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16. Abstract This report documents the analysis of existing sources of freeway operations data in the Dallas Urban Area. Recommendations are made for sampling vehicle detectors to be strategically placed to provide operational data prior to full implementation of a freeway management system. In addition, a procedure for interfacing to 911 emergency services to provide notification and location of freeway incidents not otherwise detected is proposed. A graphical Internet display format is described for presentation of these data to the traveling public.					
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**INVESTIGATION OF SOURCES OF FREEWAY SPEED DATA IN THE
DALLAS AREA AND PRESENTATION TO TRAVELING PUBLIC BY
ELECTRONICS MEANS**

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Research Project Title: Investigate Existing Sources
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TEXAS TRANSPORTATION INSTITUTE
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IMPLEMENTATION RECOMMENDATIONS

The primary objective of this project is to evaluate alternative sources of traffic operations information on freeways in the Dallas Urban Area and to recommend means for presenting these data to the traveling public to assist in trip planning. Several existing sources of travel data are available but not in sufficient extent to provide comprehensive information across time and space in the Dallas Urban Area. The project recommendations may be implemented without the capital costs of major infrastructure improvements. The following implementation steps are recommended:

1. Utilize existing sources of freeway traffic information including closed circuit television, vehicle detectors, commercial providers, vehicle probes (Automatic Vehicle Locators or AVLs), and courtesy patrol reports to the extent possible to build a base of freeway operations data.
2. Supplement existing data sources with non-intrusive detectors (e.g. radar, video, sonic) located at strategic points on the freeway system to sample traffic operations as indicated by speed or occupancy.
3. Enhance and expand the prototype workstation operator display to display freeway operational conditions including speed levels and incident locations.
4. Establish a link to 911 emergency services for automated download of freeway incidents to be displayed on the operator's workstation.
5. Enhance the TxDOT District Internet display to include access to the speed level and incident information available on the operator's workstation. Publicize the availability for access by the traveling public at home or workplace Internet sites.

The approach recommended could be adapted to other areas of the State where a full deployment of ITS infrastructure has not taken place.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation, nor is it meant for construction, bidding, or permit purposes. The Engineer in charge of this project was James D. Carvell, Jr., P.E. NO. 27027 (Texas).

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Appreciation is extended to Dr. Dan Middleton, TTI Associate Research Engineer, who directed the research from which much of the literature survey was drawn.

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1. BACKGROUND

1.1 BACKGROUND AND SIGNIFICANCE OF WORK

The Dallas TxDOT District has recently completed an Area-Wide Intelligent Transportation System (ITS) Plan for the Dallas area (*I*). The plan makes specific recommendations for near-term (one-five years) and medium-term (six-ten years) periods for implementation of Advanced Transportation Management Systems (ATMS), Advanced Transportation Information Systems (ATIS), and Advanced Public Transportation Systems (APTS). Some of these systems will be deployed along US 75, SH 183, IH 635 and at a limited number of freeway segments. However, full deployment will not take place for a number of years.

Recommendations under the ATIS category include making traffic information available to the traveling public at the home or at the work place. The information will assist in making decisions as to travel routes or travel modes. One method of furnishing such data is via the Internet. Developing a home page and format for presenting such information can be accomplished in rather short order. Other methods for presentation of such data would include strategic placement of kiosks or provision of dial-in information, cable TV, or transmission to handheld PCs.

Providing real-time freeway information to travelers will assist them in making better choices for time, route, or mode of travel and will be a visible demonstration of the ITS services prior to full system implementation. There is not sufficient infrastructure to obtain and process freeway speed data at this time. However, several sources for real-time travel time data exist at present which can be converted to speed data. These include:

- DART Buses with GPS;
- Private Vehicle Tracking Provider; and
- Automatic Vehicle Identification (AVI) System (TollTags™).

The DART GPS System is in place and operational. However, the means to determine travel times have not yet been implemented. There are at least two commercial providers of vehicle tracking systems in the region. The district has tested the use of one of them on the courtesy patrol vehicles. There are currently over 200,000 North Texas Tollway Authority (NTTA) TollTag users in the area. Use of the tags is being considered as payment media in downtown parking garages, Dallas-Fort Worth International Airport, and Dallas Love Field Airport.

To take advantage of the numerous existing TollTags, TollTag reading stations could be placed strategically in the field to obtain travel time (and thus speed) data. TollTags could be issued to certain segments of the population to provide additional data. Where gaps in freeway coverage exist, it may be possible to strategically place non-intrusive vehicle detectors such as radar, video, or ultrasonic technology that would not require cutting freeway pavement. Monitoring and data processing could be accommodated in the TxDOT Satellite Control Center.

The use of TollTag readers and privately operated AVL systems offers the opportunity for public - private partnerships which are an essential element of (ITS) implementation.

Additional speed estimates could be obtained by sampling temporary detector installations at key locations along area freeways. Full lane coverage would not be necessary since the proposal would be to provide a “snapshot” or sample of speed conditions along segments of area freeways. Sample stations would be a more economical means than full lane coverage. Additionally, non-intrusive type sampling detectors such as radar, microwave, or video image detectors would provide a more economical solution than closing freeway lanes to install loop detectors. It is emphasized that sampling detectors are just that: speed level sampling stations. (They are not intended to replace ultimate full lane coverage which may be required in future systems.) However, it is envisioned that detection equipment could be integrated in future deployment.

1.2 PROJECT OBJECTIVES

The objectives of this study are stated as follows:

- Determine the non-traditional freeway speed sources available in the Dallas area;
- Determine the extent to which coverage of the area freeways is presently provided and where gaps may exist; and investigate how speed data might be obtained to fill these gaps;
- Determine the feasibility of using these sources in presentation of speed data on area freeways to the traveling public in the home or workplace via the Internet, strategically located kiosks, and other methods which may become identified;
- Demonstrate the concept on a mock-up home page showing the Dallas Freeway Network; and
- Document findings with potential costs, benefits, and recommended actions.

2. LITERATURE AND CURRENT PRACTICE SURVEY

2.1 INTRODUCTION

Several sources were available for current practice and technology in vehicle detection. A comprehensive literature search was recently performed on another TTI project and the results were readily available. In addition, TTI recently completed the *1997 Freeway Management Handbook* (2) for the Federal Highway Administration and made on-site visits to 10 freeway management centers throughout the country, compiling current practice in freeway management (3). Contacts with other freeway management operators were made by telephone interview.

2.2 OVERVIEW

The literature and current practice survey consisted of three subtasks:

- An in-depth literature review recently developed by TTI on another project for TxDOT (4);
- Direct contact with several current freeway management practitioners; and
- Supplemental review of current usage.

2.2.1 Literature Review of Vehicle Detector Technology

An extensive literature search of current vehicle detection technology was conducted by TTI on another research project to the Texas Department of Transportation (TxDOT) (4). The literature review is reproduced in Appendix A. Of particular interest to this project are non-intrusive detectors, i.e., those that do not require cutting or drilling of the roadway. Table 1 shows a summary of non-intrusive sensors currently in use worldwide and their approximate costs. Costs will vary depending on specific application.

2.2.2 Practitioner Survey

Appendix B provides a summary of a survey of freeway management practitioners. A review of this survey shows that most operating systems continue to rely almost exclusively on loop detectors and managers are generally satisfied with their operation. They emphasize that proper installation and maintenance are essential. Several agencies have installed and tested other types of detectors with varying success or satisfaction with results.

2.2.3 Supplemental Review

In addition to the previously noted literature review and practitioner survey, information was gathered through WinSPIRS and the University of California at Berkeley PATH database for recent unique applications of various vehicle monitoring technologies. A summary of these citations is shown in Appendix C.

Table 1. Summary of Non-Intrusive Sensors

TECHNOLOGY	VENDOR/PRODUCT	STATED CAPABILITIES	APPROX. COST	ADDITIONAL EQUIPMENT
Active Infrared	Schwartz Electro Optics, Inc., Autosense I	volume, occ., density, speed, class, presence	\$6,500	PC, mounting bracket
Passive Infrared	ASIM Engineering Ltd. (Switzerland) IR 224	volume, occ., presence	\$1,400	PC with interface box and display software (optional)
Passive Magnetic	3M Microloop	volume, occ., presence, speed (with 2 sensors)	\$500 - \$800 (b)	
Passive Magnetic	Nu-Metrics NC-40, NC-90A G-1, G-2 (wireless)	NC-40: vol., occ., presence NC-90A: same + speed, class, length G-1: vol., occ., presence, temp. G-2: same + speed, class, length	NC-40: \$550 NC90A: \$895 G-1: \$975 G-2: \$1,695	PC, computer interface (\$450), software (\$745) & protective cover (\$158 NCs only)
Radar	EIS, Inc. RTMS X1	volume, occ., speed, presence, turning movements, class.	\$3,500	PC for setup and for serial data
Doppler Microwave	MicrowaveSensors, Inc. TC-20/TC26B	volume, occ., (20 is short range, 26B is long range)	TC-20: \$630 TC-26B: \$375	
Doppler Microwave	Whelen Engineering TDW 10/TDN 30	volume, occ., speed (TDW is wide bm), (TDN is narrow bm)	\$995	PC for serial data (optional)
Passive Acoustic	AT&T/IRD SmartSonic TSS-1	volume, occupancy, speed	\$1,450	Mounting brackets, PC for serial data - opt.
Video Tracking	ELIOP Trafico S.A. (Spain) Eva 2000 S	volume, occ., density, presence, speed, class, headway, (price varies w/ features)	\$7,000 - \$17,000	386 PC, camera, software
Video Tripline	Econolite Autoscope 2004	volume, occ., density, presence, speed, class, headway, turning movements	\$17,000 (1 camera unit) \$24,000 (4 camera unit)	486 PC (cameras included)
Video Tracking	Peek Transyt VideoTrak 900	volume, occ., density, presence, speed, class, headway, turning movements, incident detection	\$18,000 (4 camera unit)	486 PC, cameras
Video Tripline	Rockwell International TrafficCam	volume, occ., speed, presence	\$3,800	386 PC (camera included)

Source: Reference (5)

(Costs shown are order of magnitude and may vary depending on specific application.)

3. EXISTING SYSTEM DESCRIPTION

3.1 INTRODUCTION

A number of data sources in the Dallas area could be used to gather information on freeway travel speed and operating conditions. Those sources include closed-circuit television (CCTV) cameras, loop detectors, TxDOT courtesy patrol, Dallas Area Rapid Transit (DART) buses, commercial radio, and television broadcasts. Access to these sources enables TxDOT to measure or approximate speed, which in turn enables a Level of Service (LOS) or freeway operating condition to be estimated. Once this information is known, it can then be presented to travelers to assist them in making travel route or travel mode decisions. Thus, while specific speed measurements are not now possible, traffic operation indicators of freeway conditions are available from these other sources.

3.2 SOURCES OF DATA

3.2.1 Loop Detectors

Loop detectors are capable of measuring speeds of vehicles on the freeways as well as measuring the flow of traffic. A speed trap is created by the detectors because they are placed in the freeway a known distance apart. Since the spacing of the detectors is known and the time between activation of successive loops can be measured, the speed of a vehicle can be calculated. Once this is known, the LOS or operating conditions of the freeway can be determined. Loop detectors are not operational on Dallas freeways as yet, but have been installed on US 75 (North Central Expressway) for future use.

3.2.2 Closed-Circuit Television (CCTV)

Closed-circuit television (CCTV) cameras are another source of estimating operating conditions. Cameras are located along a limited number of the freeways in Dallas, including IH-35, IH-635, and US 75. The locations of these cameras can be seen on a map in Figure 1. A summary of the camera operational status is provided in Table 2. The cameras are presently (and in the future) used to monitor traffic for freeway incidents and operating conditions of the freeways. Where vehicle detectors are not yet installed, an estimate of the speed range of traffic can be made by the control center operator from the CCTV. This information can then be furnished to the traveler by various means.

The City of Richardson can also be an information provider. Richardson has installed cameras along US 75 to detect and verify traffic incidents. When an incident is verified by the Richardson cameras, that information can be forwarded to TxDOT to help in traffic management. Other area cities also have plans for CCTV cameras.

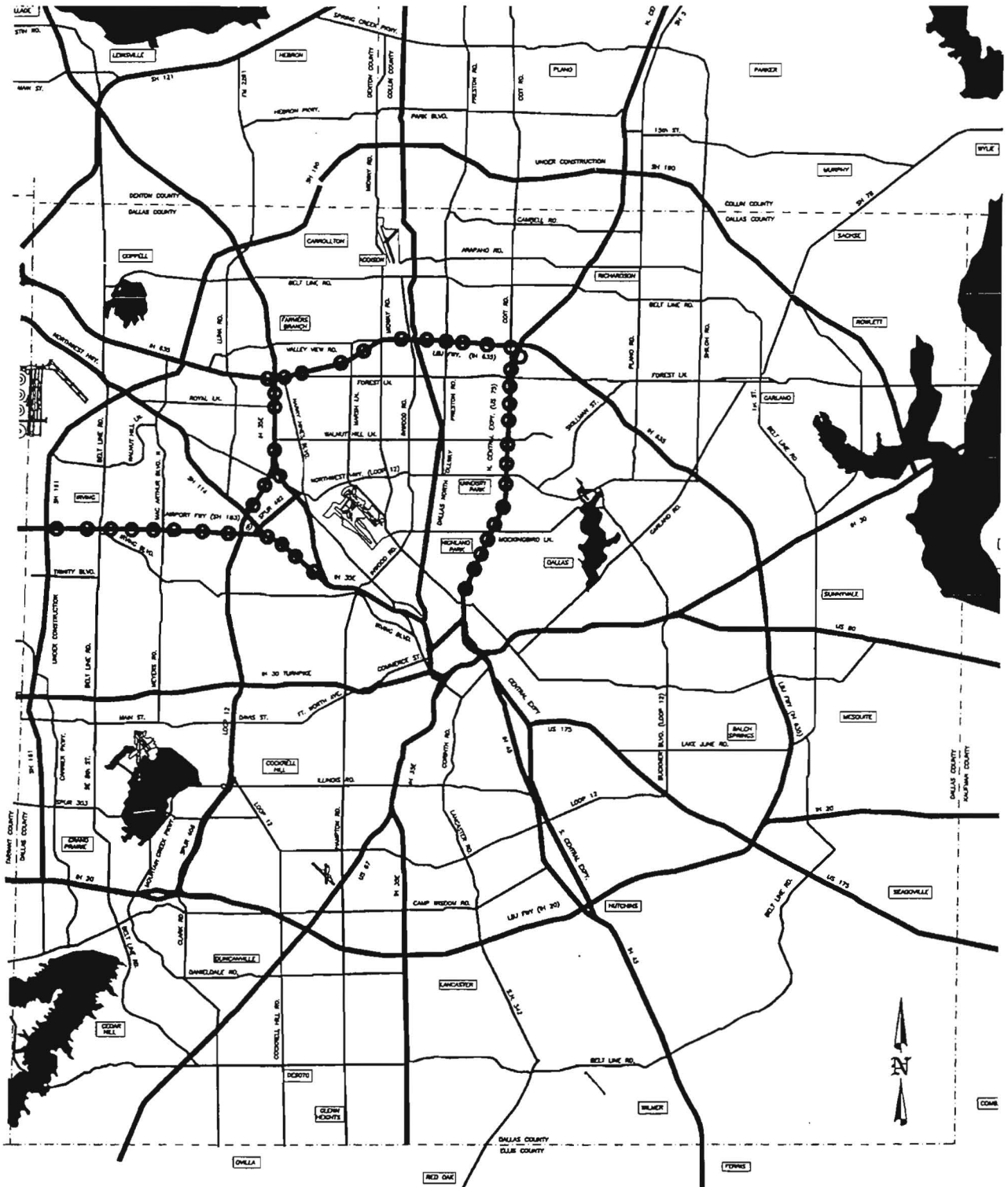


Figure 1. Closed-Circuit Camera Locations in Dallas

Table 2. Summary of Camera Operational Status

Freeway	Number of Cameras	Limits		Planned Schedule
		To	From	
US 75	7	IH-635	Park Lane	Operational
US 75	8	Park Lane	IH-45	June 1998
IH-635	9	US 75	Harry Hines Blvd.	April 1998
IH-35E	4	IH-635	Loop 12	December 1998
Loop 12	2	IH-35E	SH 183	December 1998
SH 183	12	Valley View Lane	IH-35E	December 1998
IH-35E	5	Marsalis Avenue	US 67	January 1999
US 67	7	IH-35E	IH-20	January 1999

3.2.3 TxDOT Courtesy Patrol

The TxDOT courtesy patrol also provides a source for monitoring travel conditions as the vehicles traverse the area freeways responding to incidents. While monitoring the freeways, the courtesy patrol could report on freeway operating conditions and speed levels at locations along the freeway. This can be done by cellular phone or by radio. Although the Automatic Vehicle Location (AVL) presently installed in courtesy patrol vehicles does not provide location data in a manner timely enough for freeway speed measurement, future systems may include a more accurate Global Positioning System (GPS) locator.

3.2.4 Dallas Area Rapid Transit (DART)

Dallas Area Rapid Transit has more than 1,000 buses equipped with GPS equipment. Many of the buses travel on area freeways and location, heading, and speed information are available from transmitted data.

3.2.5 Commercial Broadcast Stations

Radio and television stations are another source of information that is presently available. This source of information is most available during the peak hours of travel on weekdays, although some radio stations provide off-peak and weekend reports. Several stations have airborne reporters enabling them to survey the freeways in a timely manner. Information about incidents reported to the public can be used by TxDOT for determining operating conditions and sometimes freeway speed estimates.

3.2.6 Commercial Traffic Information Providers

The commercial traffic information providers in the region, Metro Systems, and Shadow Broadcasting, are another source of information. The providers can inform TxDOT of the operating conditions they observe at the same time they inform their primary clients, the local radio and television stations. Although the information could not be directly provided to motorists (because commercial providers sell that service), it could be used for information on dynamic message signs or other distribution media. The television stations of the Metroplex are another information provider. The four major television stations in the Metroplex (KDFW, KXAS, WFAA, and KTVT) all have Towercams (cameras located on the tops of buildings or towers). They are located throughout the city and could be used to gather supplementary information for the TxDOT cameras.

3.2.7 TollTag™ Readers

It is estimated that over 200,000 vehicles in the Dallas area have TollTags which are used for toll collection on the Dallas North Tollway. Many drivers with TollTags also travel on other freeways. Another source for speed and operating conditions is TollTag readers on the freeways. Installing the TollTag readers would allow traffic to be monitored and speed on the freeways to be estimated. The Texas Department of Transportation is currently testing this concept on IH-635. Installation of TollTag readers in and around the Dallas North Tollway may provide additional sources of information.

3.3 AREAS OF GAPS IN COVERAGE

Much of Dallas County is not as yet covered by system detection or other electronic monitoring. These areas include: the freeways east of US 75, and on IH-45, IH-30, US 67, and IH-20. TxDOT plans to have full surveillance coverage by the year 2000. To do this, cameras will be installed approximately every mile on the freeway. Gaps also exist in time when there is little or no monitoring of the freeways. For example, the TxDOT Satellite Control Center is not manned during the weekends and radio and television stations only report the operating conditions at certain times during the week. Table 3 shows the times and days that data sources are being used to monitor the freeways.

