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16. Abstract

This report documents the development of an automatic vehicle identification (AVI) system for monitoring traffic conditions on urban freeways. The AVI system is being implemented in Houston in a stage construction program. Phase 2 covers 98 miles of urban roadways on four radial freeways. The report outlines the system design and the hardware and software requirements for measuring travel times and average speeds and processing and distributing the results in real time (within one minute of detection).

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DESIGN AND IMPLEMENTATION OF AUTOMATIC VEHICLE IDENTIFICATION TECHNOLOGIES FOR TRAFFIC MONITORING IN HOUSTON, TEXAS-PHASE 2 FINAL REPORT

by

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Research Report 1999-1F
Research Study Number 7-1999
Research Study Title: Development and Implementation of an AVI System Phase 2 - Houston

Sponsored by the
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TEXAS TRANSPORTATION INSTITUTE
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IMPLEMENTATION RECOMMENDATIONS

Urban freeways are highly susceptible to conditions that reduce roadway capacity and/or increase traffic demands that causes traffic congestion, and increased operation costs to motorists. Any procedure, technique, or traffic control that lessens the influence of capacity-reducing events and manages the increases in demands should be considered in a program to improve mobility and safety.

The operation of Phases 1 and 2 of the five phase "Real-Time Information Program" demonstrates a reliable method of monitoring traffic conditions on a freeway, toll road, and high occupancy vehicle lane (HOVL) system. The research staff recommends the automatic vehicle identification (AVI) technology be considered for implementation by TxDOT in other appropriate locations throughout the state. This recommendation is based on the following:

1. The application of Amtech Corporation's radio frequency identification (RFID) technology to measure vehicle speeds as they travel along the roadway has proven to be effective. The 95 percent read accuracy of vehicles with transponder tags provides dependable information on the condition of the roadways for the general public. The travel information can be disseminated by radio reports, roadside variable message signs, and other communication techniques (Internet, etc.).

   The acceptance and compatibility of the Amtech technology with other transportation agencies related programs increases the roadway updates by placing more tags in the travel stream. The overhead antennae/reader stations and use of telephone lines for communication minimize the inconvenience to the traveling public during installation and general maintenance.

2. The AVI technology provides cost flexibility in developing a traffic management system. The "Real-Time Information Program" introduced by the Houston District provides spacing of the antennae/reader stations at approximately 5 kilometers

throughout the system. This spacing provides a good measure of incident detection. Reducing this spacing, by adding station sites, improves incident detection and enhances the operation of the traffic management system, but increases cost. Conversely, a traffic management system with fewer stations at greater spacing reduces cost, but can still provide a beneficial traffic monitoring program.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data 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. It is not intended for construction, bidding, or permit purposes. The engineer in charge of this project was William R. McCasland, P.E. #21746.

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SUMMARY

GOAL

The goal of the project was to develop a traffic monitoring system that could be installed in a short-time range over a large network of freeways at a reasonable cost. The purpose was to provide timely information on the traffic conditions on the freeway, toll road, and high occupancy vehicle lane (HOVL) system and make this information available to the traveling public from the Houston Traffic Management Center (TranStar) by way of radio reports (traffic service companies) and roadside dynamic message signs. Motorists could then select a route or mode of travel that would reduce their travel time.

OBJECTIVES

Specific objectives of the project were to:

- provide an electronic traffic monitoring system that utilizes an automatic vehicle identification (AVI) system using radio frequency identification (RFID) technology;
- select a system compatible with other Houston area transportation agencies operating or developing similar transportation monitoring technologies;
- require that all necessary electronic field equipment be installed above the traffic to minimize the inconvenience to the traveling public;
- require that the AVI system meet operational requirements for vehicle tag read accuracy and field data transmission during a test phase;
- solicit citizen volunteers as traffic probes; and
- provide a system that can be readily expanded.

CONCLUSIONS

Amtech System Corporation, selected to provide the electronic technology for the project, continues to prove successful in achieving the requirements set forth by the TxDOT/TTI study staff during the installation and testing phases of the project.

Thirty-two hundred transponder tags were issued to citizen volunteers in Phase 2, making a total of 4,200 tags distributed in Phases 1 and 2. These volunteers act as traffic probes and contribute to the travel data collected for the program. The technology's compatibility with the Harris County Toll Road Authority's (HCTRA) automated toll collection program (known locally as the EZ tag program) provides access to over 120,000 additional vehicles with transponder tags. This number is expected to increase with the South Sam Houston Tollway now in service. Other statewide Amtech installations provide a small additional number of vehicles that contribute to the program. The success of HCTRA's EZ tag program is expected to preclude the need for additional TxDOT tags, except for special applications. This high volume of transponders is important because the more transponders that are available in the traffic stream, the more frequently the database can be updated.

The Amtech technology lends itself to system expansion not only in geographic terms, but also in adding interim reader stations to better identify incident locations.

The benefits of the AVI system are difficult to measure directly because the system's purpose is to provide information to the public so that travelers can make decisions about the route and timing of their trips. The AVI system has demonstrated that it can be a good source of information in identifying operational problems on the freeway, toll road, and HOVL system.

