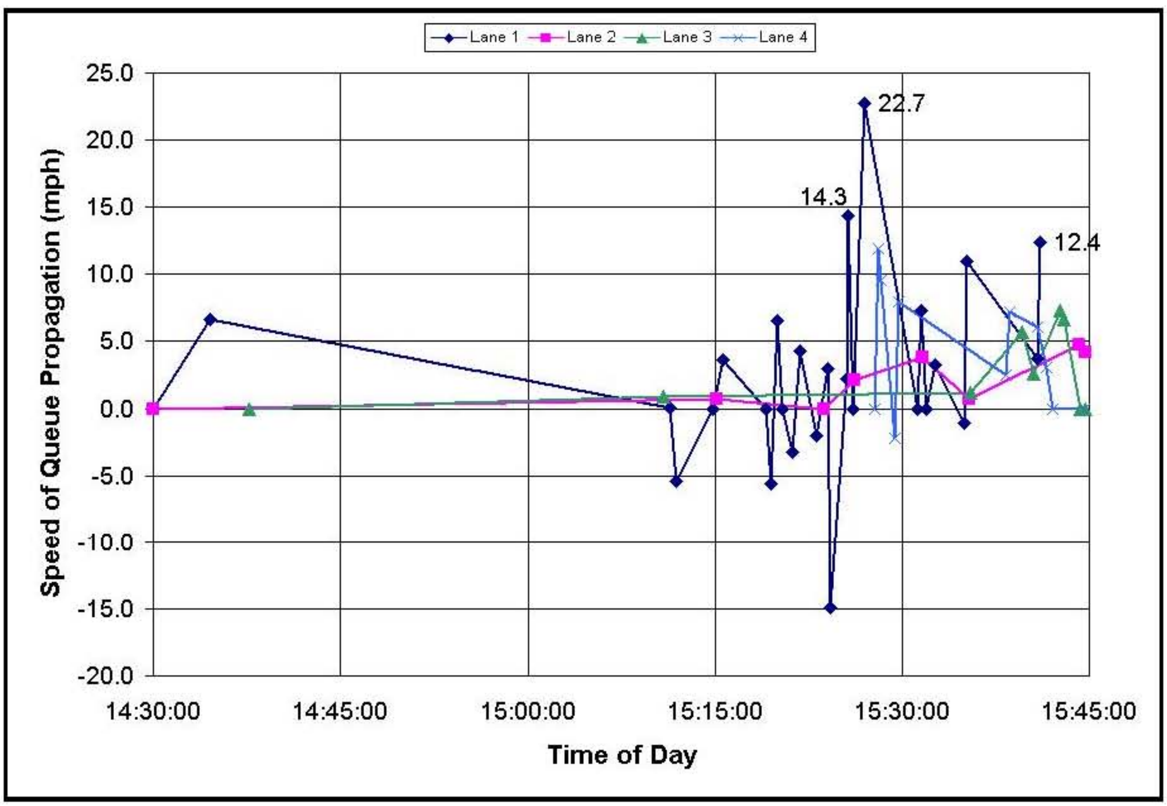

Figure A-20. US 75 Queue Propagation Data for April 25, 2002 – All Lanes.