Table 3. Data Sources at the Times of the Day

Hours of the Day

Days of the Week

	5:00 AM	6:00 AM	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
Monday	Radio	Radio	Radio	Radio						
	TV	TV	TV							
	CP	CP	CP	CP	CP	CP	CP	CP	CP	CP
Tuesday	Radio	Radio	Radio	Radio						
	TV	TV	TV							
	CP	CP	CP	CP	CP	CP	CP	CP	CP	CP
Wednesday	Radio	Radio	Radio	Radio						
	TV	TV	TV							
	CP	CP	CP	CP	CP	CP	CP	CP	CP	CP
Thursday	Radio	Radio	Radio	Radio						
	TV	TV	TV							
	CP	CP	CP	CP	CP	CP	CP	CP	CP	CP
Friday	Radio	Radio	Radio	Radio						
	TV	TV	TV							
	CP	CP	CP	CP	CP	CP	CP	CP	CP	CP
Saturday										
Sunday										
	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM	11:00 PM	12:00 AM
Monday		Radio	Radio	Radio						
	CP	CP	CP	CP	CP	CP	CP			
Tuesday		Radio	Radio	Radio						
	CP	CP	CP	CP	CP	CP	CP			
Wednesday		Radio	Radio	Radio						
	CP	CP	CP	CP	CP	CP	CP	CP	CP	
Thursday		Radio	Radio	Radio						
	CP	CP	CP	CP	CP	CP	CP	CP	CP	
Friday		Radio	Radio	Radio						
	CP	CP	CP	CP	CP	CP	CP	CP	CP	
Saturday		CP	CP	CP	CP	CP	CP	CP	CP	
Sunday		CP	CP	CP	CP	CP	CP	CP	CP	

CP---TxDOT Courtesy Patrol

3.4 TIMES AND LOCATION OF COVERAGE BY DATA SOURCES

There are certain times of the day when the coverage of the freeways is more prominent than others. The radio and television stations cover the freeways primarily during the peak hours of the weekday. The television stations generally only report in the morning from about 5:30 A.M. to 8:00 A.M. while the radio stations report every morning and afternoon, with at least two stations reporting during off-peak times as well. The basic times that are reported by the radio stations are from 5:30 A.M. to 9:00 A.M. in the morning and from 4:00 P.M. to 6:30 P.M. in the evening. The TxDOT Satellite Control Center is staffed from 6:00 A.M. in the morning until 10:00 P.M. in the evening. During this time, the operator monitors cameras and loop detectors. If TollTag readers are installed on the freeways around Dallas, they also could be monitored by the control center. Courtesy patrol is another data source that can be used while they are on patrol duty. The courtesy patrol is on duty from 5:30 A.M. to 10 P.M. Monday and Tuesday, 5:30 A.M. to 12 A.M. Wednesday, Thursday, and Friday, and from 4 P.M. to 12 A.M. on Saturday and Sunday.

3.5 SUMMARY

There are several sources on the freeways that can be used to gather speed and traffic condition data. These sources include CCTV cameras, loop detectors, and courtesy patrol. However, loop detectors and CCTV cameras will not be deployed extensively in the near-term. TollTag readers offer an attractive alternative, but they appear to be a costly solution even though they are non-intrusive and can be installed expeditiously. However, their effectiveness diminishes as distance from the Dallas North Tollway increases. There are physical gaps in electronic surveillance and the need for supplementary data sources is apparent. Operational data is available from commercial media sources, but the data is of a more subjective nature and must be interpreted for use in the system.

4. POTENTIAL SOURCES TO AUGMENT EXISTING SOURCES

4.1 INTRODUCTION

Section 3 documented existing sources that can provide information on travel conditions and speed on Dallas freeways. It was noted that while limited in coverage, there are some good sources of information available for gathering these data. TxDOT receives information through its courtesy patrols and surveillance system, although the system is not fully deployed. Other sources include radio and television traffic reporting, traffic information providers, DART, and the police.

Monitoring the police bands of the radio can also inform TxDOT and the motorists of potential delays. Any information that TxDOT receives about an incident and the possible delays that may occur can then be posted on the dynamic message signs located along the freeways or on a speed/operating condition map available via the Internet or kiosks. Monitoring police bands and traffic information providers would likely require at least one person dedicated to that task in addition to the principal operator of the TxDOT Satellite Control Center.

4.2 ADDITIONAL SOURCES FOR SPEED AND TRAFFIC OPERATING CONDITIONS

Given that total coverage for freeway surveillance will not be available in the near-term, and media and police broadcast monitoring requires additional personnel dedicated to that task, other sources were investigated. Detection systems that can be deployed in timely and cost-effective manners were investigated. It is desirable that any additional detection not require intrusion into pavement or structures.

4.2.1 Non-Intrusive Detectors

Non-intrusive detectors are detectors that can be installed and maintained with little effect on the flow of traffic. These types of detectors can be installed on an overpass above the freeway, on a sign structure, or on a pole along the side of the freeway. From a performance standpoint, the most desirable location for these types of detectors is generally over the freeway. Coverage of all lanes of the freeway will be more accurate if the detector is placed over the traffic lane. Non-intrusive detectors can also be mounted on poles located on the sides of the freeway. When mounted on a pole, the detector is installed approximately 40 feet above the freeway and positioned so that readings for each lane can be taken. However, when a detector is situated in this manner, the accuracies of the readings decline the further away from the detector readings are taken. Shadows and occlusion are the primary factors affecting accuracy. Shadows occur when the sun is behind an overpass. The shadow of the overpass then falls into the reading area which keeps the vehicle from being noted by the detector. Occlusion is an event where a vehicle does not get sensed because it cannot be seen by the detector. The site for the non-intrusive detector also depends on a power source. If a power source can be reached more easily from a side-of-the-road detector than an overhead detector, it will more than likely be placed on the side of the road, and vice versa.

Non-intrusive detectors could be placed between cameras on the freeways or where cameras are not yet deployed. As noted in Section 3, the CCTVs currently planned for many Dallas freeways are to be operational by January 1999, and are to be placed approximately one mile apart. With the camera spacing of one mile, non-intrusive detectors could be placed between every two or three cameras as an additional form of detection and speed measurement. Where there is no other form of detection on the freeway, a suitable distance to space the non-intrusive detectors is three to four miles. Placing the first complement of non-intrusive detectors at these distances would enable TxDOT to evaluate the functionality of the detectors while additional detectors could be placed between the original detectors in the future.

4.2.2 Types of Non-Intrusive Detectors

There are several non-intrusive detectors on the market. They include video detectors, radar detectors, and acoustic detectors. Each of these detectors performs various functions ranging from gathering speed data to counting passengers in a vehicle.

4.2.2.1 Video Detectors

Video detectors can collect several types of data. Along with the standard types of data of speed, volume, and classification, video detectors can also determine dwell time and detect incidents. Visual monitoring for incidents using a video detector is not a primary use for this type of detector. Since the detector must stay in one position to gather the other types of data accurately, detecting an incident visually by video detector would happen only coincidentally.

Video detectors can be mounted on a freeway overpass or on a pole along the side or median of the freeway. Location and operating conditions have an effect on the accuracy of the data. Some conditions that may affect the data from the video detector are shadows, direct sunlight, water on the camera lens, and pole movement caused by the wind.

Video image detectors have been deployed along the Houston freeways. They are gathering speed data, counting vehicles, and determining occupancy. The TxDOT Dallas District has field tested video detectors, as has the TxDOT Fort Worth District. Preliminary results are favorable.

4.2.2.2 Radar Detectors

Radar detectors do not gather quite as much data as video detectors. They gather speed data, volume, and classification data. They also detect low speeds or sudden changes in speeds which can indicate an incident.

This type of detector can be placed in the same basic positions as the video detectors. One additional place that can be considered for mounting the radar detector is on a sign structure. Whether it is on an overpass or a sign that is on the side of the freeway is not a significant concern. When mounting the radar detector, care must be taken to calibrate the device carefully to verify it is gathering the data correctly.

4.2.2.3 *TollTagTM Readers*

Approximately 200,000 motorists in Dallas now have TollTags for use on the Dallas North Tollway. However, many of them use other freeways located around Dallas. Installing TollTag readers along freeways would be another potential source of data for TxDOT. Presently, the only TollTag readers are at the toll booths on the Dallas North Tollway. However, the TollTag system manufacturer, Amtech, has installed three readers along Westbound IH-635 between Coit Road and Marsh Lane for a study being conducted for TxDOT. The study will evaluate the suitability of TollTags as a method to measure traffic conditions off the Tollway. If additional readers are placed along the freeway, the data could then be used to help determine the speeds or operating conditions of freeway traffic.

The City of Farmers Branch is conducting a study with TollTag readers on an arterial street parallel to IH-635. This street, Valley View Lane, is used by motorists as a through route when an incident has occurred on IH-635. When an incident occurs, the street can become almost as congested as the freeway and the signals should be adjusted to accommodate diverted traffic. With the TollTag readers along Valley View, the delay can be estimated and the signals automatically re-timed to maximize the flow and decrease the delay in response to the incident.

4.3 CITIZEN INPUT

Citizen input is also another potential source of information. Many incidents that occur on the freeways are reported to 911 emergency telephone response systems by cellular phones. Some motorists also telephone radio stations to report incidents that they have seen on the freeways, but stations generally do not broadcast those reports in a timely manner. In a related TTI study, (6) it was found that 17 percent of the population has wireless phones. Given that many of the phones are used on area freeways, a link to 911 could provide much useful information on freeway operating conditions.

4.4 SUMMARY

Potential sources that may enhance the effectiveness of the existing sources of data include non-intrusive detectors, broadcast media, and TollTag readers. Non-intrusive detectors, which seldom interfere with traffic, are very good sources of data. As with the media and TollTag readers, they can be used to gather speed and operating condition information, and also to inform TxDOT or motorists of delays on the freeways. These potential sources will aid in the effectiveness of the other sources on the freeways by informing TxDOT of incidents in their early stages, or by supporting what another source has indicated.

5. VIABILITY OF USING IDENTIFIED DATA SOURCES

5.1 INTRODUCTION

In previous sections, various existing and potential sources of freeway operations data were identified. Examples of those sources are loop detectors, automatic vehicle identifiers (i.e., Toll-TagsTM), and the courtesy patrol. The sources named, and additional sources, not only generate speed data, but occupancy, flow, and location can be determined. This section will assess the quality, reliability, and consistency of travel data from these sources as well as assessing formats of the data and the means by which it will be received, analyzed, and formatted for presentation.

As mentioned previously, other sources may be available to aid in gathering freeway operations data. CCTV is another prime source of data. The local media are another possible source of data. While they cannot generate speed or occupancy data, they can inform travelers of the problems. AVLs are another possible source of data. The 911 system is a possible source that could also be used in gathering freeway data. Incident information could be forwarded from the 911 operators to a freeway management system operator who could verify the incident by CCTV and then post messages on the dynamic message signs or on an Internet page to warn travelers. (The San Antonio TransGuide system (the area's regional transportation control center) interfaces directly with 911 and automatically posts traffic-related events on a situation map and in a tabular format).

5.2 COMPARISON OF THE QUALITY, RELIABILITY, AND CONSISTENCY OF THE DATA

Various operational monitors and sensors have advantages and disadvantages. These attributes must be weighed against each other to determine the value of the sensor. Some attributes that must be considered are cost of system, ease of installation, maintenance, and effect on traffic.

5.2.1 Loop Detectors

Properly installed and maintained, loop detectors are a very good source of operational data. They can measure speed, occupancy, and the flow of traffic. They measure the speed by measuring the time for a vehicle to travel from one loop to the next. Since the loops are located at predetermined distances, the speed can then be calculated. Various speed levels can give an indication of the freeway level of service or quality of traffic flow. While loop detectors give good measures of speed and flow of traffic, they are very difficult to install and maintain on existing roadways since lanes of the freeway must be shut down, causing congestion and potential incidents. Installation during construction of freeway lanes is desirable, but not always possible. The cost of loop detectors is also a factor. The price of a loop detector is approximately \$2,250 per loop. In order to measure speed, two detectors (\$4,500) are required.

5.2.2 Radar Detectors

Radar detectors can also be considered for measuring freeway operations. They can be placed overhead or along the side of the freeway, and can cover multiple lanes of traffic. This type of

detector is valuable due to the range of information it can gather. Radar detectors can measure information on speed, volume, occupancy, and vehicle classification. While it cannot “see” an incident occur, it can be used for determining if one has occurred. If the speed of traffic suddenly falls or if the occupancy of the lanes increases substantially in a short amount of time, those are indicators of an incident. Calibration of the radar is critical and can have a detrimental effect if not performed. Alignment of the radar units to receive optimum monitoring may require extra maintenance. Maintenance is not a major drawback to radar sensors since maintenance personnel can usually make repairs without having to close a lane of traffic. The Electronic Integrated Systems RTMS radar detector price is approximately \$3,300 per detector (5) with another \$700 added for data storage. Another detector is distributed by Precision Solar Controls and it is priced at approximately \$5,000 per detector unit.

5.2.3 Video Imaging Detection Systems (VIDS)

A video imaging detection system can be used to gather traffic data including volume, speed, classification, and occupancy. Video detection systems are best suited for determining volume and occupancy. The cameras used can monitor multiple lanes of traffic while having multiple zones within each lane. This helps in determining speed and volume of traffic. The positive aspects for the VIDS are basically the same as for radar detectors. Lanes of traffic seldom must be closed for installation and maintenance is much easier. Negative attributes of the VIDS are greater than radar detectors, but are not extreme. Alignment of the cameras to an exact location is critical and complicated with VIDS. Other possible drawbacks of VIDS are shadows and occlusion. Shadows are a problem that cannot be controlled; however, occlusion can be. Occlusion is when a camera does not count a vehicle because it cannot see it. To combat this problem, VIDS cameras are placed as high as possible on poles. If this is done, the occlusion problem can be reduced and it will also reduce the particles that get onto the camera lens from the road. Video detection units are placed on poles along the roadside or on overpasses. By placing VIDS on overpasses, maintenance is made easier and usually only one lane of traffic must be shut down for installation. Video systems can range from \$5,000 - \$25,000, depending on the system (5).

Table 4 shows a cost comparison of the different types of detectors available. Table 5 breaks down the overall costs and compares them by cost per detection zone.

5.2.4 Automatic Vehicle Identification (AVI)

Automatic vehicle identification is another possible method to collect data on speed and volume. Most AVI systems throughout the country use a small box containing a microchip that is placed on the inside of the windshield of a vehicle. When a vehicle passes a certain point along the freeway, a reader takes the information and stores it. When the vehicle passes the next reader, the approximate speed of the vehicle can then be calculated. The AVI readers are installed in basically the same manner as radar detectors and VIDS. They are placed along the freeway on either an overpass or a pole. Some positive aspects of using AVI are the ease of maintenance and the number of vehicles currently using AVI in the Dallas area. Approximately 200,000 motorists have TollTags for use on the Dallas North Tollway. TxDOT is also conducting studies along Westbound IH-635 between Coit Road and Marsh Lane. The AVI reader is similar to the

Table 4. Cost Comparison of Detectors Presently Available

Type of Detector	Distributor	Approximate Cost
Loop Detector	Multiple Vendors	\$2,250/loop – cabinet, equipment, and local control unit
Video Image Detection System (VIDS)	Peek – Traffic Odetics Econolite Nestor	\$18,000/4 camera system \$20,000/4 camera system \$21,000-\$35,000/unit \$19,150/unit (4 camera system)
Sonic	SmarTek	\$3,500/unit-w/o options
Radar/Microwave	Electronic Integrated Systems-RTMS Precision Solar Controls	\$3,500/unit \$5,000/unit
TollTags™	Amtech	\$50,000/site

Table 5. Cost Breakdown and Comparison per Detection Zone

Type of Detector	Distributor	Coverage	Approximate Cost
Loop Detector	Multiple Vendors	1 lane	\$4,500/zone
Video Image Detection System (VIDS)	Peek-Traffic Odetics Econolite Nestor	5 lanes/camera 3-6 lanes/camera 6 lanes/camera 6 lanes/camera	\$4,000/zone \$5,000/zone \$21,000-\$35,000/zone \$4,800/zone
Radar/Microwave	Electronic Integrated Systems-RTMS	4-6 lanes/camera	\$4,000/zone
TollTags™	Amtech	1 site/4 antennae	\$3,200/point

Note: The approximate costs are a comparison for a loop equivalent. However, more than one loop of coverage is possible with the VIDS and radar detectors.

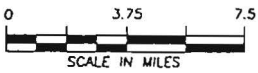
radar detector, but equipment costs are higher. The large number of TollTags (probes) in the area makes them very attractive, but costs of reader stations may be prohibitive.

5.2.5 Automatic Vehicle Location (AVL)

DART has a number of buses that travel along the freeways. The buses are equipped with a GPS that tracks the buses and helps determine how quickly it takes a bus to go from one point to another. Once the time has been determined, the speed of the vehicle can be determined by dividing the length of travel by the elapsed time to get from the beginning point to the end point. A positive aspect about AVL is that whenever a bus is on the freeway, its point may be determined and its speed calculated. However, bus headways vary from five to 20 minutes during the peak period and not all freeways are used by a bus route. Figure 2 illustrates the bus routes on the Dallas area freeways during the peak period. Figure 3 shows the bus routes during off-peak periods. DART buses are the only public vehicles in Dallas equipped with GPS. If more vehicles had GPS, automatic vehicle location would be of more use. Private company vehicles use the system, but many such companies consider the location data proprietary and are reluctant to make it available.

5.2.6 Freeway Cameras

Freeway cameras or CCTV cameras are an excellent source of traffic operations levels. There are 39 cameras functioning on the freeways of Dallas with 15 more planned for operation by January 1999. (See Figure 1.) Freeway cameras are an integral part of the area-wide ITS plan. While these cameras cannot measure speed of vehicles on the freeway directly, they can be used to monitor the freeway for incidents and possibly for speed estimates. When the occupancy of a lane increases, the cameras can be used to scan the freeway for an incident and to verify that an incident has occurred. When a citizen reports an incident on the freeway, the CCTV cameras can be used to verify where the incident has occurred. They can also be used to estimate the LOS on the freeway. CCTV cameras cannot measure speed data, but can be used to estimate the LOS and verify that an incident has occurred.