I. INTRODUCTION

Responding to a new direction in transportation system development in the United States under the Intelligent Transportation System (ITS), the Houston District of the Texas Department of Transportation (TxDOT), introduced the "Real-Time Information Program" (RTIP) in 1992. TxDOT contracted with the Texas Transportation Institute (TTI) to develop the necessary hardware and software systems.

The program encompasses five phases. Phases 1, 2, and 3 (Figure 1) provide coverage of the central freeway system in the Harris County area. Phase 4 provides special applications of automatic vehicle identification (AVI) for monitoring incident detection, HOV bus operations, and shuttle bus operations. Phase 5, which has not yet been approved for implementation, expands the system on the Sam Houston Tollway and provides initial installation on Beltway 8. Phases 1 and 2 were operational at the time of this report, and Phases 3 and 4 are under construction. The reader sites are identified in Figure 1.

PROGRAM PURPOSE

The purpose of the program is to measure the travel time and average speed conditions of the freeway, toll road, and HOVL roadways and to relay this information back to the public in a timely manner by way of radio reports, roadside message signs, and other communication techniques. This information enables an individual to select an alternate route, or different mode of travel, if the traveler can determine that the usual route is experiencing delay. The travel modifications would result in reduced delay for the diverted traffic and less congestion on the primary route. A TxDOT demonstration project, conducted by TTI in 1991 (1) using cellular phones to provide traffic data, proved the viability of developing real-time information systems.

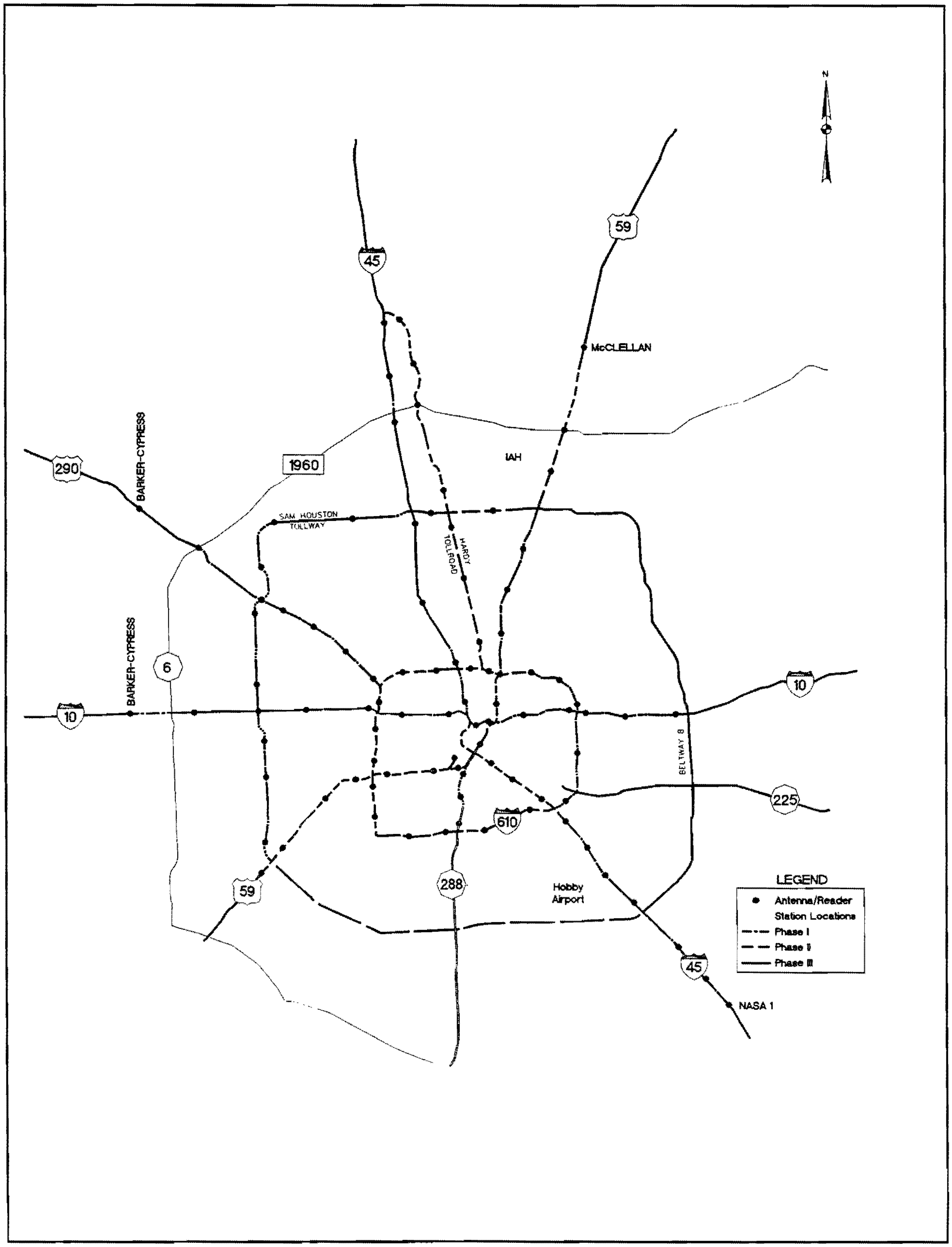


Figure 1. Automatic Vehicle Identification (AVI) System Antenna/Reader Station Location and Phase Construction

PROGRAM TECHNOLOGY

The RTIP utilizes an AVI system as one of the technologies for monitoring traffic conditions. AVI antennas and readers mounted on existing roadway structures monitor the passage of the vehicles equipped with transponder tags. A transponder tag, which is powered by a small battery, reflects encoded radio signals transmitted from the antennas/readers. The reflected signals are modified by the identification code of the tag so that the tag's information can be read by the antenna/reader system.