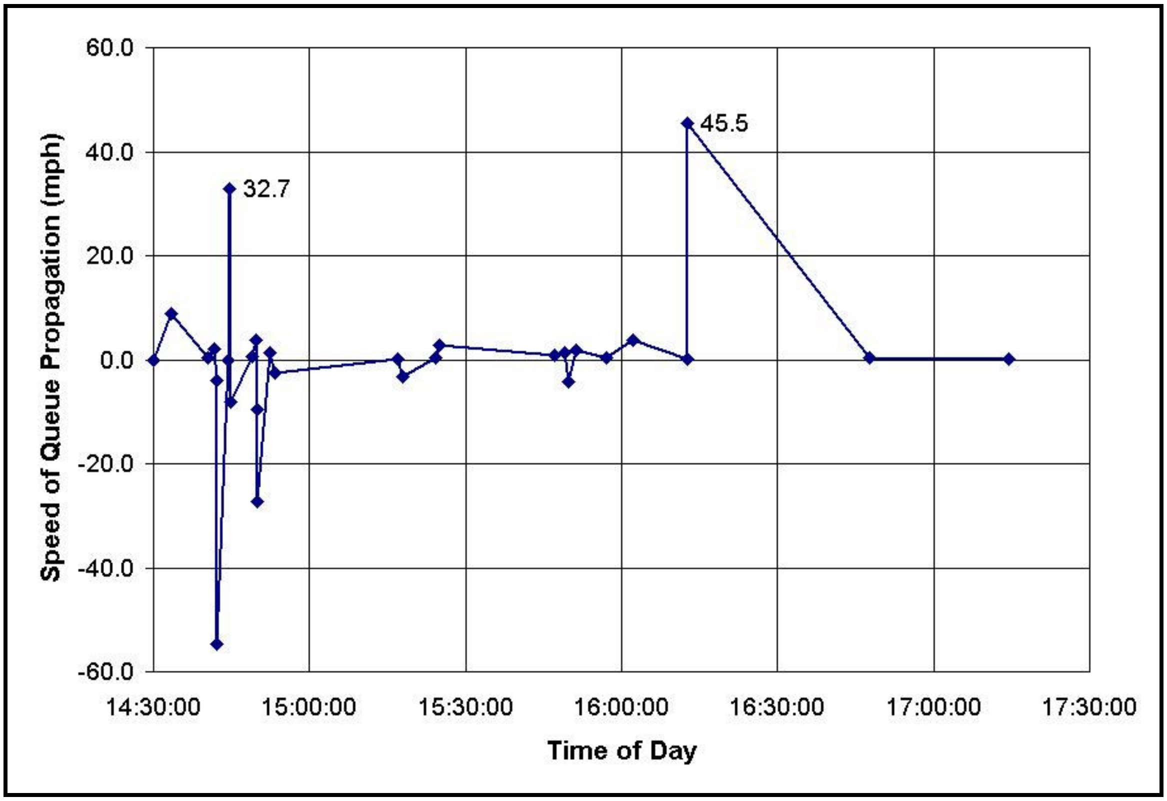

Figure A-21. US 75 Queue Propagation Data for May 1, 2002 – Lane 1 of 4.