LEGEND	
--	COUNTY LINE
==	FWY OR TOLLWAY
—	REGIONAL ARTERIALS
▣	0-10 MIN PEAK HDW
▤	10-20 MIN PEAK HDW
▥	20-45 MIN PEAK HDW
▧	>45 MIN PEAK HDW

Figure 2. Peak Period Bus Routes

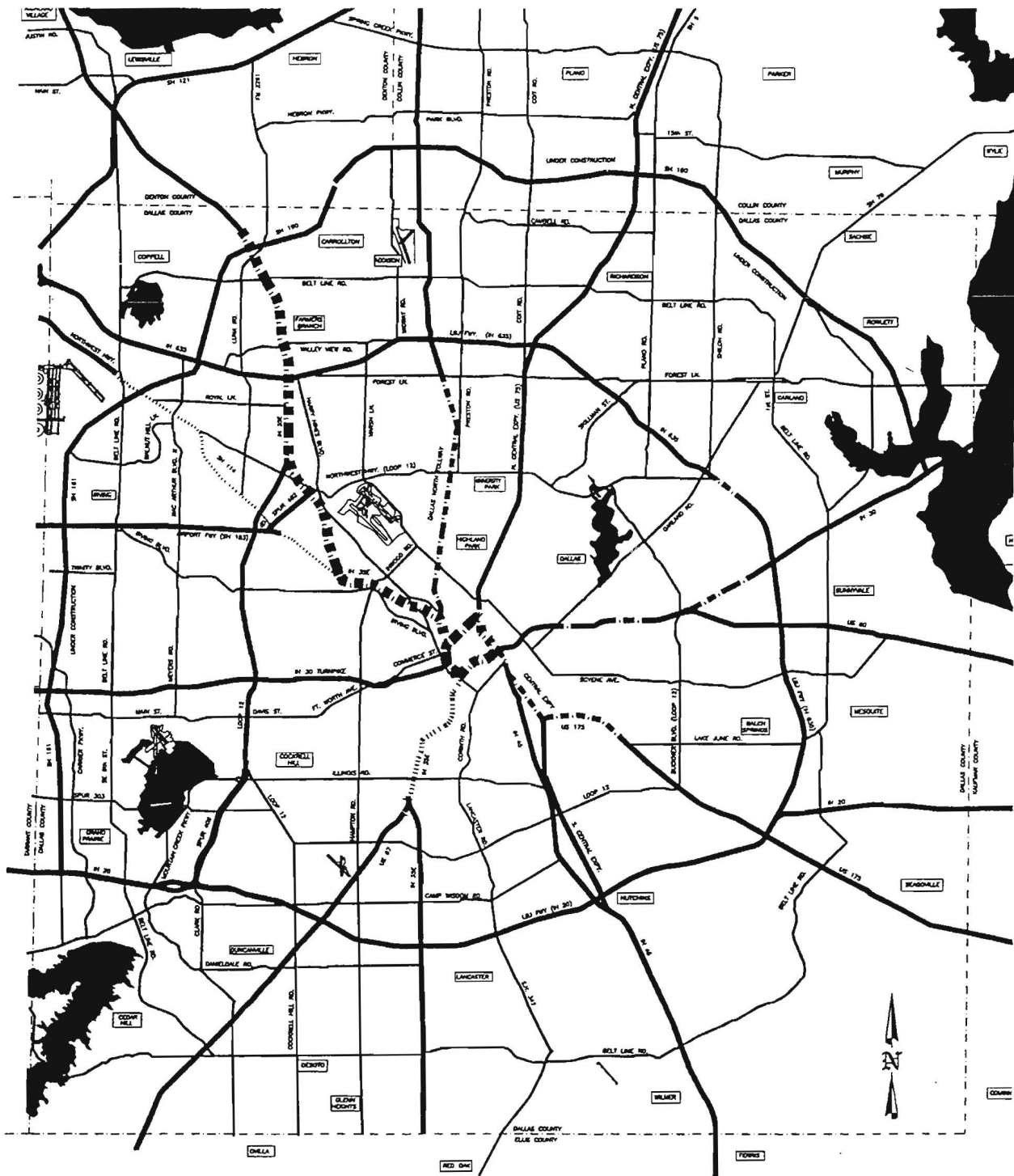


Figure 3. Off-Peak Period Bus Routes

5.2.7 Courtesy Patrol

The data forwarded by the courtesy patrol would be reliable, but it would not be consistent across time and space due to the wide area of coverage. With the courtesy patrol monitoring the freeways, its drivers can report what the average speed of the traffic is, but it could not be done at precise intervals since unscheduled stops are made to assist motorists. The courtesy patrol vehicles are equipped with an AVL system; however, it does not provide location information in a manner timely enough for speed measurements. In the future, the courtesy patrol will be equipped with a GPS system that provides more accurate information. There would still be gaps of coverage due to time and space constraints mentioned above.

5.2.8 911 Emergency Services

Information from the 911 operators would be a good source of data. When the information is received, non-traffic related call categories (e.g., domestic violence) can be filtered out. After that is done, CCTV cameras could be used to verify that an incident has occurred. Messages can be posted on dynamic message signs, Internet sites, or kiosks to inform motorists of the incident and the courtesy patrol can be dispatched to the scene. A related study (6) has noted the desire of 911 Emergency Services to cooperate in the exchange of information with transportation control centers and a system of information exchange is in place in San Antonio.

5.2.9 Local Media

News media in the Dallas area offer an additional source of information. Two commercial information providers, Metro Systems and Shadow Broadcasting, furnish information to radio and television stations in the area. They inform the stations of incidents that have occurred, how long they have been there, and an estimated time for clearance. A negative aspect of the commercial providers is the absence of reporting when an incident has been cleared. Also, if the clearing is reported, it may be delayed. Most commercial broadcast stations have their own traffic reporters. They have the same negative aspects as the commercial providers. In addition, monitoring numerous broadcasts is labor intensive and the operator would not always be available for other duties. The positive attributes of the local media are informing travelers of incidents and the queues that have formed behind them. This enables travelers to delay their trip or plan a different route. The local media also offer approximate estimates of delay due to the incident and suggest alternate routes around the scene.



Figure 4. Location of Existing and Planned Cameras on the Dallas Area Freeways

5.3 SUMMARY

Several sources of data have been evaluated in previous sections. This section has evaluated the quality, reliability, consistency, and cost factors of those sources. No one source of data is clearly sufficient to cover the entire Dallas area. Different data sources will be needed to fill the gaps in the Dallas system. Of the sources discussed, loop detectors give quality data, are reliable, and give consistent data. However, when loop detectors are installed or require maintenance, traffic is interrupted. Radar detectors are a very attractive form of detector. They not only gather speed data, but they also gather occupancy and volume data. The data taken from this type of detector is usually high quality, consistent, and very reliable. The cost of a radar detector is also another positive aspect. VIDS are another type of detector that can gather information on speed and occupancy, reliably, and consistently. VIDS is a fairly economical data source. AVI is another good source of data. It can be used to determine speed levels accurately. These data are of good quality and reliable; however, the biggest drawback of AVI is the cost of the field readers. AVLs are potentially a good source of data. However, there are not enough vehicles on the road with this type of equipment to get comprehensive results. Freeway cameras and courtesy patrol are two positive sources of data. Both monitor the freeway and can give quality information about incidents to an operator in the control center who can then inform motorists of the problems on the freeway. Another potential source that would give consistent and quality data to the control center is 911 Emergency Services. Local media reports are already being used by travelers, but coverage is not uniform. The data they supply are of fair quality and the media are consistent and reliable about when reports are aired.

Overall it appears radar detectors, freeway cameras, courtesy patrol, and 911 Emergency Services would be the best sources for gathering data. Figure 4 shows a map of existing loop detectors and possible sites for other types of detectors on Dallas freeways.

6. RECOMMENDED SYSTEM

6.1 INTRODUCTION

Previous sections have documented the existing and planned sources of freeway operations data that will be available for measuring freeway conditions on the Dallas Urban Area Freeway System. The information sources noted could be used to provide the quantitative nature of freeway speed levels on freeways and location of freeway incidents. Although TxDOT has begun installing advanced freeway management hardware and software systems, full deployment will not be completed for five to eight years. In the meantime, it will be desirable to provide travelers with freeway operation information from existing sources. Since an Internet-based map will be available for presentation of such data, other sources available in near-term have been investigated. The following paragraphs describe recommended supplemental data sources, a demonstration of the concept on a limited Dallas-based network, and a proposal for a near-term freeway operations status Internet map.

6.2 RECOMMENDED NEAR-TERM DATA SOURCES

6.2.1 Vehicle Detection

Sources of freeway speed and incident information are numerous. Detectors are one source, and they come in a wide variety of types with varying capabilities. Table 1 gives a comparative analysis of several popular types. Detectors can cover network surveillance or probe surveillance and be either intrusive or non-intrusive. The most commonly used detector is the inductive loop, an intrusive detector that provides network surveillance. However, because of their intrusive (cutting into pavement surface) nature, these detectors are expensive to install and experience wear and tear which can lead to expensive maintenance. When installed during roadway construction or rehabilitation projects, these may be the best choice, but installation in existing roadways requires costly road closures on operational lanes.

Two other network detectors of note are the radar and acoustic detectors. Both have been shown to be reliable sources of data. These detectors are non-intrusive, so they do not require pavement cuts or road closures. They are usually mounted on overhead sign bridges or bridge structures. The detectors can be mounted directly over the freeway main lanes or to the side of the freeway. Costs are comparable to loop detectors and therefore they are becoming a popular replacement.

With the planned and operational camera deployment, video-image detection devices are a third type of network surveillance to consider. Video-image detection varies greatly in regard to the type and accuracy of the data that they collect, and as a result, also vary greatly in price. Given the extensive types of data that these systems can provide, they may become a reasonable option to planning data collection activities as well.

These systems may provide a high benefit/cost ratio in comparison with other systems. Another added benefit of systems that provide data for incident detection is the visual surveillance

capability that is permitted during incident situations. This capability allows operators to verify incidents and to activate information messages for travelers.

The last type of detector found in the comparison table is the probe surveillance type. These types of detectors are non-intrusive because they do not require pavement cuts, but they do rely heavily on the placement of electronic tags or other devices in motorist vehicles and the costly equipment to monitor them. Dallas has approximately 200,000 vehicles that have TollTags already in their vehicles for automated toll payments on toll facilities. An AVI system placed in areas close to the toll facilities may provide substantial data from the existing tagged vehicles. There are, however, several major drawbacks to these systems. Capital and installation costs are high, and the data availability is limited by the number of tags within the system area.

Another type of probe surveillance system, the AVL, was not compared in the previous table. This type of system is usually deployed in a fleet of vehicles that would be maintained and monitored by a single entity, such as a transit agency with the bus fleet, or a police department with the police cars. The system works by deploying some type of locating device such as a GPS device in each of the vehicles. Location data collected by the vehicle are then sent to a monitoring station via radio or satellite communications. While this type of probe surveillance will provide information on travel time within an area, it is not a comprehensive source. It is proposed that DART's AVL system and the courtesy patrol AVL systems be used to enhance the speed information from the chosen detection system.

Since existing sources are not sufficient for full coverage of the freeway system in the Dallas urban area, it is proposed that sampling detection stations be installed at key locations throughout the area. Sampling detectors may be radar-type detectors mounted on bridge structures or poles alongside the freeway. One lane would be sufficient for sampling but a more detailed analysis may show that the incremental cost to cover all lanes may be incremental since power, phone service, and basic installation costs will be required for one sensor. Although video detection systems may be more costly if only applied to one lane, they are more cost competitive with radar detectors where all lanes are to be monitored. Again, a cost trade-off analysis may show that it is economically feasible to install video-based systems at key locations.

A more detailed analysis will be required at the time of design of the system to determine the specific type of vehicle detection system to be deployed. A map of recommended sampling points to augment the existing system is shown in Figure 5.

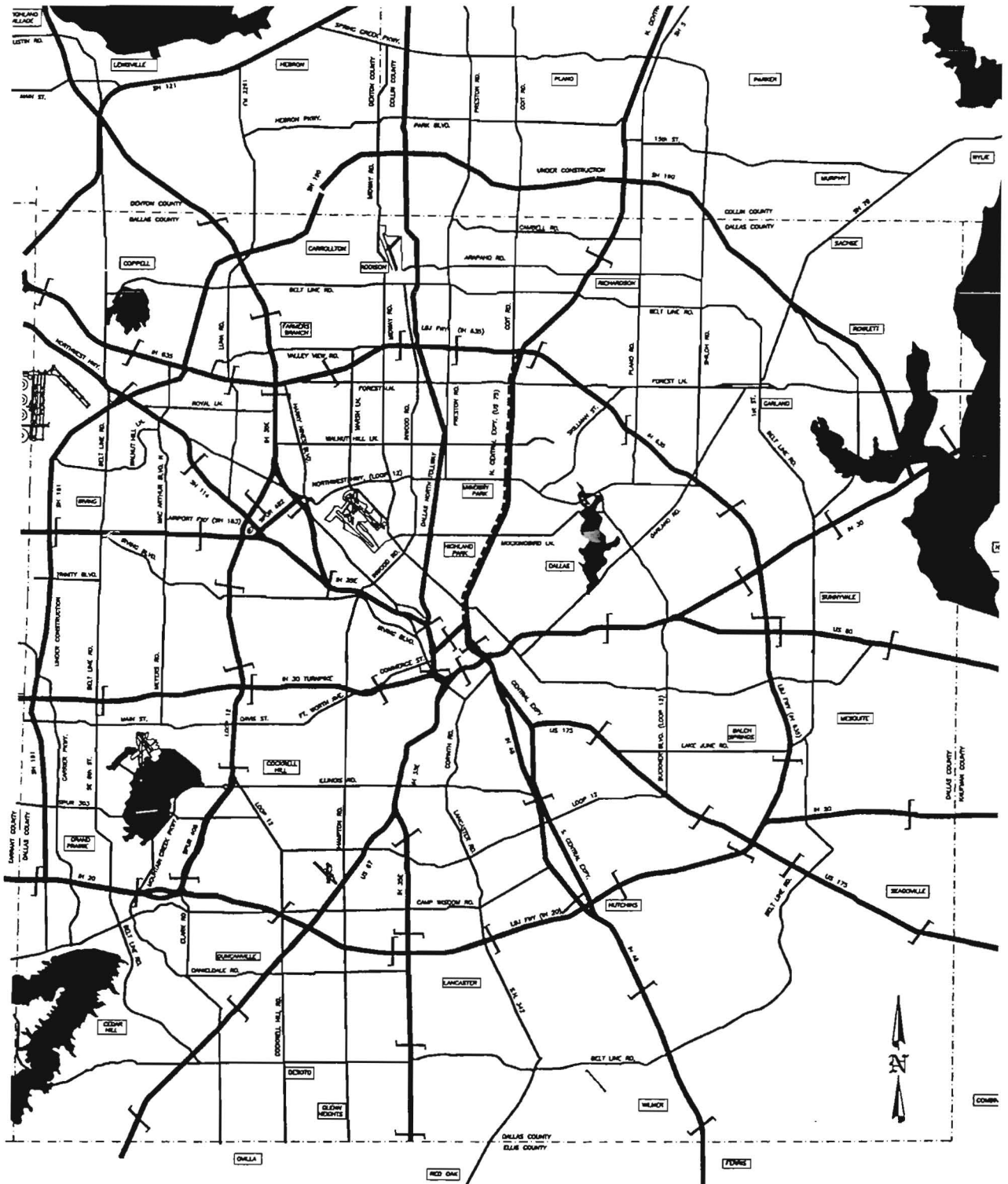


Figure 5. Recommended Sampling Points to Augment Existing System

6.2.2 Other Sources of Speed/Incident Information

Incidents can cause capacity reductions in the range of 26 to 79 percent, resulting in congestion, delay, and possibly secondary accidents (11). Information on incident location could help operators pinpoint trouble spots as soon as they are reported. This type of information system could greatly enhance the operational efficiency of the Dallas TxDOT Satellite Transportation Management Center (TMC). The primary source for reliable incident information is provided by 911 Emergency Services.

In San Antonio, Texas, several agencies including 911, have teamed to provide this information to the operators in the traffic management center as well as on the TransGuide (TxDOT TMC) web site. The majority of the traffic incidents are phoned in by the motorists directly to 911 centers. As the calls are taken, accident-related information is input into a computer system by the 911 operators. San Antonio 911 information is maintained by the City of San Antonio, and is distributed to the police department instantaneously, and to the TxDOT traffic management center every three minutes.

Emergency 911 information covers incidents occurring not only on freeways but on all roads. Thus the information from 911 would increase the coverage area of the current Dallas Satellite TMC. This information could be used by the TxDOT Satellite TMC operators to post messages on the freeway variable message signs, or to dispatch courtesy patrol vehicles to assist at the scene of the incident. The California Department of Transportation estimates that for each minute the time to clear blocked lanes is reduced, a motorist's delay is reduced by four or five minutes (11).

The inclusion of the 911 data would be fully automated. Since the data are currently in electronic format and include geographic location information, icons could be added to the operator's workstation map automatically. Functions such as alarms or other notification systems can be added for freeway incidents to further notify the operator that an incident has been posted to the system. These incidents can then be verified by the operators through the field cameras and noted in the accident log.

Other sources of freeway speed/incident information were studied, however, none were as comprehensive or reliable as the 911 data. Sources included Shadow Broadcasting and Metro Systems. These are commercial information providers that furnish traffic reports to radio and television stations in the area. Information includes where the incidents have occurred, how long they have been there, and an estimated time for incident clearance. The data format precludes this type of data from being incorporated in an automated fashion. Reports are distributed in a textual paragraph format that can easily be read by broadcasters over the air. The data could, however, be used as supplemental information in the comments section of the operators incident input form.

6.3 DEMONSTRATION OF CONCEPT

In conjunction with this project, a prototype incident management software component was developed for the TxDOT TMC. The component allows operators to enter information about incidents that are detected through visual camera scans, called in by the courtesy patrol, the media, or other sources. An incident input screen (shown in Figure 6) allows operators to produce accident logs by entering accident information one accident at a time. The form asks operators if the accident has been verified, the severity of the accident, the time, and also allows for special comments or notes to be added. Each incident is geographically located on the operator's workstation map producing a display. As shown in Figure 7, by clicking on the incident icons, the accident information input window automatically opens allowing operators to view or append information about the accident. Figure 8 shows a tabular representation of the logged incidents. The Dallas incident management software allows for sharing of map displays of operational status with multiple users and agencies and individual users can select from a library of icons which may have unique application to the agency. Figure 9 demonstrates the concept of speed level indications. Although active detectors are not available at this time, the system is set up to receive such inputs and display speed levels. Note the icons for incidents are different from previous figures, having been selected from the library of icons mentioned previously. Each agency or person accessing the system can select the icon that best suits their needs.

Incident Properties

Road: WB IH 635

Cross Street: Rosser Road

Classification:

- Undetermined
- Accident
- Stalled Vehicle
- Abandonment
- Vehicle Fire
- Road Debris
- HAZMAT
- Other

Status:

- Detected
- Acknowledged
- Verified
- Cleared

Affected Lanes:

- Left Shoulder
- Left Lane
- Lane 2
- Center
- Lane 4
- Right Lane
- Right Shoulder
- Entrance Ramp

Associated DMSs:

- 366 EB Ackard
- 635 EB Preston
- 635 WB Forest
- 635 WB Prestor
- 635 WB Webbs
- 75 NB Coit
- 75 NB Meadow
- 75 SB Collins

Notified:

- Police
- Courtesy Patrol
- Maintenance
- PIO
- Dallas

Comments: [Empty text area]

Snapshots: [Empty text area]

Buttons: OK, Cancel

Figure 6. Sample Incident Input Screen (11/98)

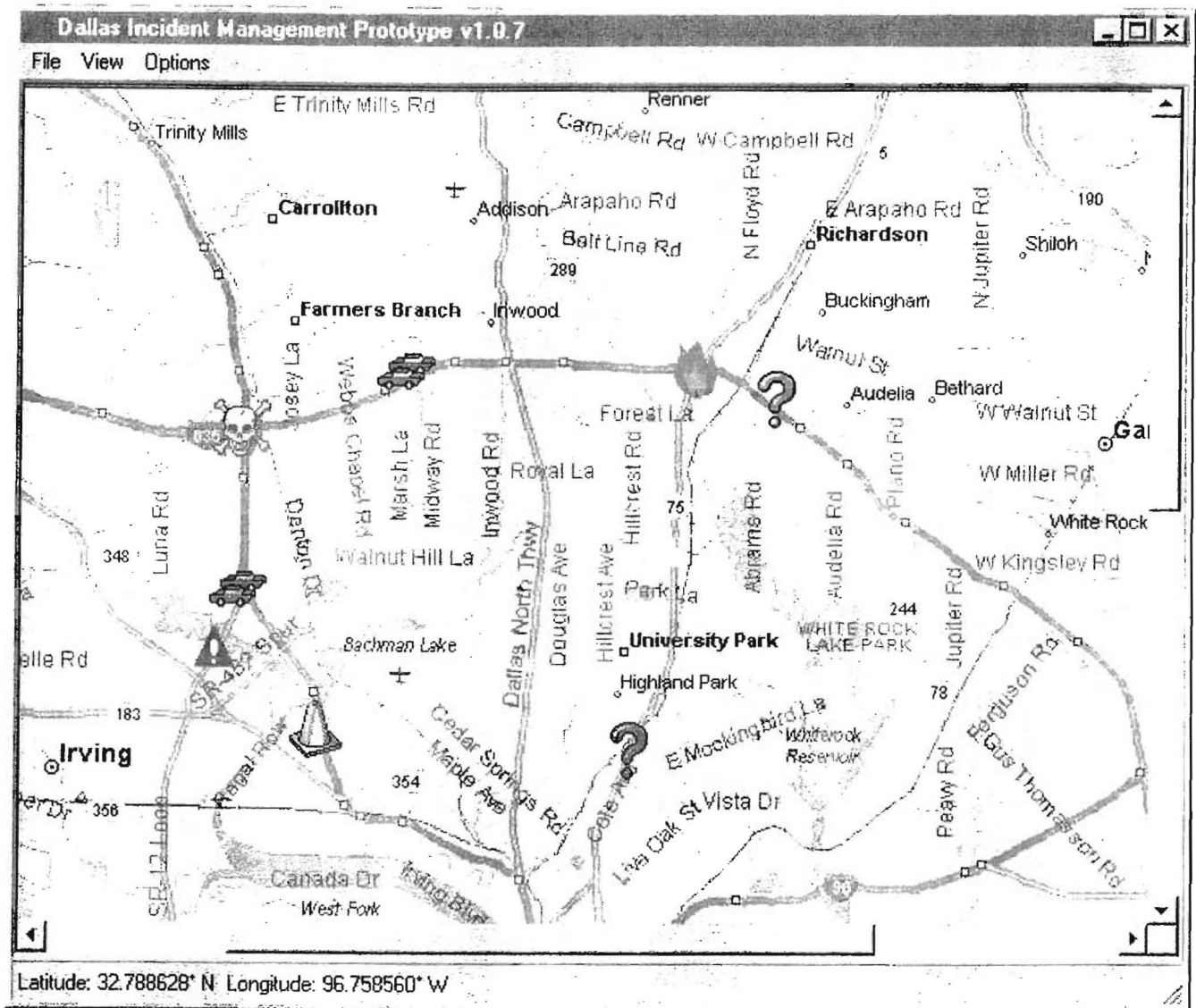


Figure 7. Geographic Location of Incident on Operator's Workstation Map (11/98)