The antennas/readers are installed along the freeway, toll road, and HOVL system at approximately 5 kilometer intervals. The beginning stations on the radial freeways and toll road are approximately 32 kilometers from the central business district (CBD). As a vehicle with a transponder tag attached to the windshield passes the antenna/reader station, the antenna/reader activates (reads) the encoded message on the transponder tag. The message is transmitted over telephone lines to a computer in a traffic management center. The message identifies the transponder number, location of the reader, and time of day. As a vehicle passes successive AVI reader locations along a route, software determines accurate travel times and average speeds. The system design requires that field information be transmitted to the computer within one minute. This "real-time" information is then processed and formatted in tables and maps, and made available to the general public and appropriate transportation agencies.

TRAFFIC PROBES

A critical element in the development of the AVI project was the recruitment of 4,200 citizen volunteers to serve as traffic probes as they travel along the freeway, toll road, and HOVL system. By agreeing to place a transponder tag on the windshield of their vehicles, the volunteers provided the traffic data necessary for continuous updates of traffic conditions. The Phase 1 contract (I 45N, I 10W, US 290) provided for 1,000 tags and the Phase 2 contract (I 610, US 59, Hardy Toll Road, I 45S) provided for 3,200 tags. Recruitment of citizen volunteers to serve as traffic probes in the Real-Time Information Program proved to be difficult. The reluctance of citizens to place an electronic device on their vehicles was not expected by the study staff. The recruitment process, distribution of tags, and citizen response was covered in detail in the Annual Research Report (2) submitted to TxDOT in 1995, and the Phase 1 Final Report (3) submitted to TxDOT in 1996.

Tag Status

The 4,200 tags in Phases 1 and 2 had been distributed to volunteers by June 1995. A survey of tag reads to determine the number of TxDOT tags in service was first conducted for the week of July 15, 1996. The survey showed that 2,000 tags were in service for that week. The survey conducted for this report shown in Table 1, shows that this has dropped to 1,765. Researchers do not have an explanation for these reductions. Because of the increase in EZ tag reads, this reduction of TxDOT tags has not impacted the daily operation of the program. Upon completion of all phases of the program, the study staff will contact participants to determine their status in the program.

EZ Tags

The ability to read the HCTRA EZ tags when those vehicles are operating on the freeway system has greatly contributed to the success of the program. The study office did not contact the 120,000 plus EZ tag users directly to seek permission to read their tags in the Real-Time Information Program, but instead relied on the publicity generated by the news media. This resulted in several phone calls from EZ tag users expressing concern that their tags were being read without their permission. Researchers assured these individuals that their anonymity was being protected by HCTRA. They were advised that if this explanation was not satisfactory, their tag number could be masked out of the program. To date, no EZ tag user has made this request.

Probe/Tag Read Distribution

All automatic vehicle identification (AVI) tags or toll tags that utilize the Amtech technology can be read in the Real-Time Information Program. The following agencies and private companies are represented in the program:

- HCTR–Harris County Toll Road Authority;
- HJBT–J.B. Hunt Trucking Company;
- MTRO–TxDOT tags on METRO buses;
- OTA–Oklahoma Turnpike Authority;
- OTHR–All other tags (approximately 20 sources); and
- TxDT–TxDOT tags excluding METRO buses.

The following tables identify the number of probes and reads for the week of April 14, 1997, for AVI Phases 1 and 2. These tables are compared to the week of July 15, 1996, as reported in the Phase 1 Final Report (3). Table 1 identifies the total number of probes by agency/company for the week. Table 2 identifies the total number of probes by freeway and agency/company for the week. Depending on trip length and direction, an individual probe can be identified on more than one freeway. Table 3 identifies the total number of tag reads by freeway and agency/company for the week. These reads reflect the number of reader stations that an individual probe passes on a trip.

Table 1. Number of Probes on All Freeways for Week: 04/14/97 to 04/18/97 (AVI Phase 1 and AVI Phase 2)

FREEWAY	TAG TYPE						TOTAL
	HCTR	HJBT	MTRO	OTA	OTHR	TXDT	
Frequency	92,481	459	252	2,759	3,005	1,513	100,469
Percent	92.0%	0.5%	0.3%	2.7%	3.0%	1.5%	100%