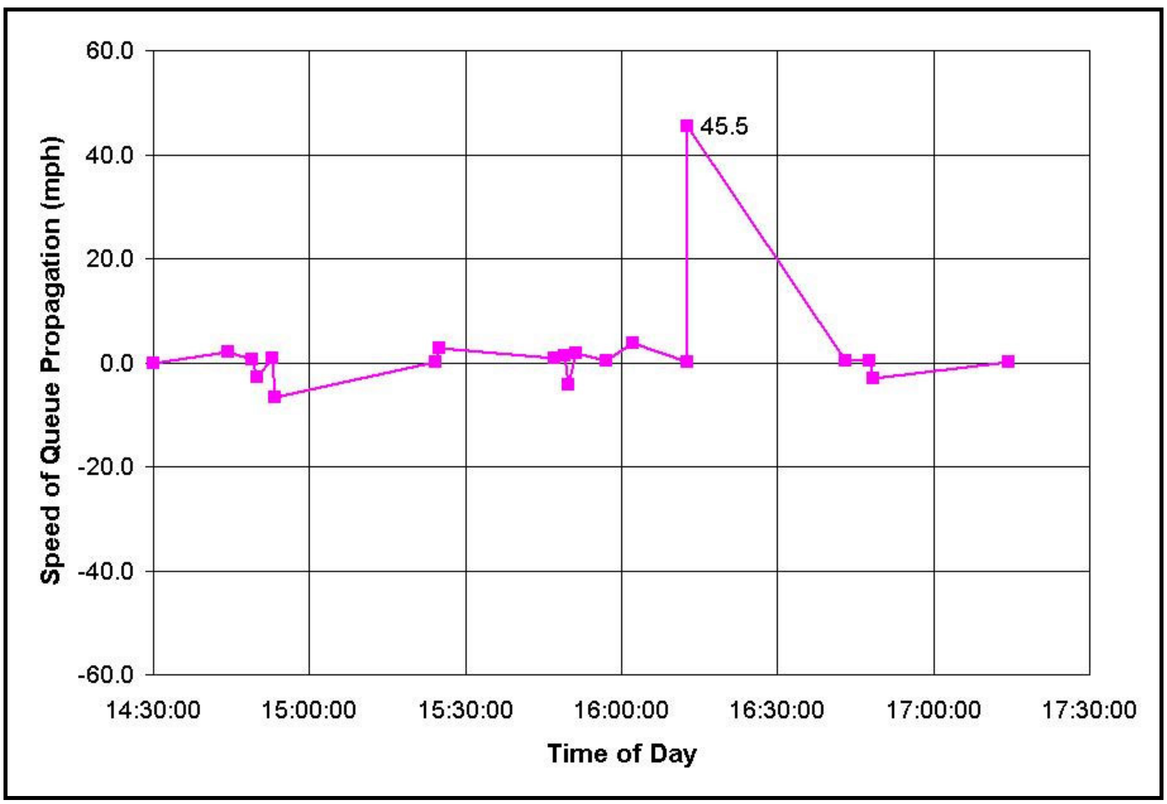

Figure A-22. US 75 Queue Propagation Data for May 1, 2002 – Lane 2 of 4.

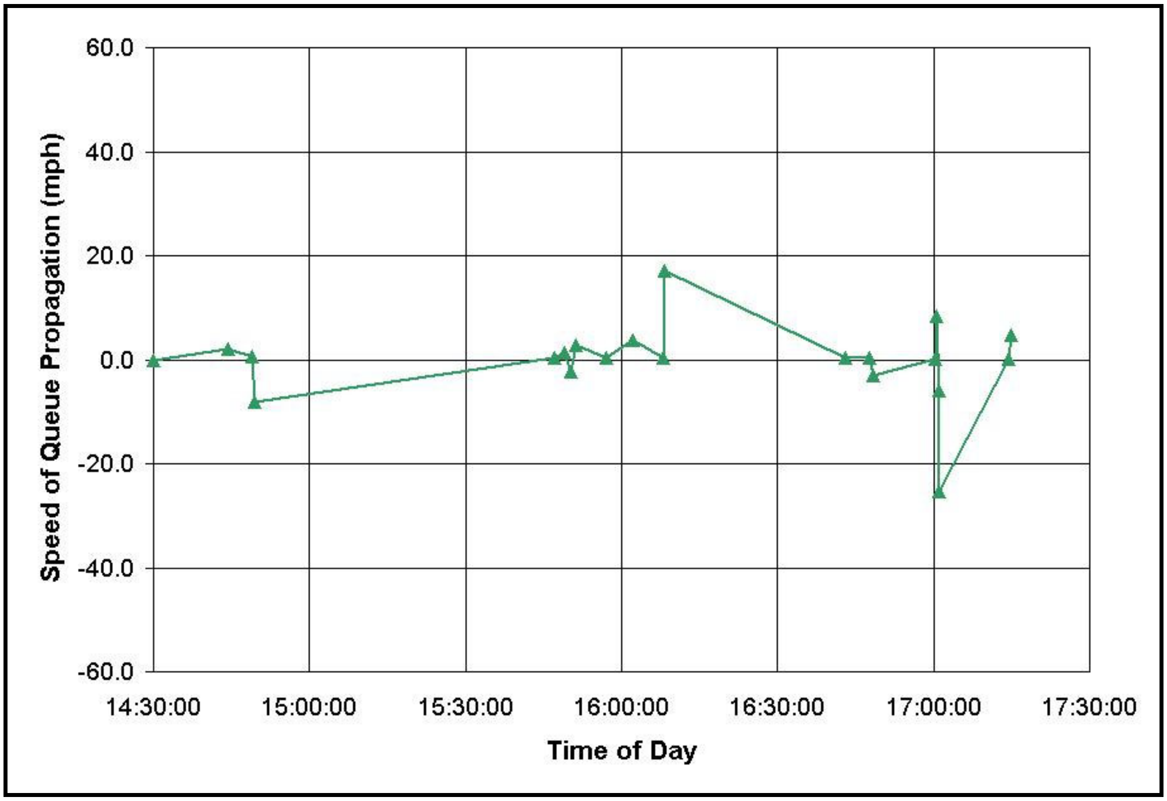

Figure A-23. US 75 Queue Propagation Data for May 1, 2002 – Lane 3 of 4.