Incident Summary					
Incident Type	Location	Status	Detected Time	Acknowledged ...	Verifie
Vehicle Fire	EB IH 635 At US 75	Detected			
Road Debris	SB US 75 Approaching Walnut ...	Verified			8/13/98
Undetermined	SB US 75 At Monticello Blvd.	Acknowledged	8/13/98 3:40:0...	8/21/98 10:47:...	
Accident	SB IH 35E At Loop 12	Detected	8/16/98 4:15:3...		8/16/98
Undetermined	EB IH 20 At Robinson Road	Detected	8/14/98 2:21:5...		
Undetermined	EB IH 635 At Greenville Avenue	Detected	8/14/98 2:22:3...		
Road Debris	SB Loop 12 At Elm Fork Trinity ...	Acknowledged	8/14/98 2:37:3...	8/14/98 2:38:1...	
HAZMAT Spill	WB IH 635 At Emerald Street	Acknowledged	8/24/98 3:44:1...	8/24/98 3:44:3...	
Accident	WB IH 635 At Rosser Road	Verified	8/17/98 9:30:1...		8/17/98
Abandoned Vehicle	SB IH 35E At Requal Row	Verified	8/25/98 9:59:3...		8/25/98

Figure 8. Incident Summary on Operator's Workstation (11/98)

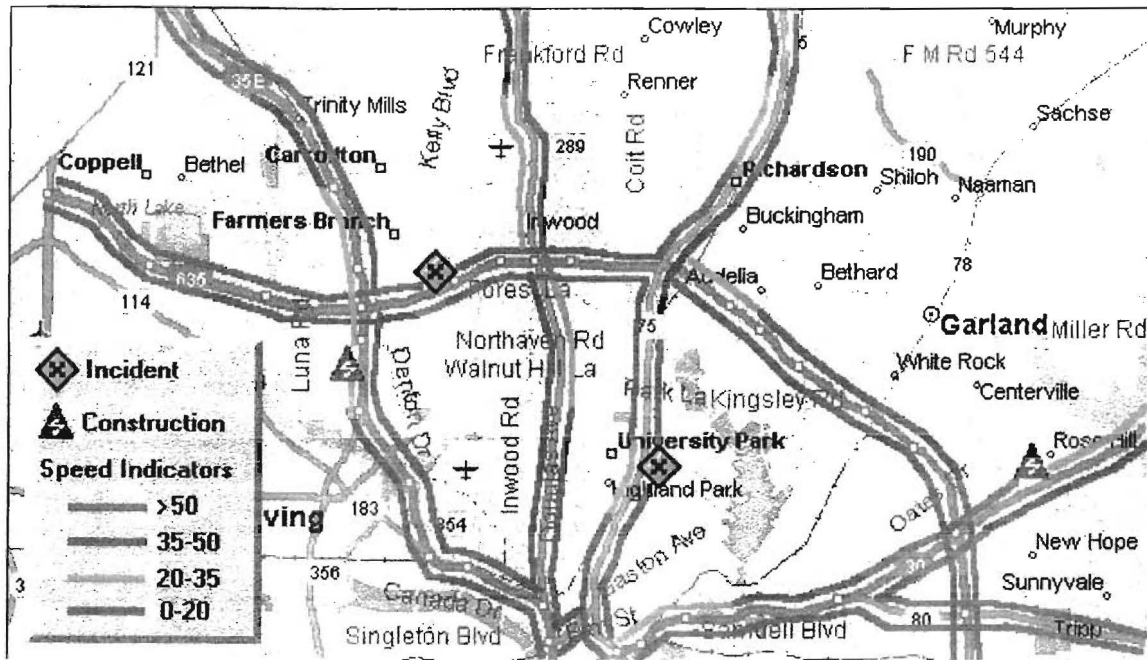


Figure 9. Speed/Incident Display Concept (11/98)

6.4 NEAR-TERM PROPOSAL FOR TXDOT-DALLAS INCIDENT INFORMATION DISTRIBUTION SYSTEM

Congestion has now spread beyond the urban limits into the suburbs and is costing the nation billions of dollars in fuel consumption and travel delay (7). Texas is no exception to this rule, and in fact has two major cities ranked in the top 20 most congested cities in the nation (8). According to the *Urban Roadway Congestion Annual Report* (9), published in 1996 by TTI, Houston was ranked 12th, and Dallas was ranked 17th.

Congestion is defined as 'travel time or delay in excess of that normally incurred under light or free-flow travel conditions'. Typically, congestion is broken down into two categories:

- 1) Recurrent Congestion - Congestion caused by factors such as rush hour, dense employment centers, shopping areas, recreation/special events, roadway construction, and changes in terrain.
- 2) Non-Recurrent Congestion - Congestion caused by unpredictable incidents such as accidents, spills, stalled vehicles, roadway maintenance, and bad weather.

Recurrent congestion is responsible for about 40 percent of motorist delay, while non-recurrent congestion is responsible for the other 60 percent (9). As such, national motorist delay due to non-recurrent congestion is estimated at approximately 2.9 million hours each year.

In an effort to manage congestion, the Dallas area has already begun to implement an ITS that will monitor freeway traffic with cameras and other detection devices. Data from these devices are transmitted back to the TxDOT satellite transportation management center (TMC), where operations personnel use the information to manage incidents and congestion. The courtesy patrol vehicles also report to the operations personnel, providing another source of traffic information. All of the information is verified and then presented to the motoring public by means of electronic dynamic message signs (DMS). This new information allows motorists to

make educated route choices and avoid incident locations. As some of the traffic is diverted, congestion is reduced and the bottlenecks clear more quickly. ITS systems elsewhere, in cities across the nation, have seen reductions in fuel consumption by 22 percent, reductions in time lost to congestion delay of about 33 percent, and a decrease in accidents of up to 30 percent (10). Dallas should also begin to see these types of benefits over the next few years as the system matures. The completed implementation of the Dallas ITS will cover 280 miles of freeway; however, only 32 miles are presently operational.

With the currently deployed ITS program the Dallas area has limited incident/traffic information, and also a limited means of distributing information to the motoring public. The typical Dallas commuter deals with recurrent congestion on a regular basis. Unfortunately, the majority of delay is caused by unexpected incidents or non-recurring congestion. The concept of advising motorists of incident situations before they physically encounter them is typically referred to as 'Advanced Traveler Information Systems (ATIS)'. Internet web sites, phone (cell phone) call-in services, paging systems, kiosk applications, and radio/television advisories are all useful means of communicating incident/traffic information to the traveling public. Of these various mediums, Internet web sites are the most common initial platform for ATIS distribution.

Many cities, such as Atlanta, Seattle, Washington, Philadelphia, Houston, and San Antonio, have developed traffic-related web sites to distribute data to the public. These web sites come in all shapes and sizes with widely varying functionality. Atlanta has a comprehensive incident information interface (<http://www.georgia-traveler.com/traffic/rttraff.htm>). Seattle has gone interactive with a personalized traffic reporting system (<http://trafficview.seattle.sidewalk1.com>). The growing popularity of the Internet, both at home and in the work place, is making Internet traffic sites an ITS staple.

The following is a proposed approach for a near-term incident information distribution system which could be implemented with minimal cost using the Internet. The proposal builds upon existing incident data sources, current control center mapping interfaces and software, and also expands the functionality of the prototype TxDOT web site to act as an information distribution mechanism. The development would consist of four interrelated tasks:

- 1) Access Incident Data,
- 2) Develop Workstation Interface System for Incident Data,
- 3) Enhance Prototype Web Site and
- 4) Develop Personalized Interactive Web Feature.

Each task will be described in detail in the following sections.

6.4.1 Access Incident Data

Several agencies have been identified as possible sources of incident information. These sources include radio and television stations and cellular phone reports, as well as commercial traffic information providers such as Metro Systems and Shadow Broadcasting. However, none seem to compare to the comprehensiveness and accuracy of the data collected by Emergency 911 centers. Access to the 911 data would greatly enhance the current operations at the TMC by alerting the operator to incident situations, even before they may be spotted with the system

cameras. These data also allow for a larger coverage area than what is currently available with the functioning Dallas ITS. However, the most important feature of the 911 data is the standard formatting which would allow for an automated posting system, thus negating the need for additional operators to maintain the incident system.

In order for the proposed solution to work, it is necessary to obtain approval from the appropriate agencies to access the 911 data in electronic format. After this is achieved, the data would then be integrated into the operator's workstation environment as if it were information from a camera or other detection device. The information shown in Table 6 is a sample data set from the San Antonio 911 system. Each record represents a different incident. Incidents that appear in the 911 database are not always traffic related, but also include such events as family violence, robbery, etc. For this reason, the data must be filtered before use in the TxDOT traffic management center. The only records of concern to TxDOT for this application would be major and minor accident records and records of road debris and spills.

6.4.2 Develop Workstation Interface System for Incident Data

As an initial step, the 911 data would be added to the control center workstations, both in visual and textual formats. Since the 911 data typically include latitude and longitude information (X, Y coordinate information), their integration into a GIS map is fairly straightforward. An accident icon can be placed on the map for each set of (X,Y) coordinates transmitted from Emergency 911. The icons should represent the relative severity of the incident, either minor or major. The operator incident management display continues to be enhanced in the Dallas Satellite TMC. Figures 6-9 show graphics from the system. As updates are received by the control center, the system should automatically update the icons on the map (adding additional icons as they are received, or updating the severity of the incident if it happens to change). Unfortunately, most Emergency 911 centers do not transmit information about the clearing of a traffic incident. This information is usually handled at the responding agency level (i.e., police department, fire department, etc.). To deal with this lack of information, a default time limit can be set for each accident severity, and the icon and textual information will be displayed until the time has expired.

As with the other information systems that are tied into the control center workstations, the operators should have control over the presentation of the data, and should also be able to override the functions of the automatic posting system. For example, if the control center has received data about an accident that happens to be within the surveillance area of the current traffic cameras, the operator would be able to observe the accident and would also be able to obtain the specific time that the incident clears. If the default post time for a major accident is set at 45 minutes, and the accident is still blocking lanes at one hour past the initial posting time, the operator should have the ability to continue the posting past the default clear time. The operator should also have the ability to add any incidents to the map that are not received by Emergency 911, but are observed through the system cameras. Along these same lines, the operator may also need to add additional comments about the incident in a comment section that would appear in the textual format. This additional information could also be used to supplement information that will be provided to the motorist through the various distribution mechanisms.

Table 6. Sample 911 Data Format

Disposition	Dispatcher	Date	Time	Incident Type	Address	Latitude	Longitude
U	T	19971216	1716	FAM-VIOL	00101 ACME RD N	131189	584897
U	W	19971222	0906	ACC MAJR	05611 DURANGO ST W	138690	580140
U	W	19971222	0907	TRF RELAT	00339 DOLORES AV	133347	587073
U	W	19971222	0908	ACC MAJR	00318 IH 10 W	138180	580390
A	E	19971202	1344	ACC MAJR	00515 FRIO ST S	157871	577790
A	T	19971202	1347	ACC MINR	00115 ALICIA AV	133784	585117
A	W	19971216	1718	FAM-VIOL	BLESSING ST EAGLE ST	131719	589535

Disposition U = Unassigned
A = Assigned
H = Held

Dispatcher C = Central
E = East
W = West
P = Northwest
N = Northeast
S = South
T = Traffic

Date format (yyyymmdd)

Time Military Time (0-2400 hours)

Latitude Reported in State Plane Coordinate System

Longitude Reported in State Plane Coordinate System

With the implementation of the future AVL system on the Dallas courtesy patrol vehicles, the accident-enhanced map could also be used to locate and dispatch the nearest courtesy patrol vehicle.

6.4.3 Enhance Prototype Web Site

The Dallas satellite software included a prototype web site. General information on roadway closures, DMS messages, and "snapshots" of camera images were included. The site was disabled pending a statewide standard which is currently under development. The following paragraphs address how this system may be structured locally.

The basis of the web site should be graphic in nature. When dealing with geographically sensitive information, users are more likely to glance at an incident map than to read the locations of the incidents from a textual list. Once the user has determined which incidents may affect their travel plans, more information of a textual nature may be desired. The Atlanta web site is an example of displaying incident information in both formats (several examples from the Atlanta web site follow in Figure 10). Figure 10-A shows the initial user interface screen and gives directions on how to access the information on the web site. Web sites are not always as intuitive as they may seem to the developer, so brief instructions on the initial screen will increase usage by advising users of the functionality of the site.

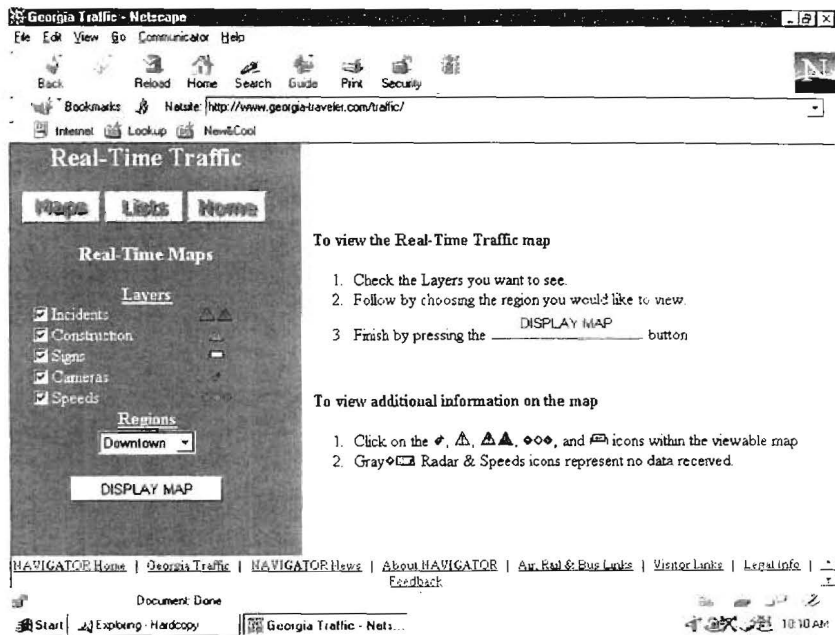
On the Atlanta site, users may choose between map view and list view from any menu. Once a user has chosen to view incident information in map view, he/she proceeds to the view shown in Figure 10-B. This figure shows two frames, one with the indicated layers and region, and the other with the regional map graphic and icon layers. From this view, the user can click on any of the icons shown on the map for more detailed information. Figure 10-C depicts the view that is returned after clicking on the orange incident icon. This view gives detailed information in the left frame as follows:

Accident
Northbound I-285 SOUTH OF I-85
Low Impact
Left Shoulder Affected
Expected Cleanup at
30 June, 11:52 AM

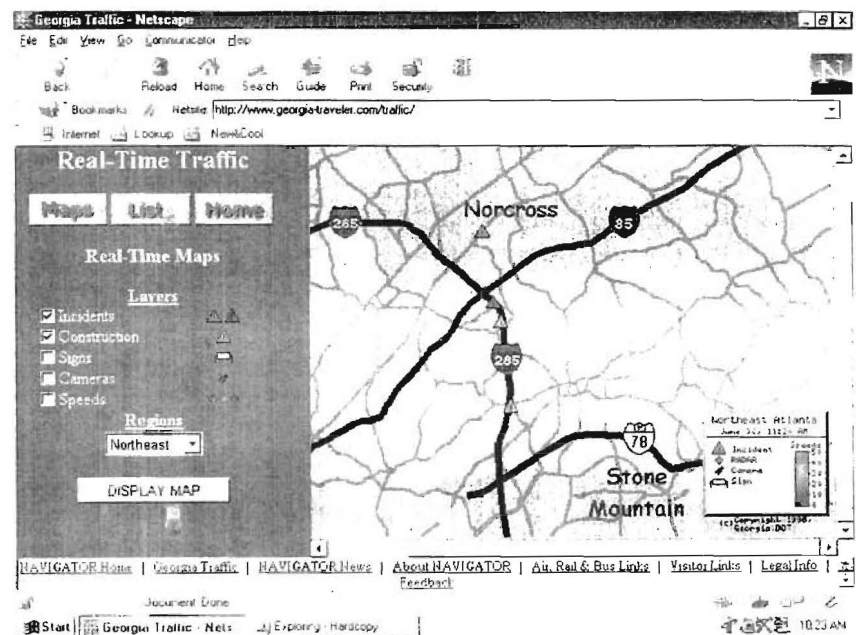
Operator additions to accident information enhance this application. The more information that can be distributed to the traveling public, the more intelligent they will become in their travel choices.

For those who prefer lists, this form of information is available by clicking on the lists button shown in the left frame of Figure 10-C. Figure 10-D is an example of a textual incident list from the Atlanta web site. The list format is not as easily comprehended as the graphical map interface, especially to those who may not be very familiar with Atlanta roadways. This list does, however, do a good job of giving overall roadway incident conditions and the general magnitude of incidents at a glance. Operators may also be able to use information such as this to call in supplemental help for the courtesy patrol if so indicated. An additional operator option may be to indicate, in the list format, which courtesy patrol unit is attending to the incident if any.