Table 2. Number of Probes by Freeway for Week: 04/14/97 to 04/18/97									
			TAG TYPE						
PHASE	FREEWAY		HCTR	HJBT	MTRO	OTA	OTHR	TXDT	TOTAL
AVI Phase 1	I 10 Katy	Frequency	40,749	242	120	945	852	598	43,506
	US 290 NW	Frequency	31,588	95	31	521	431	486	33,152
	I 45 North	Frequency	33,547	201	97	1,465	1,150	524	36,984
AVI Phase 2	US 59 Eastex	Frequency	7,045	115	35	679	256	123	8,253
	Hardy Toll	Frequency	23,814	64	10	111	76	187	24,204
	I 45 Gulf	Frequency	15,822	20	55	285	252	429	16,863
	Loop 610	Frequency	55,415	340	133	1,826	2,074	1,059	60,847
	US 59 SW	Frequency	41,526	81	144	584	543	758	43,636
	Beltway 8	Frequency	10,014	22	34	121	75	111	10,377

Tag Types:

HCTR-Harris County Toll Road Authority
HJBT-J.B. Hunt Trucking Company
MTRO-TxDOT tags on METRO buses
OTA-Oklahoma Turnpike Authority
OTHR-All other tags
TXDT-TxDOT tags excluding METRO buses

Table 3. Number of Reads by Freeway for Week: 04/14/97 to 04/18/97									
			TAG TYPE						
PHASE	FREEWAY		HCTR	HJBT	MTRO	OTA	OTHR	TXDT	TOTAL
AVI Phase 1	I 10 Katy	Frequency	284,963	1,223	3,535	4,523	3,459	4,720	302,423
	US 290 NW	Frequency	328,652	514	1,364	2,884	2,160	7,349	342,923
	I 45 North	Frequency	253,737	1,385	3,373	8,189	7,057	4,848	278,589
AVI Phase 2	US 59 Eastex	Frequency	41,082	330	440	1,919	666	910	45,347
	Hardy Toll	Frequency	356,027	25	11	724	618	1,727	359,132
	I 45 Gulf	Frequency	78,331	40	2,630	812	1,429	3,229	86,471
	Loop 610	Frequency	573,551	2,355	1,266	10,909	9,635	15,099	612,815
	US 59 SW	Frequency	331,414	478	5,236	3,100	3,350	7,595	351,173
	Beltway 8	Frequency	27,983	35	93	168	167	309	28,755
	Total		2,275,740	6,385	17,948	33,228	28,541	45,786	2,407,628

Tag Types:

HCTR-Harris County Toll Road Authority
HJBT-J.B. Hunt Trucking Company
MTRO-TxDOT tags on METRO buses
OTA-Oklahoma Turnpike Authority
OTHR-All other tags
TXDT-TxDOT tags excluding METRO buses

The total number of probes from all sources for the week of April 14th was 100,469, which equals 2,407,628 total reads. This is a 46 percent increase in the number of probes and a 38 percent increase in total reads from the week of July 15, 1996. This increase is directly attributed to the increase in EZ tags (HCTRA) operating on the freeway mainlanes.

The total reads of 2,407,628 provide a tag read rate of three to six reads per minute per station during the peak hours of freeway operation and a tag read rate of three to five reads per minute per station for off-peak hours of operation. This provides an excellent measure of the operating conditions of the freeway/toll road system and exceeds the project goal of one tag read per minute during the peak hours. The HOVLs continue to operate at one tag read per two to three minutes during their periods of operation. This is considered satisfactory because of the lanes' low volume and low congestion.

FUNDING

Funding for the five phases of the program includes both state and federal funds. Phase 2 was funded through the Congestion Mitigation Air Quality (CMAQ) improvement program. This is part of a category of funds created by ISTEA. The Real-Time Information Program qualified for instrumental in determining the traffic conditions that enable the traffic and incident management systems to be adjusted to improve the quality of traffic flow, thereby reducing the traffic exhaust emissions critical to improved air quality.

II. SYSTEM DESIGN

GENERAL GUIDELINES

The project staff planned to develop a traffic monitoring system that could be quickly and easily implemented on the freeway, toll road, and HOVL system with minimum inconvenience to the motoring public.

Researchers contacted companies throughout the United States that provide AVI electronic detection systems and invited representatives to make presentations and provide material explaining their technology. TxDOT/TTI study staff established and presented the following installation and operational requirements to interested companies:

1. Antennas are to be installed above the traffic. An aboveground AVI system will utilize existing sign and roadway structures. Installation of in-pavement detection sensors is considered cost prohibitive because of the freeway lane closure requirements and resulting traffic congestion.
2. The system design must be capable of 95 percent accuracy. That is, 95 percent of vehicles equipped with transponders will be identified by the AVI system when operating at freeway conditions of high volume and high speeds.
3. The system must be responsive. The system must have the capability to transmit field data to a traffic management center within one minute after the transponder has been read.

Because electronic monitoring of transportation is a relatively new science in this country, the TxDOT selection team felt that a company with longevity and a successful track record was a crucial element in the selection process. State law permits the selection of an equipment supplier (vendor) as sole provider on this type of project upon approval of the Department of Information Research Office in Austin. The contract to install the equipment must be awarded on the basis of competitive bidding.

After review and evaluation of the companies that presented their qualifications, the team selected the Amtech Systems Corporation technology for this project.