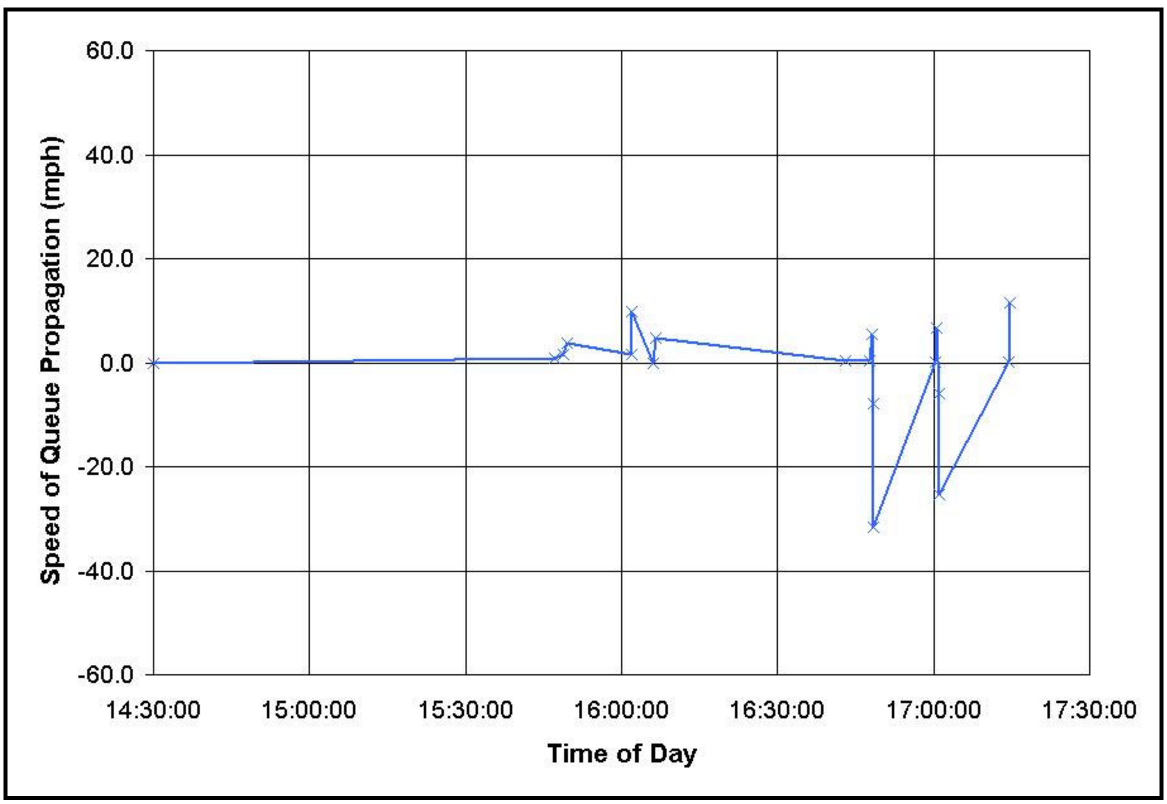

Figure A-24. US 75 Queue Propagation Data for May 1, 2002 – Lane 4 of 4.