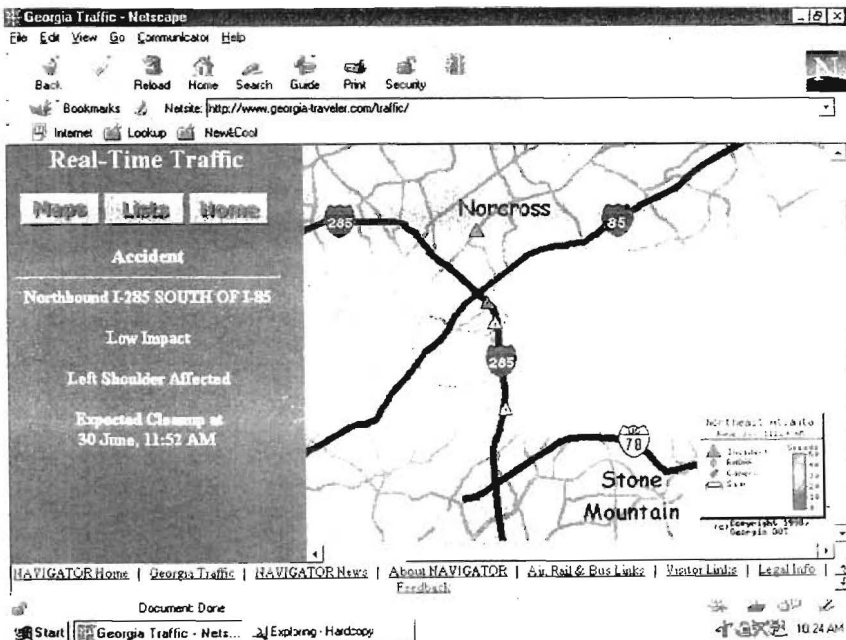
Figure 10. Real-Time Traffic Map Examples (11/98)



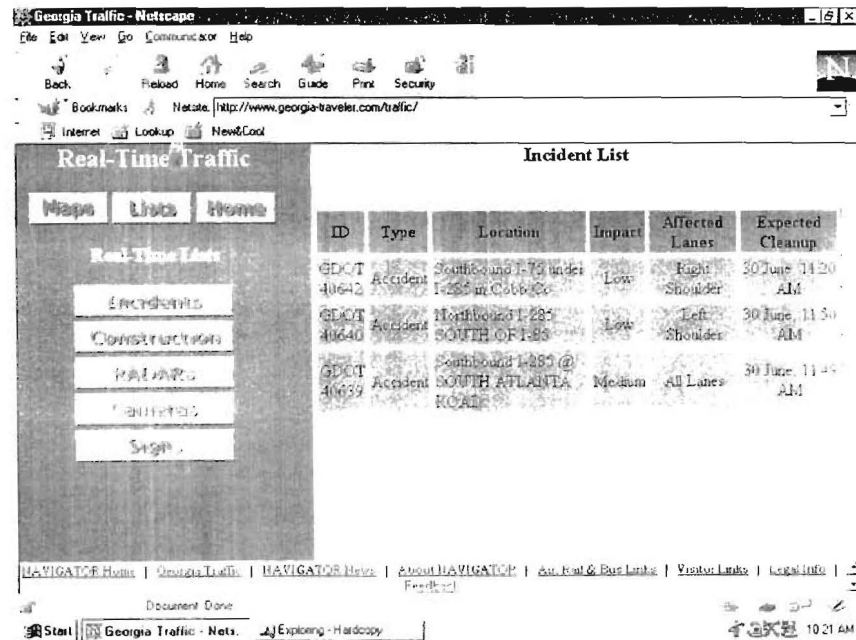
A. Initial Web Site User Interface Display



B. Click-able Accident Map Display



C. Textual Information from Click-able Accident Icon



D. Incident Listing in Textual Format

6.4.4 Develop Personalized Interactive Web Feature

By using the broad penetration of the Internet into homes and businesses, and new web development software, Dallas can take web interactivity to the next level. This level would go beyond clickable icons and real-time traffic information to a whole new arena of personalized traffic reports. Seattle has been among the few web pioneers to accomplish such high levels of web interaction. Seattle users receive e-mail from an automated reporting system based on information that is input in a user profile web questionnaire.

On the main page of the traffic information web site, users are asked if they would like to receive personal traffic reports. If the user clicks on this link, it takes them to several other web form pages where they enter information regarding their typical commuting routes, time of travel, name, and e-mail address, etc. The data is then stored in a database. According to the schedule input by the user, the system automatically queries the incident/traffic data for the specific user's route for that time of the day. The resulting data are then formatted into a standard message and sent to the user at his/her home or work e-mail address. The personal message reports the estimated travel time for the designated route, and gives information regarding any current incident conditions along the route.

Figure 11-A shows the initial web site form used to collect user information. Users are prompted to enter e-mail address and name to get started. At the bottom of each form page is a "next" button to lead the user through the personal travel profile. The second form page asks for route starting and ending points, whether or not the user would like information on alternate routes, and the delivery schedule for e-mail reports for each route (See Figure 11-B.) Routes are entered one at a time, and several different routes can be chosen for different times of the week (See Figure 11-C.) On other form pages, users can personalize the way that the web site is displayed on their computer, so that each time they return, the web site instantly displays the information of interest. (See Figure 11-D.)

The site seems to be fairly intuitive, however, the ability to pick routes from a visual interface would make the site more user friendly. Users would then be able to see which route sections have been chosen and verify that they have entered the correct route. The current Seattle site only allows route choices to be made in a textual format. Additional information is provided on the Seattle site regarding restaurants and sporting events. This type of information could be added as a future enhancement and may even foster public-private funding partnerships. The following text is from an e-mail message received by the Seattle system:

To : Jennifer Ogle@SAN@TTI

From : "Sidewalk's Trafficview" <traffic-errors@seattle.sidewalk1.com>

Subject: Trafficview Report: Fastest route is 16.4 minutes.

Date : Wednesday, June 24, 1998 at 7:06:28 pm CDT

Enter to win a \$2,500 prize package of entertainment, recreation and dining this summer including gift certificates to El Gaucho, Pampas Club and Chez Shea. <http://seattle.sidewalk.com/SidewalkSummer>

Here is your customized report:

Traveling from SE 8th St. on I-405 to West Valley Hwy. On I-405

Fastest Route:

I-405 to destination

Distance: 11.9 miles

Est. Freeway Time: 16.4 minutes

Average Speed: 43 MPH

Current Incident Report as of 4:53 PM

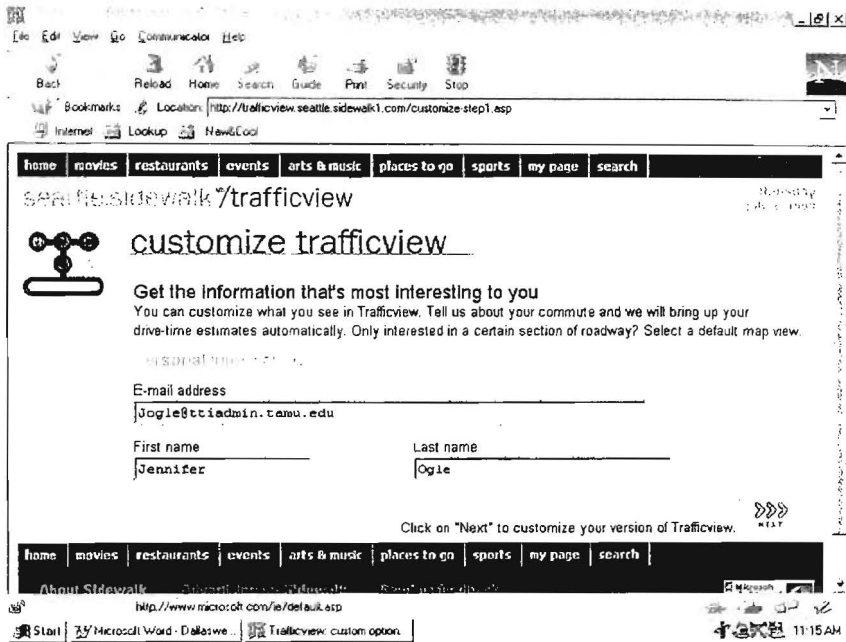
I-405 Southbound just north of S 188th accident blocking lane 3

I-405 Southbound just north of interurban disabled vehicle blocking carpool lane

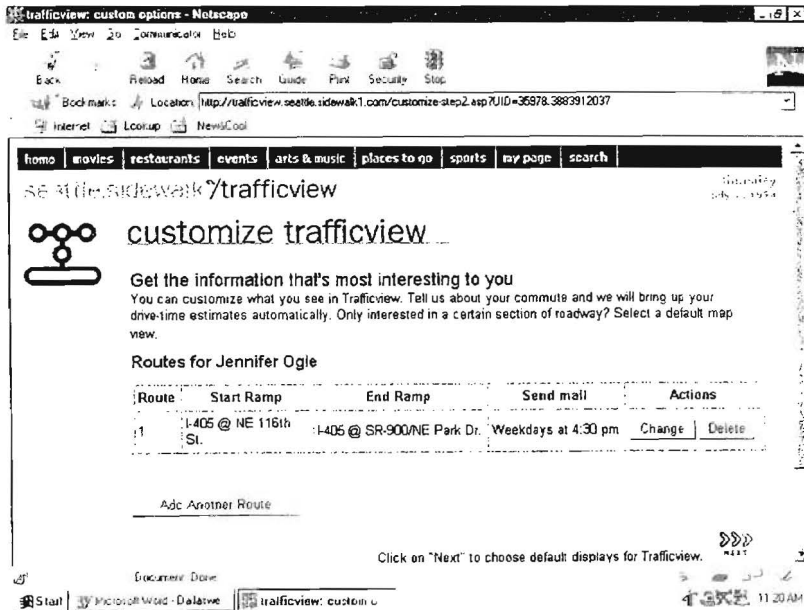
ST 900 just east of 148th disabled vehicle blocking right lane

Customize Sidewalk and receive up-to-date news about your favorite local bands, restaurants and sports teams. [Http://seattle.sidewalk.com/membersurvey](http://seattle.sidewalk.com/membersurvey)

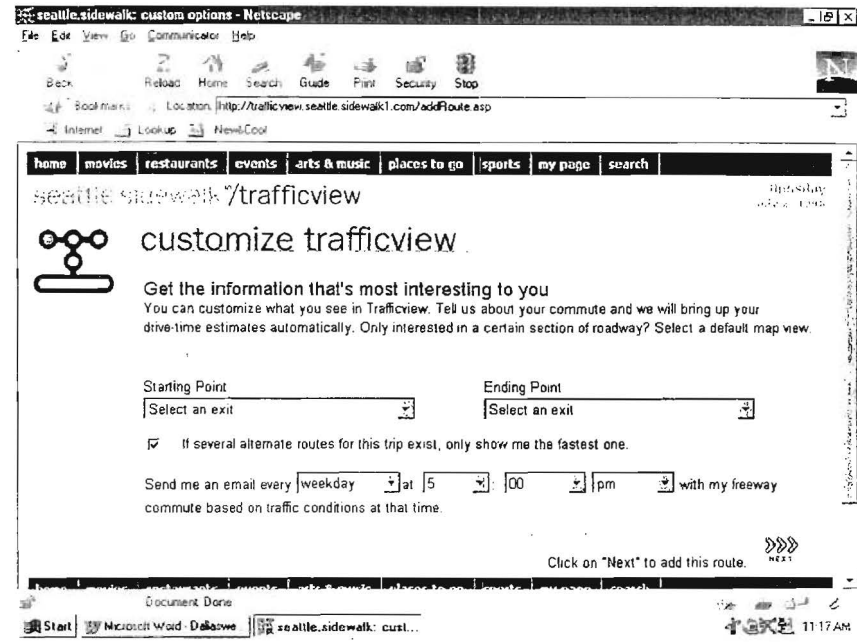
If you decide that you prefer your commute to be more of a surprise, we can stop sending you email at any time. To remove yourself from Trafficview's automatic email go to this page <http://trafficview.seattle.sidewalk1.com/cancelEmail.asp> or go back to Trafficview and uncheck the "send email" button.



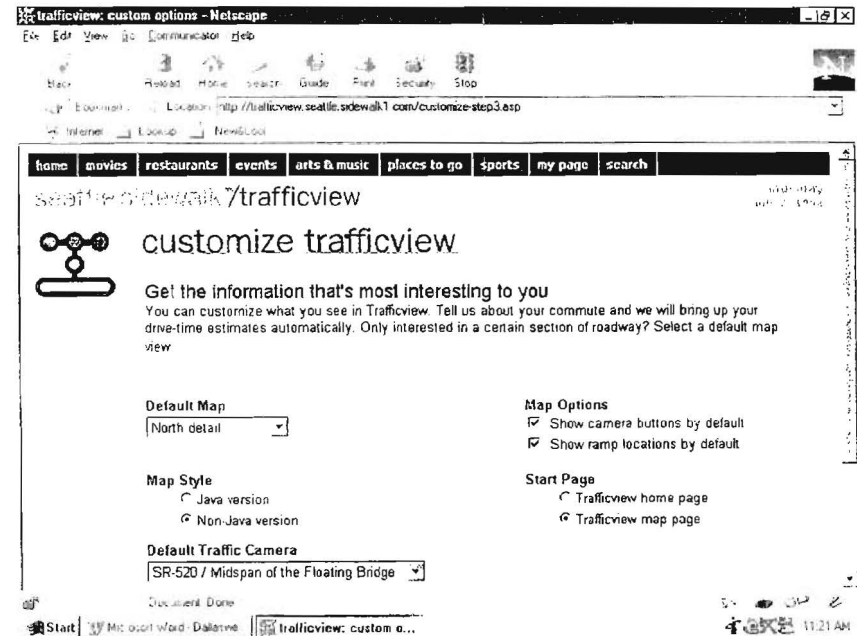
A. Personal Traffic Profile Web Form



C. Custom Traffic Route Reporting Schedule



B. Customized Route Information User Interface



D. Customization Control for Web Site Display

7. SUMMARY

The objective of this project was to investigate means to provide freeway operations data to travelers prior to full implementation of a freeway management system in the Dallas Urban Area. Existing sources of speed and operations data were investigated; gaps of data sources were identified; additional sources of data were identified; and a near-term proposal for freeway operations data was recommended.

Existing Sources of Data

Because the freeway management system is not yet fully deployed, there are not sufficient existing sources to provide a comprehensive information system. Existing potential sources include: limited CCTV coverage; AVL equipment on public transit and courtesy patrol vehicles; and reports from local radio and television stations and private traffic providers.

Gaps in Data Sources

Most of the CCTV will be located in portions of the US 75, IH-635, IH-35E, US67, and SH 183 corridors. Vehicle detectors will be located on US 75. Transit vehicles on freeways may provide AVL speed data on the more heavily traveled freeways in peak periods but headways during off-peak periods are such that a comprehensive coverage is not possible. Broadcast and private providers have similar limitations.

Proposed Additional Sources of Data

Although there is not a complete compliment of data sources available to satisfy the needs of a freeway data information system, existing sources can be used as a starting point and basis for such a system. Additional sources recommended are strategically located, non-intrusive detector sampling points on the non-instrumented portions of the freeway system. It is also recommended that a link to 911 emergency services be established for reporting of freeway incidents to the Satellite Transportation Management Center.

Near-Term Proposal for Presentation of Freeway Operations Data

A graphical Internet display format was developed and demonstrated which incorporates speed levels from the various identified sources of data. In addition, incident location based on a proposed link to 911 Emergency Services and other existing sources was demonstrated and proposed for implementation.

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APPENDIX A

LITERATURE REVIEW OF VEHICLE DETECTOR TECHNOLOGY

SOURCE: Middleton, Dan, Texas Transportation Institute, In-Process Research Report, *INITIAL EVALUATION OF EXISTING TECHNOLOGIES FOR VEHICLE DETECTION*

2.1 INTRODUCTION

Traffic detection has been utilized to obtain useful traffic information for many years. In the 1920s manual traffic signals were replaced by pretimed signals and the need to obtain traffic detection and traffic data collection was realized. One of the first detectors was a pressure sensitive, treadle type of detector that was installed in the road and detected vehicles when they passed over the plates (2). Pneumatic tubes, "electric-eye" optical, and magnetic detectors were used in the 1930s. By the 1960s inductive loop, infrared, ultrasonic, radar, and photoelectric systems were being used, with the inductive loop system becoming the predominant system by the 1970s (3).

Detectors recognize the presence of a stopped or moving vehicle and identify the passage of the vehicle by completing a circuit or detecting changes in an electrical or magnetic field. Most types of detectors are composed of three components: the sensor, the lead-in cable, and the interpreter/receiver (4). Detectors also collect or derive traffic volumes, vehicle speed, lane occupancy, density, and queue lengths. These parameters are used to predict or derive levels of congestion, incidents, and delays. Successful implementation of automatic detection and control systems is dependent on the system's reliability (5).

2.2 DETECTOR CATEGORIES

Detectors can be generally categorized as either intrusive or non-intrusive. Intrusive detector systems require intrusion into or onto the pavement or roadway during installation. Examples of intrusive detectors are inductive loops and road tubes. Non-intrusive detector systems eliminate interference with traffic operations for the most part, because they do not need to be installed into or on the roadway. Non-intrusive systems are installed over the roadway, on the side of the roadway, or beneath the pavement by pushing the device in from the shoulder (6). Examples of non-intrusive systems are video systems, infrared devices, and acoustic systems.

Non-intrusive detector systems are currently increasing in prominence due to today's congested freeways and signalized intersections, because they reduce interference with traffic operations during installation and maintenance procedures. They can also be used on bridge decks, where installation of intrusive detector systems is prohibitive due to possible weakening of the structure.

2.3 DETECTOR TYPES

The majority of vehicle detection today is accomplished using inductive loop detectors. Other common detectors include: magnetometers, piezoelectric sensors, and photoelectric sensors. Video imaging processing systems are increasing in prominence as well as other developing

systems that are mounted above the roadway. Brief descriptions of some of the existing devices and the most promising new innovations are provided below.

2.3.1 Inductive Loop Detector

The inductive loop detector is composed of one or more turns of insulated loop wire installed in a shallow slot that is sawed in the pavement, a lead-in cable, and a detector electronic unit. Induction can be characterized as producing a change in a body without physical contact with the body (7). Electrical induction in a traffic signal system is comprised of a detector unit that passes a current through the stranded loop wire, thereby creating an electromagnetic field around the wire. Moving a conductive metal object, such as a vehicle, through this field disturbs the electromagnetic field, producing a change in energy level. As the vehicle enters the electromagnetic field of the loop, it causes a decrease in the inductance of the loop and an increase in the oscillation frequency. The inductive loop detector, which was introduced in the 1960s, continues today as the most commonly used form of detector, even though its weaknesses are widely recognized.

Proper installation of the loop in the road surface is important to improve the reliability of the system. Some pavement surfaces, such as bridge decks, preclude the saw cutting necessary to install permanent inductive loop detectors. A primary disadvantage of inductive loop detectors is the expense of relocating or repairing loops after installation. This procedure requires extensive traffic control and results in congestion and motorist delay (8). Traffic control costs and delay costs for loop installations make loops less competitive than their newer detector counterparts. Detector “cross-talk” and increased pavement stress are two additional disadvantages of inductive loop detector systems. Additionally, there are several adverse conditions that affect the operation of ILDs. These conditions include high voltage power lines under the pavement, a pavement subsurface with a high iron content, and unstable pavement conditions. Underground wires, conduit, and pull boxes are susceptible to being damaged by other utility work. Modern detection equipment can overcome the first two conditions, but changing or unstable pavement conditions result in increased maintenance costs (9). One advantage of ILD systems is their ability to operate in all weather and lighting conditions (8).

There are diverging opinions on the reliability of inductive loop systems. Some agencies believe that inductive loop technology is the best available, while others claim that inductive loop detectors malfunction so frequently that they are simply not worth repairing (3). One study that interviewed several California Department of Transportation personnel, indicated that only one-half of the inductive loop systems installed are currently in operation. In this same study, Illinois Department of Transportation personnel stated only 5 percent of the inductive loop systems in their jurisdiction are inoperable at any given time. Illinois officials attribute this success to an active maintenance program which monitors each loop (3). Such programs are costly, but maintaining a low failure rate requires them.

Bikowitz and Poss (10) analyzed 15,000 inductive loop detectors in New York State and found that loop failures were mainly caused by either improper installation, inadequate loop sealants, or wire failure. The study revealed several installation processes needed revision to improve the

inductive loop detector's reliability. Improper saw cutting techniques, loop wire splicing, and inadequate loop sealant bonding resulted in loop wire breakage.