Amtech was selected because of its experience in implementing similar systems in Texas, Oklahoma, and Louisiana with good reports from these locations. Critical to the selection was the Harris County Toll Road Authority's (HCTRA) use of Amtech technology for their toll tag program and the City of Houston Aviation Department's planned use of Amtech technology for traffic management at the two city airports. This compatibility of technologies has provided thousands of additional probe vehicles traveling the freeway mainlanes and HOVLs. As of April 1, 1997, HCTRA had issued over 120,000 toll tags.

Amtech's AVI system uses radio frequency identification (RFID) technology. The system consists of vehicle transponder tags, antennas, RF modules, and software. Transponder tags are small, battery powered, electronic devices that reflect and modify received continuous radio wave signals. Antennas broadcast and receive radio frequency signals generated by RF modules. Readers receive the signal from the antennas and RF modules, and transmit the data to a host computer located in a transportation management center. Leased telephone lines were selected to transmit the data because telephone communications provided flexibility of coverage on any freeway and allowed quick implementation of the program. To date, the use of telephone communication has been reliable.

Amtech's acceptance as provider of the technology hardware was contingent upon its system's meeting the outlined requirements in the testing phase of the contract. Amtech was responsible for providing the necessary computer software and field equipment to meet these requirements.

The computer system provided by Amtech is located in the TTI office at 701 North Post Oak Road. The system is connected to the Houston TranStar Center at 6922 Old Katy Road. TranStar is the new multi-agency transportation and emergency management center for the greater Houston area. The AVI computer system will remain at the TTI office until TTI is directed by TxDOT to move the system to TranStar.

FIELD INSTALLATION DESIGN

The freeway mainlane reader stations were mounted on roadway overpasses, overhead sign structures, and side-mount sign structures.

The roadway overpasses spanned the freeway mainlanes and permitted all three reader stations (inbound, outbound, and HOVL) to be mounted at one location. Figure 2 shows a typical roadway overpass used in this manner.

Overhead sign structures that span the freeway mainlanes were also used in this manner (Figure 3). Overhead sign structures that span one direction of the freeway mainlanes were used for mainlane directional reader stations (Figure 4).

The bi-directional reader stations for the HOVLs were mounted on roadway structures, overhead sign structures, overhead HOVL changeable message signs (CMS), and overhead HOVL lane signal structures. Figure 5 shows a CMS overhead structure used as a bi-directional reader station.

Side-mount sign structures were used for mainlane directional reader stations (Figure 6). The directional aim of the antennas at these stations was critical in order to get reads in all travel lanes (Figure 7).

ANTENNA DESIGN

In order to meet the read accuracy requirements of the program, Amtech Corporation used two types of antennas at the field read stations: the Yagi and Sinclair. Both types were used on the

Figure 2. TC Jester Overpass (I 10W)

Figure 3. Overhead Sign Structure East of W. 34th Street (US 290)

Figure 4. Overhead Sign Structure East of FM 1960 (US 290 WB Mainlanes)

Figure 5. HOVL Overhead CMS Structure (I 10 West of I 610)

Figure 6. Side-Mount Sign Structure at N. Shepherd (I 45 NB—Gulfbank Exit)