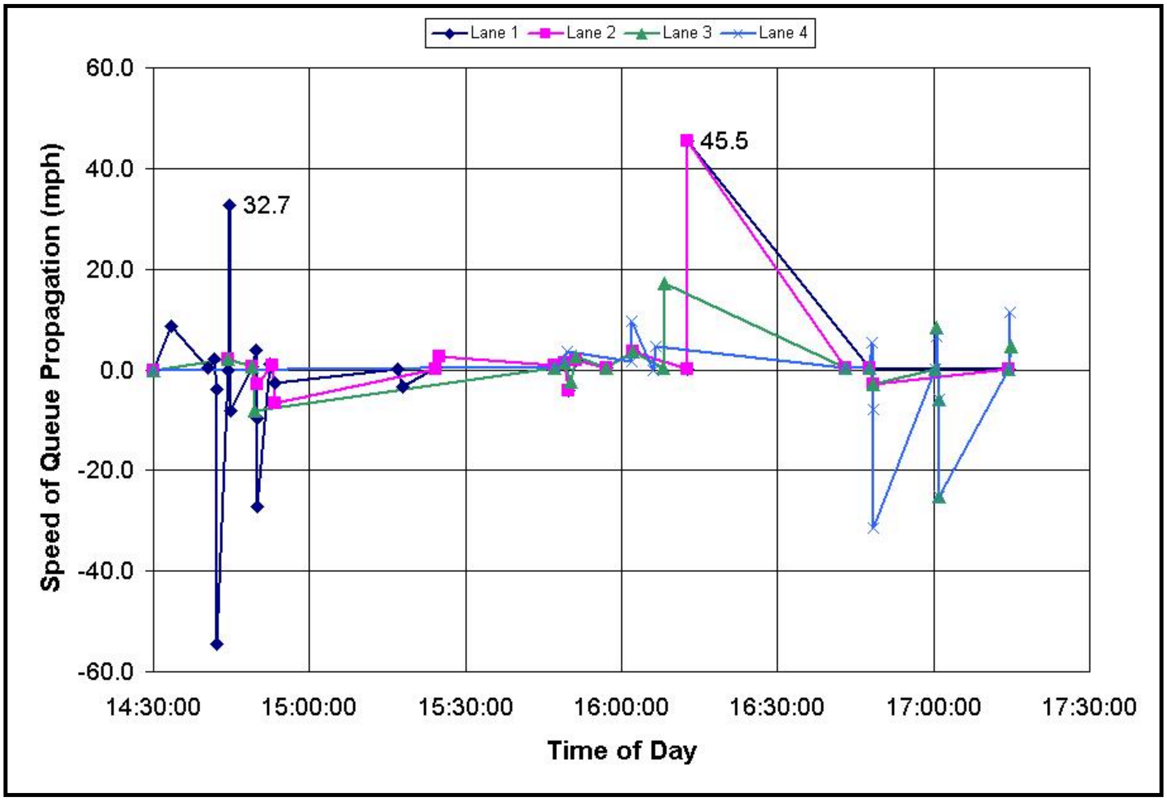

Figure A-25. US 75 Queue Propagation Data for May 1, 2002 – All Lanes.

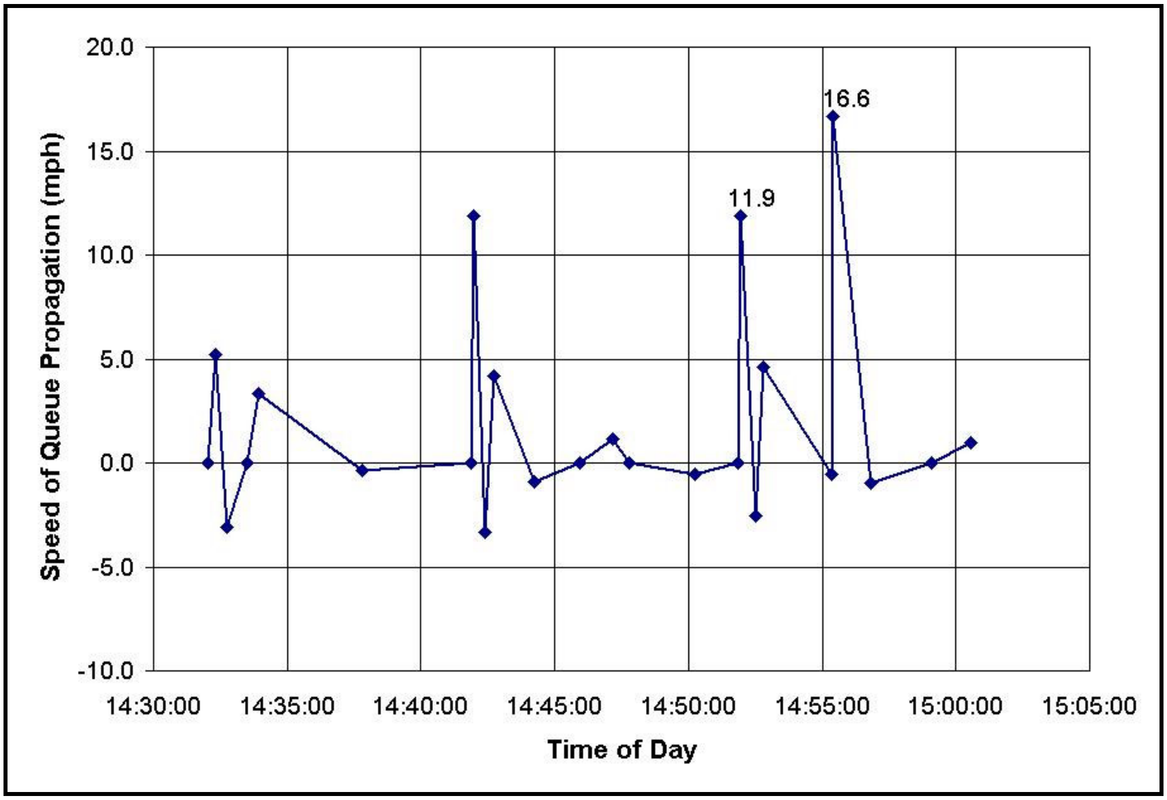

Figure A-26. US 75 Queue Propagation Data for May 2, 2002 – Lane 1 of 4.