A study by Chen and May (5) conducted in Los Angeles revealed that up to 15 percent of the 115 detectors analyzed were unavailable, and between 2 and 11 percent showed error flags during the experiment. The causes of the detector failures included: moisture, loop sealant deterioration, pavement cracking, broken wires, deteriorated insulation, corroded splices, and detuned amplifiers.

2.3.2 Microloop Detection Systems

A microloop detection system is a passive sensing system that is based on the earth's magnetic field. When a vehicle passes through the detection zone, it temporarily distorts the earth's magnetic field. This magnetic field change creates an electrical circuit change in a specially designed circuit in the microloop. Advantages of using microloop detection systems include speed of installation, installation below the pavement in the subgrade, and less wire needed to create the loop. Disadvantages of microloop systems include installation difficulties and the narrow effective width of the detection field, thereby requiring several probes to detect a variety of design vehicle types (9).

2.3.3 Magnetometers

A magnetometer consists of an intrusive sensor about the size and shape of a small can, a lead-in cable, and an amplifier. The cylinder portion of the magnetometer contains sensor coils that operate in a manner similar to inductive loops. These coils are installed in a small circular hole in the center of each lane and communicate with the roadside by wires or radio link. Magnetometers function by detecting increased density of vertical flux lines of the earth's magnetic field caused by the passage of a mass of ferrous metals, such as in a vehicle. They operate in either presence or pulse modes and are embedded in the pavement. Magnetometers are more durable than loop sensors, require less cutting of the pavement, are easier to install, and can be installed underneath bridge decks without damage to the deck. The disadvantages of magnetometers are similar to those of inductive loop detector systems, in that they sometimes double count trucks, and are less likely to detect motorcycles due to the vehicle's small detection zone (3).

2.3.4 Magnetic Detector Systems

Magnetic detectors consist of several dense coils of wire wound around a magnetic core. This core is then placed in or underneath the pavement. Magnetic detector systems operate in the same manner as magnetometer detector systems and inductive loop detectors (11). One disadvantage of magnetic detector systems is their inability to detect stopped vehicles; because detection requires motion. Another disadvantage occurs when two magnetic detectors are placed close together, this placement can result in interference between the two detectors (6).

2.3.5 Piezoelectric Sensors

Piezoelectric sensors are a film fabricated using a crystalline form of long hydrogen, carbon, and fluoride polymer molecular chains. The crystalline chain produces an electrical charge when a mechanical strain occurs as a result of a vehicle passing over the film (12). Piezoelectric sensors have been effectively used in vehicle detection, both as axle sensors for vehicle classification and for weigh-in-motion applications for truck weight data collection.

The first piezoelectric effects were documented over 100 years ago when it was observed that quartz crystals produced an electrical charge when deformed. It was also noted that the crystals changed shape when they were placed in an electric field. Later research at the Massachusetts Institute of Technology discovered that certain ceramics could be polarized to induce piezoelectric properties. The term “piezoelectricity” derives from the Greek for “pressure electricity.” In straightforward terms, it is the material's ability to transform mechanical energy into electrical energy; or in other words, piezo sensors are transducers. Piezoelectricity can be defined as “electric polarization produced by mechanical strain in certain crystals, the polarization being proportional to the amount of strain and changing sign with it” (13).

One advantage of piezoelectric sensors is their ability to be utilized as weigh-in-motion detectors. Piezoelectric sensors serve as axle sensors, so they can be used to distinguish between vehicle types (8, 12). Modern vehicle classifiers typically use a combination of piezoelectric sensors and inductive loop detectors to count and classify vehicles in a user-definable classification scheme. Undesirable features of piezoelectric sensors include: weakening of the pavement due to required cutting, less than desirable sensor durability, reduction in sensor life due to resurfacing, and sensitivity to moisture penetration if damaged. In recent years piezoelectric sensors are becoming more extensively used in the United States.

2.3.6 Photoelectric Sensors

Photoelectric sensors have been used since the 1950s. When a sufficient amount of light hits the surface of the photocell, it acts as a transducer and conducts current to an output device. If the light is blocked, the current stops for the amount of time of the light blockage. In the 1970s, light-emitting diodes (LEDs) became commercially available and were much more desirable than incandescent lamps for this application because of a longer life span and durability under harsh conditions. Probably the biggest advantage of LEDs is their ability to be modulated thousands of times per second. LEDs operate in several visible-light wavelengths as well as in infrared wavelengths. However, infrared LEDs are often preferred because they emit more light intensity than visible-light LEDs and because most photo detectors are more sensitive in the infrared range. One disadvantage of infrared LEDs when compared to visible light LEDs is greater difficulty of alignment (14).

2.3.7 Microwave and Radar Sensors

Microwave detection sensors utilize a microwave energy beam directed onto a detection area from an antenna located either along the side or above the roadway. The antenna is angled

toward the traffic flow, thereby creating a Doppler effect when the signal is reflected. The signal sent by the system is intercepted by the vehicle and reflected or echoed back to the sensor (3). According to the Doppler principle, the motion of the vehicle causes a frequency change in the reflected signal that is known as a Doppler phase shift. This phase shift is recognized by the detection system and is used to detect the movement of vehicles and collect speed data. The operating frequency of the signal is normally in the K-band (24 GHz) or the X-band (10 GHz) (15).

Radar detectors have been commercially available for years and use a pulsed energy beam. The beam, which is either frequency-modulated or pulse-modulated, detects vehicles by determining the time delay of the reflected signal. This information is used to calculate the distance of the vehicle. Newer radar detectors promise to give both presence and passage detection as opposed to previous units that detected passage only. In 1991 the manufacturer's initial unit costs ranged from \$1,000 to \$4,000 depending on unit features. The manufacturer claims indicated life cycle costs were comparable to inductive loops. Current radar sensors for freeway applications have the ability to detect vehicles, produce traffic counts, and provide speed data across one to three lanes.

Microwave and radar detection systems are simpler to install and maintain than inductive loop systems. A principal disadvantage of microwave and radar systems is the inability to detect a stopped vehicle and to measure occupancy (3). In the past, radar systems have been vulnerable to vandalism (2). Microwave and radar systems are also expensive to purchase and operate due to Federal Communication Commission (FCC) licensing requirements (11).

2.3.8 Lasers

"Light Amplification by Stimulated Emission of Radiation" devices, also known as lasers, contain a crystal, gas, or other material in which atoms are stimulated by focused light waves. The laser unit is mounted either above or beside the roadway. The receiver is built into the transmitter, and actuations are detected by changes in the characteristics of the laser beam. This very narrow beam can be aimed more precisely than either the infrared or ultrasonic devices, thereby avoiding false actuations from vehicles in adjoining lanes. One disadvantage of the laser system is that small vehicles, such as motorcycles, traveling on the edge of a lane may be missed when using this narrow beam (11).

2.3.9 Ultrasonic Detector Systems

Ultrasonic detection systems consist of compact electronic signal generation and receiver units that are mounted either above or beside the roadway. A vehicle is detected when the energy burst that is directed at a target point is reflected faster than expected. Ultrasonic detectors can be used for both presence and pulse applications. Labell and May (3) compared ultrasonic detectors with inductive loop detectors and concluded that the flow accuracy was very similar to that of inductive loops. However, occupancy and speed measurements from ultrasonic detectors were very different from those generated by loops. One possible explanation of speed variation is that speed is calculated from occupancy, a parameter that is inaccurate. Another part of the study compared ultrasonic detectors with visual counts. In this case, the data collected by

ultrasonic detectors closely matched the visually counted data. Modifications have since resulted in improvements to ultrasonic detectors, reducing some of the above problems.

One disadvantage of ultrasonic sensors is that environmental conditions can affect their operation. Ultrasonic detectors also require a very high level of specialized maintenance. Studies of ultrasonic detectors also revealed problems with controlling the conical detection zone and in some situations found that the conical detection zone may miss vehicles (3).

The most extensive use of ultrasonic detectors is on surface streets and freeways in Japan, where government policy precludes cutting the pavement. These detectors are a major component of the Tokyo traffic control system. A central computer monitors traffic signals and vehicle motion based on these systems throughout Tokyo and then relays real-time information to motorists and police. A disadvantage of these sensors, as noted in a 1994 IVHS America presentation, is the inability to directly measure speed (16). Therefore, their use in future IVHS (now ITS) applications in Japan and elsewhere is anticipated to be limited. The state of New York continues to use ultrasonic detectors in remote areas with bad pavement. They estimate that 10 percent of their highway surveillance is provided by ultrasonic detectors (15). The Illinois DOT replaced its ultrasonic detectors with inductive loop detectors because the ultrasonic detectors were less reliable and less cost effective than inductive loop detectors (3).

2.3.10 Active Infrared Detection Systems

Active infrared sensors operate by focusing a narrow beam of energy onto an infrared-sensitive cell. Detections occur when vehicles pass through the beam and interrupt the signal. The infrared beam can be transmitted from one side of the road to the other, or from an overhead or roadside position to a device on the pavement surface. Infrared systems can provide information on vehicle height and length, in addition to simply passage of vehicles, at a relatively low cost. These sensors can be used as either presence or pulse sensors.

Preliminary testing by public agencies indicates very promising results for monitoring vehicle speeds and classifications. Active infrared systems appear to be able to operate during day/night transitions and other lighting conditions without significant problems. An advantage of the infrared sensor is the minimal disruption to traffic during installation or maintenance. The infrared sensor can be placed at the roadside or overhead on sign structures (11). The only weather conditions that appear to be problematic for this device are heavy fog and heavy dust. Disadvantages of infrared sensors include: difficulties of maintaining alignment on vibrating structures; limitations of across-the-road applications to one-lane roadways; inconsistent beam patterns caused by changes in infrared energy levels due to passing clouds, shadows, fog, and precipitation; lenses used in some devices may be sensitive to moisture, dust, or other contaminants; and the system may not be reliable under high volume conditions. For multilane applications, infrared detectors should be mounted overhead for both speed and volume measurements (11). Infrared detectors are used extensively in England for both pedestrian crosswalks and signal control. Infrared detection systems are also used on the San Francisco-Oakland Bay Bridge to detect presence of vehicles across all five lanes of the upper deck of the bridge, thereby providing a measure of occupancy (15).

2.3.11 Passive Acoustic Detection Systems

Passive acoustic detection systems are generally composed of an array of microphones that are aimed at traffic and “listen” for passing vehicles. A passive acoustic device, developed in partnership with the U.S. Navy, is a recent addition to the inventory of non-intrusive detectors. The major components of this sensor system include a controller card, from one to four independent acoustic sensors (microphones), and interconnect cables. The SmartSonic TSS-1, currently marketed by International Road Dynamics, provides a detection zone size of 1.8 m to 2.4 m (6 ft to 8 ft) in the direction of traffic, and provides one or two lane selectable zone size in the cross lane direction. The TSS-1 processing in the controller card has the capability of computing traffic flow measurements such as vehicle volume, lane occupancy, and average speed for a selectable time period. No accuracy data were available except for speeds.

In limited testing, the speed accuracy for the acoustic detection system was plus-or-minus 10 percent when compared to inductive loop detection systems. The system does not currently classify vehicles; however, addition of this feature is planned. Power requirements for the system is low, 5 to 6 watts, which will allow the use of solar panels. The cost of the acoustic sensor is \$1,450 per unit, with one required per lane per detection location. The detection system also requires a controller card at a cost of \$800. Each card can accommodate up to four acoustic sensors. The system which can be mounted in either a sidefire or overhead configuration has minimum mounting requirements of 6.1 m (20 ft) overhead and 7.6 m (25 ft) horizontal distance from the travel lane. Available information indicated that weather conditions, other than very dense fog, do not interfere with the system detection capabilities.

2.3.12 Automatic Vehicle Identification Systems

Automatic Vehicle Identification (AVI) technology utilizes a transponder inside the vehicle and a radio frequency signal unit located along side or above the roadway. The transponder receives a signal from the roadside unit and responds with an encoded signal uniquely identifying information about the driver or vehicle. A transponder card reader, part of the radio frequency unit, then processes this information. AVI systems are capable of uniquely identifying a vehicle passing through the detection area. This technology has a variety of uses as ITS technology advances including electronic toll collection (11). Electronic toll collection systems debit a special account when a vehicle passes through the toll booths. A related application for AVI systems is congestion pricing (17).

AVI systems monitor traffic conditions by using vehicles as probes in the traffic stream. The AVI system tracks a “tagged” vehicle along a freeway, allowing data to be processed at a single point location, as well as over lengths of roadway. The system utilizes “read-write” capabilities that provide two-direction information flow and information storage by the transponder. Information stored upstream on the vehicle’s transponder is then read at the next card reader location, allowing the AVI system to track a vehicle along the roadway (17). An AVI system can record headway, volumes by lane and by station, the number of tagged vehicles passing in each lane at a reader station, and the number of tagged vehicles that switch lanes between stations. A sophisticated system may also relay vehicle type, driver-input origin and destination information, and travel speed based on the vehicle’s speedometer (17). The major disadvantage of using an

AVI system as a vehicle detection system stems from the limited number of vehicles equipped with transponders.

2.3.13 Video Image Processing Systems

Video image processing research evolved during the mid 1970s. Early systems used “fixed geometry” sensors, meaning that points on the roadway being monitored could not be changed unless the camera was physically moved. This feature was undesirable, so subsequent generations of video image systems were developed to allow alteration of the detection area within the camera’s field-of-view through the use of video image processing software. Real-time detection also became available with these technological advances (18, 19). A video image processing system consists of one or more cameras providing a clear view of the area, a microprocessor-based system to process the video image, and a module to interpret the processed images (11). Advanced video image processing systems can collect, analyze, and record traditional traffic data; detect and verify incidents; classify vehicle types; and monitor intersections (20). Video image systems have evolved through the following three classes of systems: tripwire, closed-loop tracking, and data association tracking.

Tripwire systems, which were the first generation of video image processing systems, are the least demanding in terms of computer power and speed. These systems operate by allowing the user to define a limited number of detection zones in the video camera field of view . When a vehicle enters a detection zone, it is identified in a manner analogous to inductive loops. In fact, tripwire systems are the functional equivalent of inductive loop systems and are intended to replace inductive loops in areas where a large number of loops are employed. Most of the video image processing systems that are commercially available at this time are tripwire systems. Limitations of tripwire systems become obvious in the presence of shadows and changing light conditions. Another disadvantage is the limited flow information that the systems provide—counts and speeds (other variables are calculated from these two variables). Tripwire systems are currently used to provide inputs to traffic control devices (21).

Closed loop tracking systems, the second generation of video image processing systems, are an extension of the tripwire approach in that detection is performed using the same type of detection zones. These systems have the same limitations found in tripwire systems with obscurations and shadows. Closed loop tracking systems are the first attempt to perform vehicle tracking. Closed loop systems provide more traffic flow information than tripwire systems, but the complexity of both hardware and software subsystems is significantly greater than for tripwire systems (21).

Data association tracking systems, commonly used in satellite surveillance systems, are the third generation of video image processing systems. A basic requirement of data association tracking is the capability to identify and track a distinguishable object as it passes through the field of view of the camera. In this mode, the computer identifies vehicles by searching for connected areas of pixels that indicate motion when compared with the background information. A series of such vehicle detections is then associated to produce tracking data for each vehicle.

This approach requires less processing power and speed than closed loop tracking because it does not have to operate at the frame rate of the camera. It offers good performance with shadows and obscurations. Shadows are addressed using image analysis. Observed differences in the

geometry of the image reduce the effects of obscuration. A greater reliance on software sophistication may reduce the hardware costs for these systems. Data association tracking systems have the additional advantage that a series of video cameras can be used to cover a wide area, and a vehicle can be handed off from one sensor to another as it passes from one field of view to another.

2.4 FIELD PERFORMANCE TESTS

2.4.1 California Polytechnic State University Field Performance Tests

MacCarley et al. reported on results of testing 10 commercial or prototype video image processing systems available in the United States (22). The California Polytechnic State University researchers evaluated eight of the 10 systems in field performance tests. The systems evaluated in field performance tests were: Aspex Traffic Analysis System (ATAS); the Camera and Computer Aided Traffic Sensor (CCATS) by Devlonics in Belgium; Sigru, developed by Eliop in Spain; the Traffic Analysis System (TAS); Titan, a French system under development by the Institute National de Recherche sur les Transports et leur Sécurité, INRETS; Traffic Tracker; Tulip; and AutoScope.

All of the systems available for this test by Cal Poly were software-based. Some systems required specialized hardware platforms, while others ran on IBM PC-compatible platforms requiring only video digitizing cards for the camera interface. A fundamental part of the software's task involved algorithms for detecting the vehicle and measuring its speed (23, 24, 25, 26, 27). For the systems tested, two fundamental types of algorithms, Type 1 and Type 2 were examined.

Type 1 algorithms detect the time difference of light-level changes between two virtual gates in the image that are spaced a known physical distance apart. As a vehicle moves through the detection zone, it causes a difference in intensity, initially at the first gate, then at the second. This sequence of events is determined to be a single vehicle, and the vehicle velocity is determined by the time difference between the two events.

Type 2 algorithms, also known as vehicle tracking algorithms, first detect the presence of a cohesive object moving in the detection zone and then measure the vehicle's velocity along its trajectory. These algorithms are generally more sophisticated and typically require significantly greater computer processing power.

The test team used 28 test conditions in an attempt to emulate actual field conditions encountered on California urban freeways during year-round service. Parameters included day and night illumination levels, variable numbers of lanes (two to six), camera height, camera horizontal angle with the roadway, inclement weather conditions (rain and fog), camera sway and vibration, differing levels of traffic congestion, shadows, and the effects of simulated ignition noise and 60 Hz electromagnetic noise. Researchers developed a series of video test segments from several hundred hours of raw video collected over a period of a year on urban freeways. Each actual test segment was 20 minutes in length, preceded by a 10-minute initialization period to allow the test system to cancel the background and adjust to ambient light conditions. Video images came

from cameras mounted on freeway overpasses at heights varying from 8.3 m to 14.2 m above the roadway surface with a lens system that permitted viewing all traffic lanes in one direction.

Evaluation results indicated that most systems generate vehicle count and speed errors of less than 20 percent over a mix of low, moderate, and high traffic densities under ideal conditions (22). Parameters that may reduce the accuracy of a system are discussed below. Systems designed for very high camera placement were often intolerant of partial occlusion of vehicles (partially or fully hidden from view), yielding high error rates with lower camera mounting heights. Tests of high-density, slow-moving traffic yielded reduced accuracy and sometimes complete detection failure.

Transitional light conditions during sunrise and sunset also led to a reduction in accuracy. This was of significant concern because these time periods may occur during the heaviest traffic flow. Video image processing systems equipment is undergoing transition from daylight algorithms, which detect entire vehicles, to nighttime algorithms, which detect headlight pairs during these time periods. Finally, two aberrant conditions that caused particularly high error rates for most systems were rain at night and long vehicular and stationary shadows.

2.4.2 Minnesota Guidestar Field Performance Tests

The Minnesota DOT and SRF Consulting recently finished conducting a two-year test of non-intrusive traffic detection technologies under the auspices of Minnesota Guidestar. This test, initiated by the FHWA, had a main goal of providing useful evaluation on non-intrusive detection technologies under a variety of conditions. The researchers tested 17 devices representing eight different technologies: passive infrared, active infrared, magnetic, radar, Doppler microwave, pulse ultrasonic, passive acoustic, and video. The technologies were tested at a site in Minnesota that provided a wide range of weather, lighting, traffic, and geometric conditions. Two locations were selected for testing, the first location was a freeway site, and the second site was an intersection. Inductive loops were used for baseline calibration. The test consisted of two phases, with Phase 1 running from November 1995 to January 1996 and Phase 2 running from February 1996 to January 1997 (28, 29, 30). Table 2-1 summarizes the most pertinent detectors.