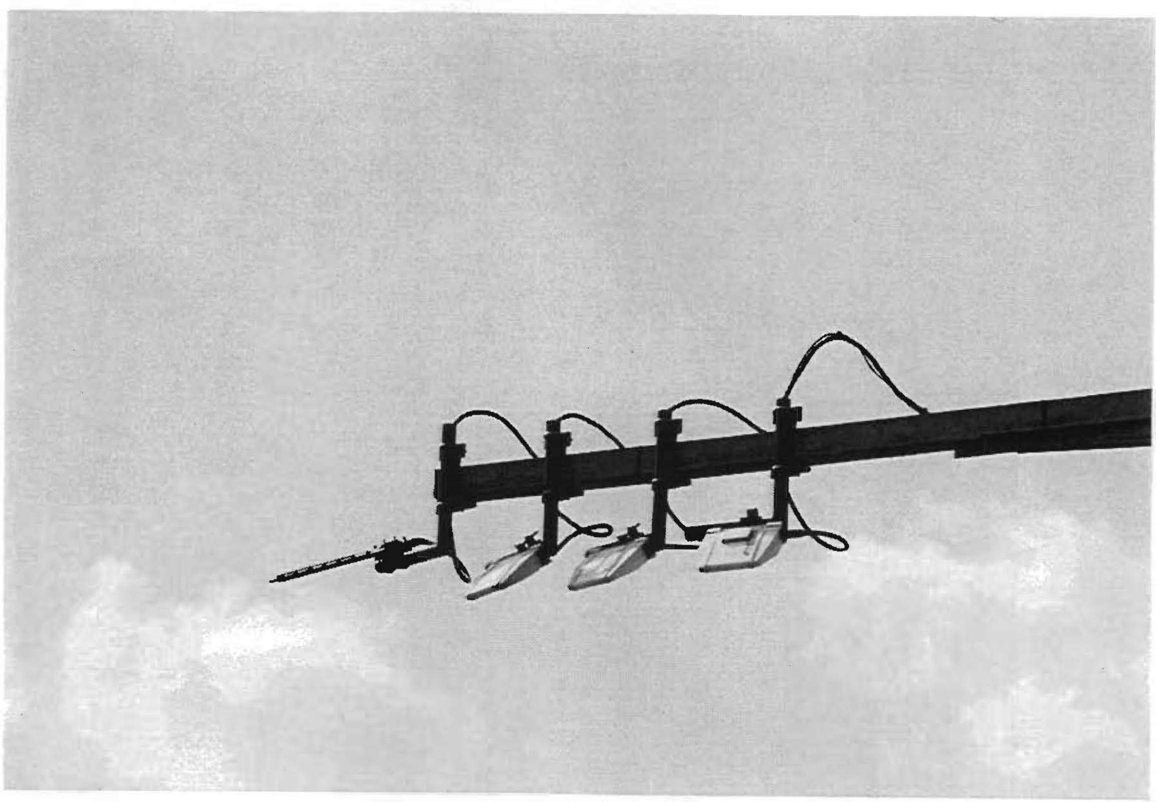


Figure 7. AVI Antennas at N. Shepherd Sign Structure

side-mount structure at North Shepherd (Figure 7). The Yagi is slenderer and longer in design than the Sinclair and is similar to a TV antenna. The Sinclair is a broader, encased type antenna.

The physical description of the two antennas also suggests their operational capabilities. The Sinclair provides a broad, but shorter field read pattern. The Yagi is more directional and provides a narrow, but longer field read pattern. The Yagi was used to provide reads on the inside lane of the freeway mainlanes and on the HOVLs. The more narrow field read patterns at these locations prevented false reads from the adjacent lanes. This provided read accuracy for both the HOVLs and the freeway inside lanes. The read patterns for a typical field station are shown in Figure 8.

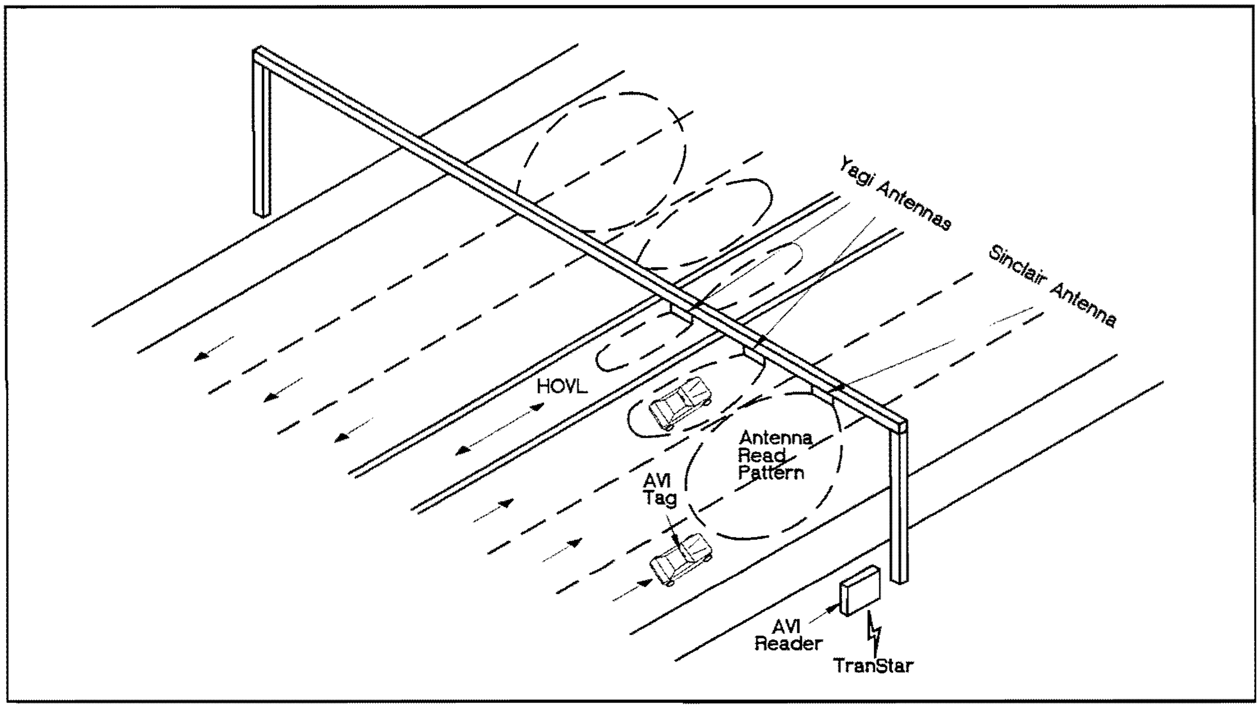


Figure 8. AVI Field Read Station

FREQUENCY OF PROBES

The AVI system is designed to sample travel conditions. Because of the time required to collect, process, and send AVI data over the leased telephone line, a one-minute interval was established as the goal for receiving updated information. During peak traffic on a four-lane freeway, one vehicle per minute with a transponder would represent less than 1 percent of the traffic volume. During daytime off-peak conditions, the percentage rises to 2 percent, and at nighttime, the percentage is much higher. Operationally, the lower volume time periods are less important than the peak periods, so the time interval between tag reads can be longer.