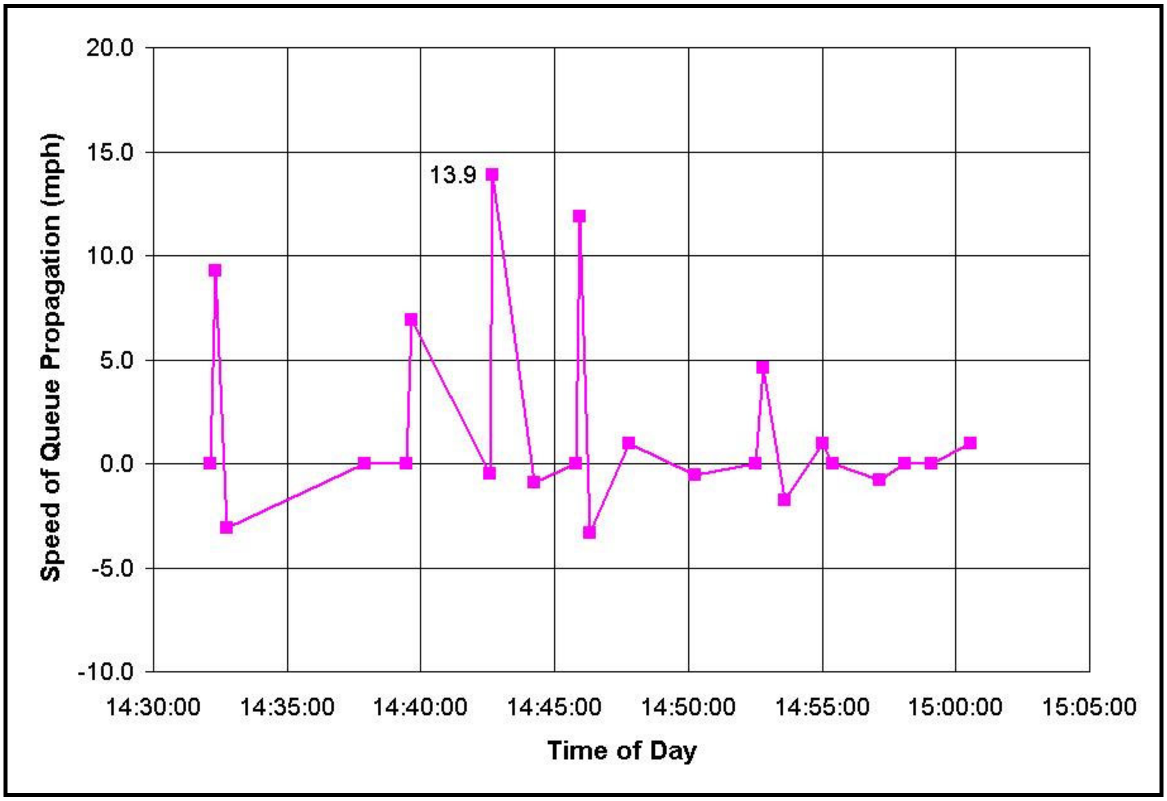

Figure A-27. US 75 Queue Propagation Data for May 2, 2002 – Lane 2 of 4.