Because of the number of technologies tested and the variety of conditions under which the technologies were tested, the results and conclusions of the research were varied and complex. Researchers found that it is important to consider the detection device's intended application when evaluating performance (30). The performance results for each of the eight technologies tested in the Minnesota Guidestar testing are discussed below.

Table A-1. Summary of Non-Intrusive Sensors ^(a)

TECHNOLOGY	VENDOR/PRODUCT	STATED CAPABILITIES	APPROX. COST	ADDITIONAL EQUIPMENT
Active Infrared	Schwartz Electro Optics, Inc. Autosense I	volume, occ., density, speed, class, presence	\$6,500	PC, mounting bracket
Passive Infrared	ASIM Engineering Ltd. (Switzerland) IR 224	volume, occ., presence	\$1,400	PC with interface box and display software (optional)
Passive Magnetic	3M Microloop	volume, occ., presence, speed (with 2 sensors)	\$500 - \$800 (b)	
Passive Magnetic	Nu-Metrics NC-40, NC-90A G-1, G-2 (wireless)	NC-40: vol., occ., presence NC-90A: same + spd, class, length G-1: vol., occ., presence, temp. G-2: same plus speed, class, length	NC-40: \$550 NC90A: \$895 G-1: \$975 G-2: \$1,695	PC, computer interface (\$450), software (\$745) & protective cover (\$158 NCs only)
Radar	EIS, Inc. RTMS X1	volume, occ., speed, presence, turning movements, class.	\$3,500	PC for setup and for serial data
Doppler Microwave	MicrowaveSensors, Inc. TC-20/TC26B	volume, occ., (20 is short range, 26B is long range)	TC-20: \$630 TC-26B: \$375	
Doppler Microwave	Whelen Engineering TDW 10/TDN 30	volume, occ., speed (TDW is wide bm), (TDN is narrow bm)	\$995	PC for serial data (optional)
Passive Acoustic	AT&T/IRD SmartSonic TSS-1	volume, occupancy, speed	\$1,450	Mounting brackets, PC for serial data - opt.
Video Tracking	ELIOP Trafico S.A. (Spain) Eva 2000 S	volume, occ., density, presence, speed, class, headway, (price varies w/ features)	\$7,000 - \$17,000	386 PC, camera, software
Video Tripline	Econolite Autoscope 2004	volume, occ., density, presence, speed, class, headway, turning movements	\$17,000 (1 camera unit) \$24,000 (4 camera unit)	486 PC (cameras included)
Video Tracking	Peek Transyt VideoTrak 900	volume, occ., density,, presence, speed, class, headway, turning movements, incident detection	\$18,000 (4 camera unit)	486 PC, cameras
Video Tripline	Rockwell International TraffiCam	volume, occ., speed, presence	\$3,800	386 PC (camera included)

^(a) Source: Reference (30)

^(b) Price is estimated.

2.4.2.1 Passive Infrared Devices

Passive infrared devices use the measurement of infrared energy radiating from a detection zone to detect the presence of vehicles. Researchers found that passive infrared technology performed well at both freeway and intersection testing locations and is a good technology for monitoring traffic in urban areas. The passive infrared devices tested during the Guidestar test were the Eltec Models 833 and 842, and the ASIM IR 224. The researchers found that passive infrared devices were not impacted by weather conditions and were very easy to mount, aim, and calibrate. However, there were significant differences in performances of the devices tested (30).

The Eltec Models 833 and 842 are self-contained passive infrared detectors that are easy to mount and calibrate. The Eltec models, which are designed to be mounted either overhead or

slightly to the side of the roadway, can be used facing either oncoming or departing traffic. However, repeatability was an issue and in some instances had significant fluctuations in count accuracy. The best performance of the vehicle occurred during a 24-hour test when the device counted within 1 percent of baseline data (30).

The ASIM IR 224, which is designed to be mounted either overhead or slightly to the side of the roadway, must face oncoming traffic. This passive infrared detector monitors three measurement zones and a vehicle must pass through all three zones in order to be counted as a detection. The IR 224 was easy to mount and calibrate, and repeatability was good. One device was observed to undercount vehicles during snowfall, however this miscounting may have been the result of vehicles traveling outside of the sensor's detection zone. The results of this device during an optimal 24-hour count period at both the freeway location (within 1 percent of baseline data) and the intersection (within 2 percent of baseline data) were among the best results obtained (30).

2.4.2.2 Active Infrared Devices

An active infrared device detects vehicle presence by emitting laser beams at the road surface and measuring the time it takes for the reflected signal to return. If a vehicle is present, the return time for the reflected signal will be reduced. The Schwartz Autosense I was the only active infrared device tested and it was not tested at the intersection location. In addition to detecting stationary and moving vehicles by presence, the Autosense I system can obtain vehicle speed and vehicle profile (which can be used for classification.) One drawback noted was that incoming data are not clearly time stamped (30).

Autosense I was found to be very accurate at counting traffic at the freeway location; however, weather conditions did impact performance of the device. The research team observed that during periods of heavy snowfall, the detector both overcounted and undercounted vehicles. The undercounting was surmised to be the result of vehicles traveling out of the detection zone. The overcounting was attributed to the falling snow reflecting the laser beams causing false detections. Researchers also observed that rain and freezing rain caused overcounting and undercounting. These discrepancies were attributed to the change in reflectivity properties of the pavement (30).

2.4.2.3 Passive Magnetic Devices

Passive magnetic devices detect the disruption of the earth's magnetic field caused by the movement of vehicles. The passive magnetic device must be relatively close to the vehicles it is detecting, therefore most applications of this type of device require installation below the pavement or in a sidefire mode. Two magnetic devices were tested during Guidestar, the Safetran IVHS Sensor 232E/231E Probe. Two Safetran 231E Probes were installed in conduits underneath the roadway and were connected to the IVHS Sensor 232E, a processing card located in a collection trailer. Volume, speed, and occupancy can be calculated from the detector data. The data from the probes, which were located approximately 6 m (20 ft) apart, could also be used to calculate speed. Installation of the passive magnetic devices was difficult and required several days. Water was also observed to accumulate in the conduit and at the handhold area of the conduit, which possibly resulted in problems with the probe's performance (30).

The probe had problems with erratic performance which could be due to intermittent grounding problems. The problems were observed during periods of rainfall. Snow and rain also affected detector performance. Overcounting during periods of snow was attributed to vehicles leaving the detection zone. Problems with rain was surmised to be due to water entering the conduit handhold and shorting out the probe connections at the splice (30).

2.4.2.4 Doppler Microwave Devices

Doppler microwave devices transmit a beam of low energy microwave radiation at a target area on the pavement and then analyze the reflected signal. The motion of a vehicle in the target area or detection zone results in a shift of frequency of the reflected signal according to the Doppler principle. This shift can be used to detect moving vehicles and estimate their speed. Four different Doppler microwave devices were tested, but the research team presented detailed data for only two of the devices. The devices tested were the Peek PODD, the Whelen TDN-30, the Whelen TDW-10, and the Microwave Systems TC-26B. The research team found that all four devices were easily mounted and calibrated, and that none of the devices seemed to be affected by weather conditions. However, the devices tested revealed differences in performance. The study did not provide data for either the Whelen TDW-10 or the Microwave Systems TC-26B (30).

Researchers found that under optimal conditions the Peek PODD was able to count vehicles at the freeway site within 1 percent of the baseline, providing that the device was properly aimed. The PODD requires that mounting be either overhead or slightly to the side of and facing oncoming traffic. These mounting requirements resulted in poor aiming of the device which may have led to undercounting during one test and overcounting during another. During one of the procedures it was observed to detect vehicles in the adjacent lane. The PODD was not able to collect good data for the intersection site. The Whelen TDN-30 also requires that mounting of the device be either overhead or slightly to the side of and facing oncoming traffic. The primary role of the device is to collect speed data. Researchers found that the device undercounted vehicles at the freeway site by approximately 3 percent and was not able to collect meaningful data at the intersection site (30).

2.4.2.5 Radar Devices

Researchers tested one radar device during the test. Radar devices use a pulsed signal that is either frequency-modulated or phase-modulated. The device determines the delay of the return signal and uses this information to detect the presence of a vehicle and to calculate the distance to the detected vehicle. The radar device tested by researchers was the EIS RTMS. This device can be mounted either overhead or in a sidefire position and can be aimed perpendicular to traffic. The RTMS was easily mounted but requires a moderate amount of calibration to achieve optimal performance. The researchers found that rain affected the performance of the RTMS. This degradation in performance was attributed to water entering the device and not to limitations of the technology. When the RTMS was used in an overhead mounted position the device undercounted vehicles by 2 percent or less at the freeway site. When the RTMS was in a

sidefire portion the device undercounted by approximately 5 percent. The RTMS was not tested at the intersection site (30).

2.4.2.6 Passive Acoustic Devices

Passive acoustic devices incorporate an array of microphones aimed at the traffic stream; a vehicle is counted when the microphones detect the sound of the vehicle passing through the detection area. The optimum position for passive acoustic devices is the sidefire mounting position with microphones aimed at the tire track because the primary source of sounds for vehicle detection is the noise generated between the tire and road surface. Researchers tested two passive acoustic devices that were supplied by the same manufacturer, the IRD SmartSonic. The devices were mounted sidefire and were noted to be relatively easy to install and calibrate. Low temperatures and the presence of snow on the roadway, which may have muffled sound, were both correlated with undercounting by the devices. When the SmartSonic devices were mounted on the freeway bridge undercounting daily traffic ranged from 0.7 to 26.0 percent. This undercounting was attributed in part to the echo-filled environment underneath the bridge. Researchers found that both SmartSonic devices undercounted vehicles during freeway testing and overcounted at intersection testing (30).

2.4.2.7 Pulse Ultrasonic Devices

The research team tested two pulse ultrasonic devices, the Microwave Sensors TC-30 and the Novax Lane King. A pulse ultrasonic detection device emits pulses of ultrasonic sound energy toward a detection zone and then measures the time it takes for the reflected pulses to return. If a pulse is returned sooner than expected the presence of a vehicle is detected. Overhead mounting of the device provides optimal signal return and vehicle detection, however sidefire mounting is possible for some devices. Pulse ultrasonic devices are relatively easy to mount, however the ease of calibration varies with devices. Weather conditions did not impact the performance of the devices (30).

The TC-30, which may be mounted either overhead or sidefire, was found to provide an accurate vehicle detection count at the freeway test site and a tendency to overcount at the intersection test site. The TC-30 was easy to mount and calibrate. Researchers observed that vehicles stopped in the detection area were counted multiple times resulting in the overcount. The Novax Lane King can also be mounted either overhead or in a sidefire configuration. The Lane King was easy to mount, however calibration was extensive for optimum performance. The Lane King was extremely accurate in counting vehicles at the freeway site, but at the intersection site overcounting occurred as the result of double counting. The two pulse ultrasonic devices interfered with one another when mounted next to each other (30).

2.4.2.8 Video Devices

Video detection devices analyze video images from a camera by using a microprocessor. Researchers tested four video systems, the Peek Transyt Video Trak-900, the Image Sensing Systems Autoscope 2004, the Eliop Trafico EVA 2000, and the Rockwell International TrafficCam--S. In general, mounting video detection devices is a more complex procedure than

that required for other types of devices. Camera placement is crucial to the success and optimal performance of the detection device. Lighting variations were the most significant weather-related condition that impacted the video devices. Vehicle shadows, other shadows, and transitions between day and night also impact counting (30).

The Peek Transyt Video Trak-900 is capable of monitoring input from up to four cameras. Initial testing by the research team at the freeway test site resulted in counting accuracy within 5 percent of the baseline. However, when the device was moved to the intersection, periodic failures began to occur and continued throughout the testing. Researchers also observed that overcounting occurred during the light transition periods from day to night and vice versa. Like the Trak-900, the Autoscope 2004 can also monitor input from up to four cameras. Researchers found that the Autoscope is capable of performing within a 5 percent accuracy at both freeway and intersection test sites. Light changes during transition periods also resulted in undercounting by the Autoscope (30).

Researchers found that the Eliop Trafico EVA 2000 detection system was capable of very accurate freeway counts, within 1 percent of the baseline. Calibration of this system was difficult as a result of a complicated user interface; however, the system was not adversely impacted by any weather condition and was the only video system that was not affected by light transitions. The EVA 2000 was not recommended for intersection applications and therefore the researchers did not supply any data for intersection testing. The last video device tested by the researchers was the Rockwell International TrafficCam--S. The TrafficCam required data to be downloaded over the serial connection. Researchers found that the TrafficCam's performance varied greatly during the testing period. Some of the performance problems were attributed to a grime buildup due to salt spray on the camera lens. Other variables that may have affected the performance were shadows and lighting conditions (30).

2.4.3 Hughes Aircraft Company Field Performance Tests

Hughes Aircraft Company conducted an extensive test of non-intrusive sensors for FHWA. The objectives of the study, *Detection Technology for IVHS* (31), included determining traffic parameters and accuracy specifications, performing laboratory and field tests of non-intrusive detector technologies, and determining the needs and feasibility of establishing permanent vehicle detector test facilities. Detector technologies that were tested included: ultrasonic, Doppler microwave, true presence microwave, passive infrared, active infrared, visible VIDS, infrared VIDS, acoustic array, SPVD magnetometer, and inductive loops (31).

The field tests were conducted on both freeway and surface street test sites. Sites selected were located in Minneapolis, Minnesota; Orlando, Florida; and Tucson, Arizona. These sites were selected to allow testing to be conducted in a variety of climatic and environmental conditions. Researchers made both quantitative and qualitative observations and judgments regarding the best performance with respect to different traffic parameters. The Doppler microwave detectors provided the best performance for gathering specific data for most categories; however it should be noted that this detection technology does not detect stopped vehicles. Researchers found that the Doppler microwave, true presence microwave, visible VIDS, SPVD magnetometer, and inductive loop technologies performed well for low volume counts. The Doppler microwave,

true presence microwave, visible VIP, and inductive loop performed well for high volume counts. The Doppler microwave was the best performing technology for low volume speed and for high volume speed. The Doppler microwave, microwave true presence, SPVD magnetometer, and inductive loop technologies performed best in inclement weather.

2.4.4 Other Field Performance Tests

Recent tests by Kyte et al. (32) substantiated that less accurate (uninterrupted flow) measurements from an AutoScope 2002 video imaging system occurred under reduced daytime light conditions, when traffic moved toward the camera (versus away), and when vertical detectors were used. In the measurement of freeway traffic volume counts using proper camera angle and detector configurations, these AutoScope tests produced data that varied from 0.6 to 9.3 percent of manually collected data.

Duckworth et al. (33) conducted tests of various traffic monitoring sensors on a highway near Boston. Sensors tested included: video cameras, passive acoustic microphone arrays, active ultrasonic acoustic ranging and Doppler sensors, Doppler radar, and passive infrared sensors. The researchers evaluated and considered the sensor performance, sensor cost, communications required raw data, and the amount of computation needed for signal processing and classification. The researchers found that the video camera provided the best performance in the areas of detection, speed estimation, and vehicle classification. However, they noted that video had limitations in poor lighting and certain weather conditions, and was the most expensive sensor tested. Pulsed ultrasound was found to be the best sensor for detection and classification when cost, the communications bandwidth requirements, and processing power were considered. Radar was the best velocity sensor for vehicles it detected. The researchers recommended that a combination sensor of pulsed ultrasound and either pulsed-Doppler ultrasound or Doppler radar be considered as the strongest candidate as an inexpensive replacement of magnetic loop detectors (33).

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APPENDIX B PRACTITIONER SURVEY

As has been noted, inductive loop detectors have been and continue to be the primary type of detector used in freeway management systems. However, the need still exists for a reliable, cost-effective non-intrusive alternative. To gauge the acceptance and experience with other types of detectors in operational systems, several system managers were contacted by telephone. The following information was obtained in these informal interviews.

Site: Minneapolis Freeway Management Center

Agency: MnDOT

Contact: Glen Carlson

- Continues to make extensive use of loop detectors.
- Tests of radar (RTMS) have not convinced MnDOT that the advantages of non-intrusive installation outweigh the reliability of a properly installed loop detector.
- VIDS may have promise for the future but not ready for freeway use due to weather, lighting, other considerations.

Site: San Antonio TransGuide

Agency: TxDOT

Contact: Pat Irwin

- TransGuide makes extensive use of loop detectors. Satisfied with performance.
- Has had good experience with acoustic detectors in a test situation and will deploy more. Mounted over lane with approximately 99% accuracy compared to loops.

Site: Detroit ITS Center

Agency: MichDOT

Contact: Thomas Mullen

- Uses loops exclusively.
- Has tested EIS microwave (doppler) detectors but not ready to deploy.
- Microwave (side mounted) able to discern vehicles across 10 freeway lanes. Trucks block line of site.
- AutoScope has been used extensively in area but not on freeways.

Site: Seattle Freeway Management System

Agency: WashDOT

Contact: Pete Briglia

- Uses almost exclusively loops.
- Will have VIDS (AutoScope) installed in about six months.
- Will also have microwave (RTMS) operational in about six months.

Site: Bay Area Freeway Management System

Agency: CalTRANS

Contact: Jim McCrank

- Uses almost exclusively loops.
- Will use overhead-mounted radar (RTMS) detectors at locations where detectors will move because of construction.
- Some AutoScope. in use but fog is a problem.

Site: Chicago Freeway Management System

Agency: Illinois DOT

Contact: Joe McDermott

- Loop based system. Very satisfied with loop performance.
- Presently installing some VID sites based for testing.

Site: Atlanta

Agency: GaDOT

Contact: Mark Demivich

- New system-no loop detectors.
- AutoScope system with 318 locations (lane points) and 57 processors.
- Volumes 85% accurate; speeds within 5 mph.
- Accuracy drops slightly after dark.

Summary

Video detection systems and other non-intrusive systems are becoming more prevalent although most agencies are still testing them and they are not being implemented widely. Atlanta is a notable exception.

APPENDIX C SUPPLEMENTAL REVIEW

In addition to a detailed literature review of vehicle detector application and technology, information was gathered through WinSPIRS and the University of California at Berkeley PATH Database for recent unique applications of various detector monitoring technologies. Abstracts of related documents follow.

Title: Using Advanced Vehicle Monitoring Systems to Extend System Capacity Along North Carolina Freeways.

Author: Steven M. Click

Publisher: Center for Transportation Engineering Studies, Dept. of Civil Engineering, North Carolina State University, Raleigh, NC. Date: March 1997

Abstract: The timely ability to accurately predict the occurrence of extended periods of significantly reduced speeds on freeways (breakdowns) is critical to effective freeway management. This paper documents the development of an easily implemented algorithm for predicting periods of 5 minutes or longer with speeds below 30 mph using single loop detector data. The study also explored the relationship between safety and congestion. Preliminary support was found for the hypothesis that sudden changes in traffic characteristics may increase the likelihood of crashes under congested conditions. Finally, the study evaluated an image-based detection alternative at selected sites along I-40 and I-77 in the Raleigh and Charlotte areas.

Conclusion: On the basis of the study findings, the following recommendations are offered which have direct applications to the CARAT project implementation: 1) detector data should be aggregated at a resolution of 1-minute intervals for the purpose of congestion prediction, 2) the detection horizon should be set at 0-5 minutes, 3) traffic counts alone are not good predictors of freeway breakdown, 4) speed over the detector is a key parameter for congestion problem, 5) a directional, time-of-day breakdown prediction algorithm provides improved performance over one that is calibrated from combined data from both directions, 6) the algorithm in Tree 5 is recommended for further investigation and application to North Carolina conditions, 7) countermeasures that can affect the minimum speed or the rate of speed drop should be further investigated as a pre-emptive method for avoiding freeway breakdowns, and 8) the relation between safety and freeway breakdown requires further investigation.

Title: Photocops May Help Drivers Get the Picture.