The strategy in both AVI Phase 1 and 2 was to target the distribution of TxDOT tags to users of the freeways and HOVLs during peak periods and to rely on tags distributed by toll roads and other agencies to supplement peak period coverage and to provide off-peak coverage. The success of the EZ tag program changed this strategy. EZ tags now provide 92 percent of the tag reads on the freeway system in a 24-hour period.

Tag Reads and Freeway Traffic Volumes

In March 1997, three freeway locations were studied to determine the daily AVI coverage and the percentage of total vehicle volume on weekdays. The tag read rate (reads per minute) for peak (6:00 a.m.-9:00 a.m.) and off-peak (9:00 a.m.-4:00 p.m.) periods for each freeway location was determined. The freeway volumes shown are 24-hour average weekday volumes for one direction of traffic and includes the peak and off-peak period volumes. The results are shown in Table 4.

Table 4. Results in March 1997

Location	Freeway Volume	Tag Reads (Total)	Tag Read (Percent)	Data Point Tag Reads	Peak Hour Read Rate (read/min)	Off-Peak Hour Read Rate (read/min)
I 610 SB at Woodway	135,325	7,650	5.7%	4,651	6.2	5.2
I 10 EB at Dairy Ashford	68,564	5,143	7.5%	3,061	4.9	2.9
US 59 NB at Edloe	121,287	4,243	3.5%	2,589	3.0	2.8

For AVI monitoring systems to be successful, the transponder tags must be read by two successive reader stations in order to measure travel times and average speeds. Two successful reads is called a "data point." If the reader stations are located several miles apart with several entrances and exits in between, many tags will be read at either the upstream or downstream reader, but not at both due to traffic entering or leaving the freeway. Some tags may not be read because of system malfunctions (the design allows for errors of 5 percent). Some vehicles may exit the freeway and then reenter sometime later. This data is filtered from the system and is discarded. Therefore, the AVI system will have many more "tag reads" than "data points." In studies at the three locations, 40 percent of the tag reads were not matched to develop data points. The "tag read rates" in reads per minute for both peak and off-peak periods are based on data point volumes.

An example of tag reads not being matched is shown in the study results in Table 4. The reader station at Dairy Ashford on I 10 shows a higher tag read percent in relation to the freeway volume than the reader station on I 610 at Woodway, but has lower tag read rates for both the peak and off-peak hours. This is a result of lower data point volumes between the Dairy Ashford station and the next eastbound station. The Sam Houston Tollway is located between these two stations. This causes the data point volumes to be reduced because of vehicles with tags exiting to and/or entering from the Tollway.

The study results indicate that the tag reads (traffic probes) are proportional to the traffic volume for each freeway and that the tag read percentage that has been obtained and the resulting tag read rate provide an excellent measure of the traffic conditions on the freeway mainlanes. The tag read rates for the peak hours of freeway operation far exceed the initial study goal of one read per minute on the high-volume freeways.

FIELD TO CENTRAL COMMUNICATIONS

Amtech was responsible for designing and installing the system that communicates the tag read records from the field reader location to the central site. This required communications between the Auxiliary Data Processor (ADP) which initially creates the tag record and the AVI host computer at the central site (Figure 9).