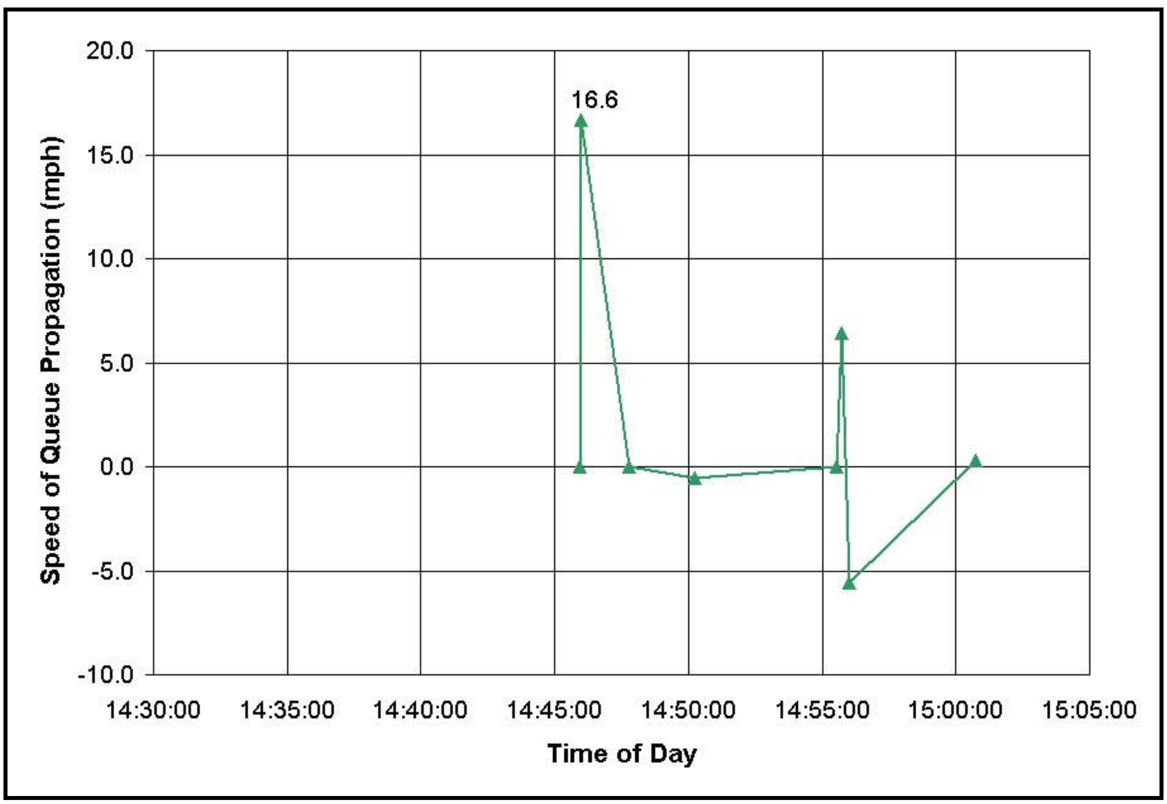

Figure A-28. US 75 Queue Propagation Data for May 2, 2002 – Lane 3 of 4.