Author: Betsy Wing

Source: Tech transfer. No. 56. Date: Winter 1997

Abstract: This article looks at the use of automatic cameras for traffic surveillance, including photo red light systems and photo radar. It describes problems encountered in enforcing these systems, focusing on the fact that there is no state legislation specifically allowing local agencies to enforce photo radar citations. The article also compares the effectiveness of speed display

systems versus photo radar. Applications of these systems in a few California cities are briefly discussed.

Conclusion: In El Cajon and Poway, the city traffic engineers report significant changes in driver behavior at red lights which they attribute in part to drivers knowing that cameras are present. The installation of the cameras has drastically reduced the red light running even at intersections where there are no cameras. Notices that automatic cameras are in use are posted at the city limits, but not at particular intersections.

Title: Traffic Surveillance and Detection Technology Development: New Traffic Sensor Technology. Final Report.

Author: Jitendra Malik, Stuart J. Russell

Publisher: California PATH Program, Institute of Transportation Studies, University of California, Berkeley.

Abstract: This document presents the final report on a project focusing on new traffic sensor technology, mainly video cameras, for traffic surveillance and detection. It describes a Transportation Management Center (TMC), designed for the collation and computation of multi-site statistics. The report discusses the following elements: tracking approach, motion-based grouping, tracking and grouping procedures, vehicle classification hardware port, parameters computed at the TMC, testing methodology, and test results.

Title: Assessing Vehicle Detection Utilizing Video Image Processing Technology.

Author: Duane Hartmann, Dan Middleton, Dwayne Morris

Publisher: Texas Transportation Institute, College Station, TX.

Abstract: This document reports on research which analyzed detection capabilities of a trip-wire video image processing system used in a freeway setting. The parameters tested included count, speed accuracy, and occlusion. The assessment determines the limits a video image system has in accurately counting vehicles and determining vehicle speeds.

Conclusion: Findings generated by non-midday tests were less conclusive due to not operating in all lanes used in midday tests. Sample sizes in each lane used an alpha of 0.05, for a 95 percent confidence interval. The AutoScope detector uses a different technique for day versus night detection. The system detects headlights at night versus the body of the vehicle during the daylight. One positive finding was that vehicles were generally detected at night at greater distances at the same camera height and vehicle speed as compared to daylight. The night tests generally produced more accurate speeds from lanes farther from the camera than closer ones.

Title: Digital Surveillance, Supervision and Control Made Simple.

Author: Danny Collard

Source: Traffic Technology International.

Date: February/March 1996

Abstract: This article describes advances in digital networks, focusing on new modular, interoperable digital signal processors as they are applied to Intelligent Transportation Systems (ITS), and in particular, traffic surveillance.

Conclusion: Transmission of multimedia information in digital form is fast becoming the norm. New standard, digital equipment now available on the market greatly facilitates the task of the network system designer and users without risk.

Title: Demonstration of Video-based Technology for Automation of Traffic Data Collection: Travel Time, Origin-Destination, Average Vehicle Occupancy.

Author: Michael C. Pietrzyk

Publisher: Center for Urban Transportation Research, University of South Florida, Tampa, FL.

Abstract: This report documents the findings of a field demonstration project that was conducted to evaluate the feasibility of a video-based traffic data collection process, compatible with traffic performance measures needed for a Congestion Management System (CMS). The report includes a background discussion of the more conventional techniques for collection of travel time, origin-destination, and average vehicle occupancy data; a discussion of comparative advantages and disadvantages of each technique; and findings of the video-based automation compared to effectiveness of collecting the same information through visual observation at each camera location.

Conclusion: The field demonstrated concluded that automation of traffic data gathering and analysis is feasible through video and machine vision technology application. This type of ITS technology satisfies a need of congestion management systems – real-time monitoring. As a result, more meaningful traffic performance data can be collected in a more cost-effective manner, and utilized more often in the transportation decision making process.

Title: Video Technologies for Roadway Surveillance and Automated Detection.

Author: C. Arthur MacCarley, Leonard Ponce

Source: IVHS and Advanced Transportation Systems.

Abstract: This paper summarizes the current state-of-the-art in video imaging and video signal processing technology for traffic surveillance and electronic detection. Technical considerations relevant to the selection of video cameras and computer vision hardware and software are reviewed. Applicable standards are identified, and evaluation criteria and test procedures are described.

Conclusion: Video camera and computer video processing technologies can play a valuable role in improved traffic management. Monochrome video cameras generally excel in resolution and sensitivity, but remain susceptible to vertical or horizontal smear at high sensitivity levels which could limit their usefulness for highway surveillance at night. Color information is a valuable feature for both surveillance and automated detection.

Conditions that degraded detection performance were 1) non-optimum camera placement, 2) transition from day to night, 3) headlight reflections on wet pavement, 4) shadows from vehicles or objects outside the detection area, 5) obscured atmospheric conditions, and 6) camera motion.

Title: Automatic Vehicle Location (AVL) for Measurement of Corridor Level-of-Service: The Miami Method.

Author: Michael C. Pietrzyk, Amy Ellen Polk

Source: Institute of Transportation Engineers. Meeting (65th:1995:Denver, CO). 1995 Compendium of Technical Papers.

Abstract: This paper describes a field demonstration project in Miami which demonstrated the use of automatic vehicle location to measure vehicle operating speeds on the city's 17 transportation corridors.

Conclusion: CUTR has demonstrated that the AirTouch Teletrac automatic vehicle location system can be used to measure average vehicle operating speeds, given sufficient electronic storage capacity, appropriate data analysis software, and a pool of willing volunteers.

Title: Probe Vehicle Sample Sizes for Real-Time Information: The Houston Experience.

Author: Shawn M. Turner, Douglas J. Holdener

Source: Vehicle Navigation and Information Systems Conference (6th:1995:Seattle, WA). 1995 Vehicle Navigation & Information Systems Conference Proceedings.

Abstract: This paper investigates the required minimum number of probe vehicles that are necessary to report real-time travel speeds and times for a desired statistical accuracy. Empirical travel time data from the Houston traffic monitoring system were analyzed to calculate travel time variation and the corresponding minimum required probe vehicle sample sizes. A regression equation was developed to estimate travel time variation, which can then be used to calculate sample sizes.

Conclusion: The existing number of probe vehicles equipped with AVI tags in Houston provide reliable real-time information. However, implementation of several recommendations would improve the accuracy and reliability of travel time data being collected by the probe vehicles. Install additional AVI tag readers where current segment lengths exceed 3 to 4 miles. Providing reader sites every 2 to 3 miles on congested segments and every 3 to 4 miles on uncongested segments provides more accurate, up-to-date travel times.

Title: Traffic Flow Wide-Area Surveillance Definition.

Author: G.O. Algood

Publisher: Oak Ridge National Laboratory, Oak Ridge, TN.

Abstract: This report focuses on Traffic Flow Wide-Area Surveillance (TFWAS) systems. It examines currently used and possible future traffic-sensing technologies. Criteria for selecting TFWAS sensors are discussed. Primary sensor technologies and special sensing categories or

subcategories are described. The capabilities of each of these sensors for providing TFWAS measures are analyzed and discussed.

Title: Monitoring the San Francisco Bay Area Freeway Network Using Probe Vehicles and Random Access Radio Channel.

Author: Jean-Paul Linnartz, Marcel Westerman, Rudi Hamerslag

Publisher: Delft University of Technology, Faculty of Civil Engineering, Delft, Netherlands.

Abstract: This report describes a method of collecting real-time data from probe vehicles automatically sending traffic reports to one or more base stations, connected to a traffic center by wired communications network. Several multi-disciplinary aspects of this data collection technique are studied analyzing and computing road traffic and message traffic flows in the San Francisco Bay Area. The results reveal that random access (ALOHA) transmission of traffic messages is a spectrum efficient, inexpensive and flexible method for collecting road traffic data and this approach can provide reliable traffic monitoring.

Title: Comparative Study of Non-Intrusive Traffic Monitoring Sensors.

Author: G. L. Duckworth

Source: Intelligent Vehicle Highway Systems.

Abstract: In this study, the authors compare the performance of inexpensive and non-intrusive traffic-monitoring sensors. These include: video cameras, passive acoustic microphone arrays, active ultrasonic acoustic ranging and Doppler sensors, Doppler radar, and passive infrared applications. Using data taken on a highway in the Boston area, the various sensor types are coupled with signal processing for counting, speed estimation, and vehicle type classification.

Title: Advanced Techniques for Travel Time Data Collection.

Author: S.M. Turner

Source: Transportation Research Record 1551 (1996).

Abstract: Travel time information is becoming more important for applications ranging from congestion measurement to real-time travel information. Several advanced techniques for travel time data collection are discussed, including electronic distance-measuring instruments (DMIs), computerized and video license plate matching, cellular phone tracking, automatic vehicle identification (AVI), automatic vehicle location (AVL), and video imaging. The various advanced techniques are described, the necessary equipment and procedures are outlined, the applications of each technique are discussed, and the advantages and disadvantages are summarized. Electronic DMIs are low in cost but typically limited to congestion monitoring applications. Computerized and video license plate matching are more expensive and would be most applicable for congestion measurement and monitoring. Cellular phone tracking, AVI, and AVL systems may require a significant investment in communications infrastructure, but they can provide real-time information. Video imaging is still in testing stages, with some uncertainty about costs and accuracy.

Conclusion: This paper described several relatively new techniques for collecting travel time data. The techniques differ in the methods of collection and the necessary equipment. Electronic DMIs rely only on a vehicle attempting to travel at the average speed of the traffic stream. License plate matching and video imaging try to capture and match unique vehicle identifiers without requiring additional effort from the motorist. Cellular phone tracking, AVI, and AVL require that motorists' vehicles be instrumented with a transmitter or transponder.

Title: Assessment of Existing Methods of "Travel Time" Acquisition and Measurement.
Author: J.R. Orselli, Y. Durand-Raucher
Source: Congress. Location: Yokohama, Japan. Intelligent Transport Systems World 11/1995. Vol. 1.

Abstract: Many techniques, devices, systems, and services involved in intelligent transportation systems deployment are based on obtaining reliable traffic data coping with real-time or travel-time estimations. This paper: 1) defines and quantifies the type of data needed to have good coverage of a network and obtain accurate travel times for at least 90 percent of the trips; 2) assesses the technologies in use or in a development phase to achieve the results of collecting real-time travel times information; and 3) outlines the most promising results from a cost effectiveness perspective. The paper will consider also the push and pull factors involved in the industrial development of technologies and systems to collect and calibrate real-time travel times acquisition. France will remain the focus for the evaluation of technical and business implementation, but the scientific aspects of this implementation will remain on a global level, with applications for any geographic context.

Conclusion: One of the main costs of the arterials and highways is the cost of the data collection network. It is interesting to be able use a network implemented for other aims for data collection. Various methods of collecting data are examined. The four methods which get "measured travel times" are complicated. The "pure calculation method," on the basis of occupancy, volumes, etc. seems to be the best and least costly one.

Title: A Comparison of Real-Time Freeway Speed Estimation Using Loop Detectors and AVI Technologies.
Author: J. van-Arendonk
Source: Compendium: Graduate Student Papers on Advanced Surface Transportation Systems. 1996.

Abstract: It is the intent of this report to compare both loop detector systems and Advanced Vehicle Identification (AVI) systems in terms of how they measure freeway speeds. This will hopefully provide transportation engineers with a guide to choosing an appropriate system. The results will then be applied to the city of San Antonio. The objectives of this report are to: 1) determine an optimal spacing of AVI roadside readers (along and across the freeway) and probe vehicle density (number of vehicles with tags) to measure average freeway speed; 2) determine an optimal spacing of loop detectors to measure average freeway speed; 3) compare both costs

(installation and maintenance) and accuracy/effectiveness of AVI systems and loop detectors to measure freeway speeds; and 4) investigate how the results could be applied to the city of San Antonio.

Conclusion: Loop detectors are very accurate at counting vehicles, however, the accuracy depends on the working condition of the detectors. According to studies on loop failures and interviews with professionals, it appears that loop detectors are prone to failures and are very susceptible to weather.

AVI systems can directly calculate travel times by having the time a particular vehicle passed a given location. It can provide very accurate freeway speed estimations at distances of up to 3 miles.

Title: Model Minimum Performance Specifications for Lidar (LASER) Speed Measurement Devices.

Source: Traffic Tech. Date: 4/1995

Abstract: Within the past few years, the use of lidar speed measurement devices for speed limit enforcement by police agencies has steadily increased. LIDAR (Light Detection and Ranging) is more commonly known as a laser speed measurement device. To insure the devices are accurate and reliable, there is a need for independent testing. To fill this need, the International Association of Chiefs of Police (IACP), requested that the National Highway Traffic Safety Administration (NHTSA) establish minimum performance specifications for lidar speed measurements. This Traffic Tech report provides information on how lidar works, lidar minimum performance specifications, lidar testing, and a NHTSA model basic operator training course on lidar speed measurement.

Title: The Economics of Video Detection Implementation on Freeways.

Author: P.G. Michalopoulos, C.A. Anderson

Source: Traffic Engineering and Control. Date: 12/1994

Abstract: Wide-Area Detection Systems (WADS) through video image processing is gaining worldwide acceptance as a proven technology for Intelligent Vehicle-Highway Systems (IVHS), as well as the preferred emerging technology for replacing loops of many practical situations. This technology has been tested and validated in many real-life applications. The advantages and sophistication of WADS are easily realized at intersections where the large number of detectors and need for wide-area measurements lead to up-front cost justification. This is not so obvious on freeways due to sparse detection and current lack of widespread WADS applications. In this paper, a direct comparison of loops versus WADS is made, assuming WADS is only being used as a direct replacement of loops. Even when ignoring intangible benefits, it is demonstrated that when an economic analysis is performed, WADS can be substantially more cost-effective than loops. Intangible benefits include stopped-vehicle and incident detectors, automatic extraction of measures of effectiveness and performance measurement, wide-area detection, continuous visual performance verification, accurate speed measurement through vehicle tracking, surveillance at minimal incremental cost, and others.

Conclusion: This study has demonstrated that when user costs are taken into account, Autoscope is more cost effective than conventional loop detectors even for sparse detection requirements on

a two-lane roadway. Benefit-cost ratios of 1.25 to 18.4 were obtained for three alternative Autoscope configurations on a freeway with two lanes in each direction. As expected, benefit-to-cost ratios are even higher when cost data are extrapolated to three and four lanes in each direction due to multiple-lane detection capability of video detection and when speed is used for accurate assessment of traffic state.

Wide deployment of WADS will enable other IVHS traffic management technologies to take root and will eventually lead to more efficient management of traffic, saving time and money and reducing congestion and pollution levels.

Title: Update of Enforcement Technology and Speed Measurement Devices. Final Report.
Author: R.R. Blackburn, R. Moran, W.D. Glauz
Source: Midwest Research Institute. Date: 12/1989

Abstract: Information was collected and analyzed on recent advances in speed enforcement technology and enforcement strategies employing these technologies. Both automated and manually operated equipment was reviewed, and both radar and non-radar technologies were included. Automated enforcement of red light violations was also examined. The new technologies are all foreign, and are being employed widely throughout the world. All of them have the capability of automatically photographing the vehicle that the equipment identifies as being in violation. Most of the systems use some sort of radar, either a narrow beam cross-the-road-technology or a short range, low power down-the-road technology. One new system incorporates digital signal processing, and can simultaneously track multiple vehicles in several lanes. All of the systems represent technical advances over the state of the art used in Europe and elsewhere 10 years ago. Recently, some of this equipment has been placed in use in a few communities in the United States. The most recent experiences have been well received by the public and the courts. In some cases, new legislation has been passed dealing explicitly with this technology. It appears that the use of this type of equipment and the related enforcement strategies is a viable alternative to traffic law enforcement in the United States. The equipment described is not endorsed nor is any device recommended over another.

Conclusion: Major conclusions have been developed with regards to the information obtained during this study. 1) Innovative approaches to speed enforcement have been tried in the United States with limited or mixed success. 2) Applied technology, especially the foreign-developed automated speed enforcement (ASE) equipment, is important to the future of law enforcement and provides an approach for improving compliance with speed laws. 3) Many of the ASE devices are versatile in that they can be deployed in a variety of enforcement strategies, including moving operations. 4) Some political subdivisions in the United States have enacted legislation enabling the use of photographic evidence of traffic violations.

Title: Field Test of Monitoring of Urban Vehicle Operations Using Non-Intrusive Technologies. Final Report.
Author: Minnesota DOT
Source: Minnesota Guidestar. Date: 11/1995

Abstract: This report documents the activities and results of a 2-year test of non-intrusive traffic detection technologies. Non-intrusive technologies are defined as data collection methods that can be done without intruding into the roadway for installation. Non-intrusive devices have the advantage of not disrupting traffic flow or exposing field personnel to dangerous conditions.

While there is potential for new technologies to replace the traditional methods of data collection, such as inductive loop detectors and road tubes, there are many questions regarding their performance. This report provides practitioners with useful information about the performance of non-intrusive technologies and specific devices within each technology.

Seventeen devices representing eight different technologies were evaluated in varying environmental and traffic conditions. The following technologies were tested: passive infrared, active infrared, magnetic, radar, doppler microwave, pulse ultrasonic, passive acoustic, and video. Testing was done at both freeway and intersection locations. Emphasis was placed on urban traffic conditions, such as heavy congestion, and locations that typify temporary counting locations, such as 48-hour or peak hour counts. The evaluation also focused on the ease of system setup and use, general system reliability, and system flexibility.

Conclusion: Most of the devices tested in this project are well-suited for temporary counting situations. Ease of installation and flexibility in mounting locations and power supplies are important elements in selecting a device to install quickly and move from location to location. In general, the differences in performance from one device to another within the same technology were found to be more significant than the differences from one technology to another.

Title: Speed-Based Traffic Monitoring: Connecticut's Experience with Radar Detectors.
Author: M.R. Mauritz, W.W. Stoeckert
Source: Proceedings of the 1994 IVHS Annual Meeting.

Abstract: As the IVHS program continues to expand, various new detection technologies are being developed and installed. These include acoustic, sonar, video, and radar. The Connecticut department of Transportation, in the development of its Advance Traffic Management System, will have the first operational system that uses radar as the primary means of detection. This system, which is being installed in the Hartford area, recently came on-line and is nearing completion of construction. The system relies on speed data being sent back from the radar detectors to monitor traffic and detect incidents. As part of the system, four different speed-based algorithms were developed for incident detection. The system also utilizes digitized video and is tied into the State's Variable Message Sign System.

Conclusion: The Connecticut Department of Transportation's Demonstration Project has shown several advantages of using radar detectors for monitoring highway traffic. The system provides

real-time accurate data regarding travel conditions within the project area. This data allows ConnDOT engineers to become familiar with and identify differences between normal and incident conditions. Testing and day-to-day operations have shown the radar detectors to be highly accurate during varying traffic and weather conditions.

Title: Headway and Speed Data Acquisition Using Video.
Author: M.A.P. Taylor, W. Young, R.G. Thompson
Source: Transportation Research Record 1225. Date: 1989

Abstract: Accurate knowledge of vehicle speeds and headways on traffic networks is a fundamental part of transport systems modeling. Video and recently developed automatic data-extraction (image processing) techniques have the potential to provide a cheap, quick, easy, and accurate method of investigating traffic systems. This paper presents two studies that use video-based equipment to investigate the character of vehicle speeds and headways. Investigation of headways on freeway traffic allows the potential of this technology in a high-speed environment to be determined. Its application to the study of speeds in parking lots enabled its usefulness in low-speed environments to be studied. The data obtained from the video was compared to traditional methods of collecting headway and speed data.

Conclusion: Video-based data collection systems allow data to be collected that have previously been unavailable using traditional techniques. The VADAS system offers a reasonably fast method of collecting and extracting survey data. Editing programs are necessary to ensure the data extracted are accurate. Considerable time savings occur when operators become experienced with this technology.