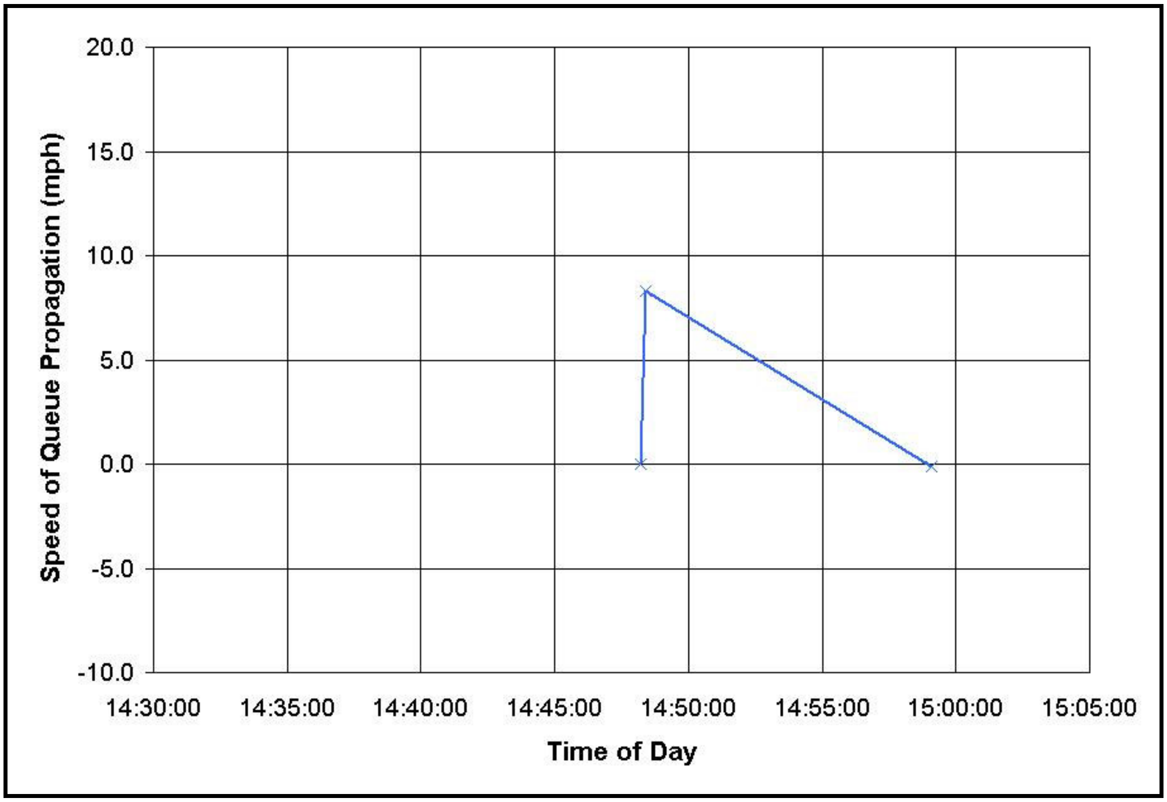

Figure A-29. US 75 Queue Propagation Data for May 2, 2002 – Lane 4 of 4.

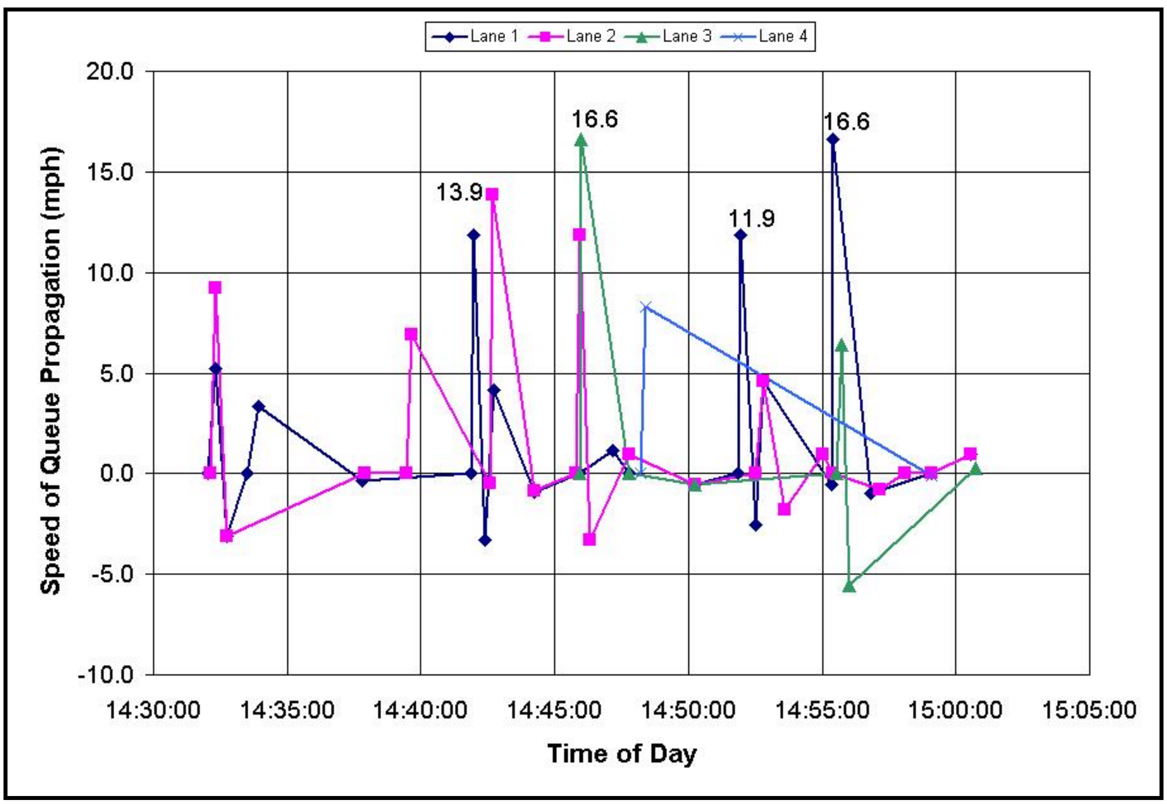

Figure A-30. US 75 Queue Propagation Data for May 2, 2002 – All Lanes.