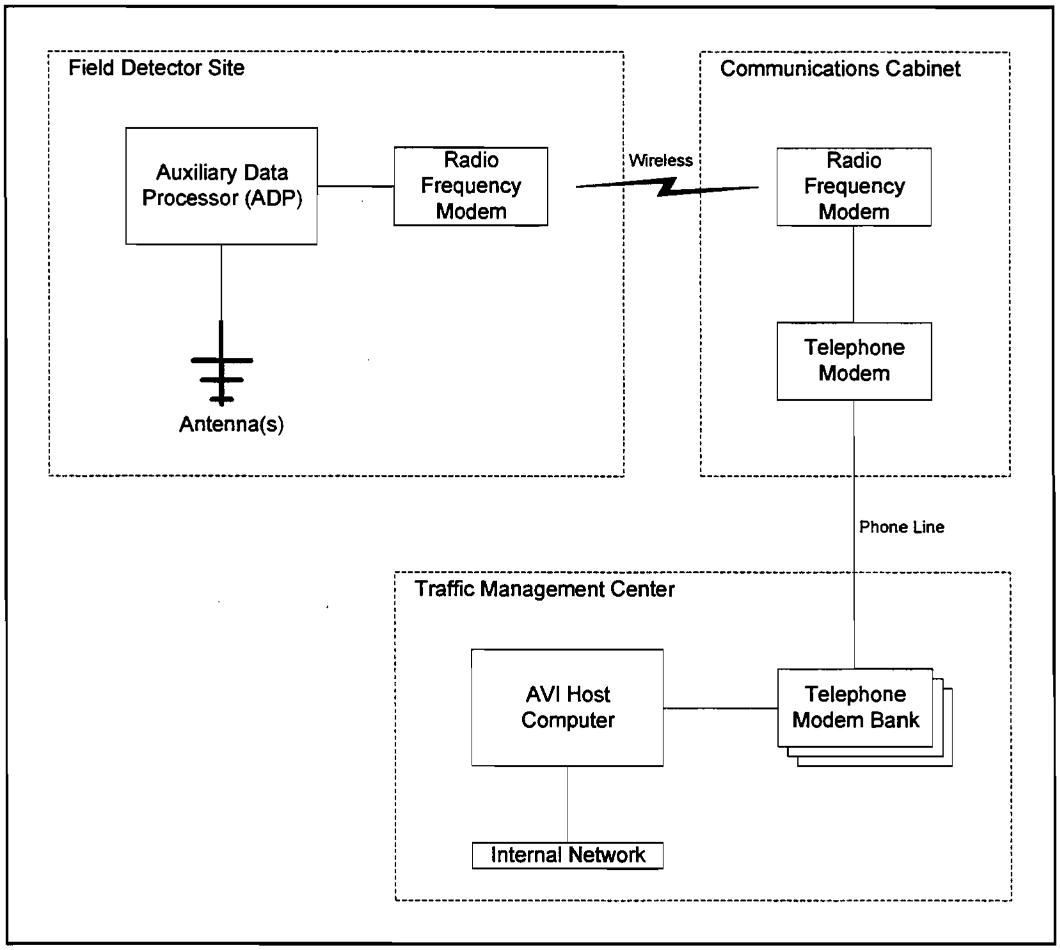


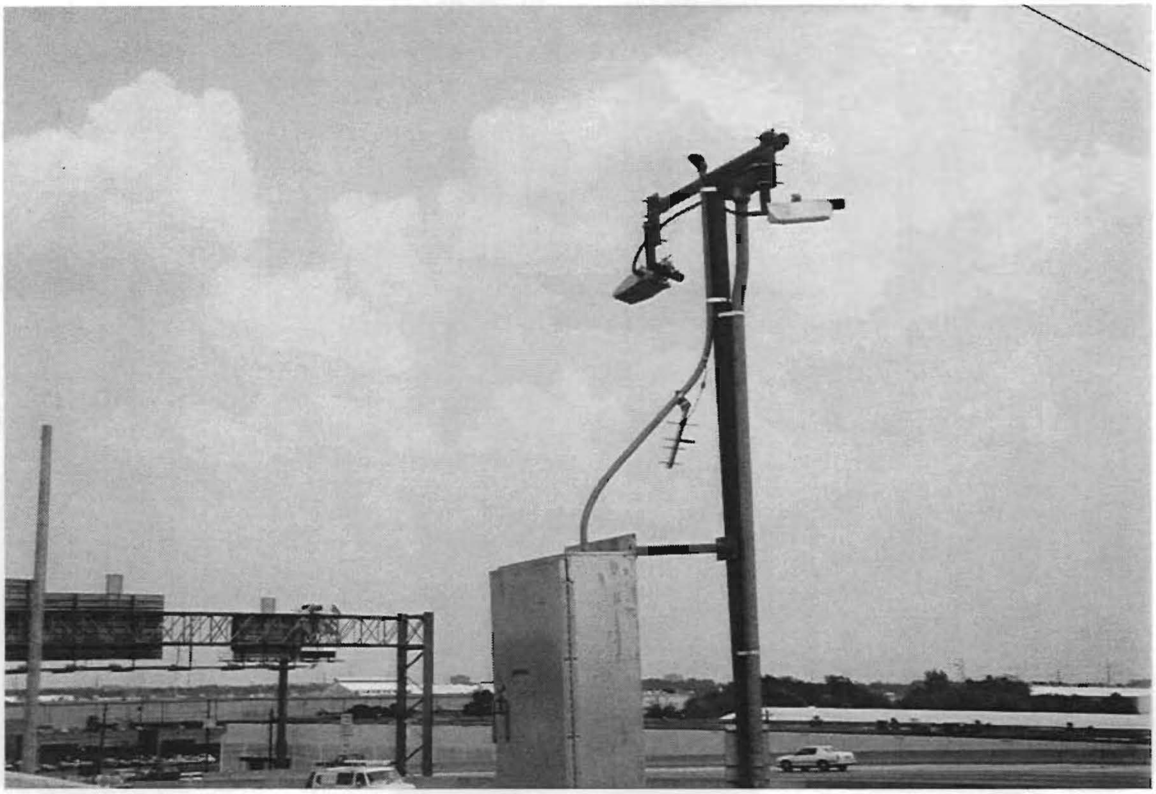
Figure 9. Field to Central Communications

Modem communication over the public switched telephone system (Southwestern Bell) is used for the primary link. Additionally, most locations use two wireless modems to communicate between the ADP located near the antennas and the telephone connection located off the right-of-way (Figure 10). The wireless connection saved installation costs by not requiring that telephone lines be installed across frontage roads.

The wireless connections use spread spectrum radio modems that do not require an FCC site license. These Proxlink brand modems provide a transparent wireless RS-232 link between the ADP and the telephone modem. These modems require line-of-site between the antennas of the two units and can operate at distances of up to 300 meters.

The telephone modem communications operate at 2400 bits per second. By utilizing the data compression that is built into the modem, the modems actually operate at a bandwidth of 9600 bits per second. One telephone line was installed at each ADP. At the central site, approximately two modems were installed for every three ADPs in the field. These central modems are grouped into a pool of modems. All ADPs dial into a central number and are forwarded to the next available line in the pool. If all lines are in use, the ADP receives a busy signal and re-dials. ADPs dial into the modem pool whenever a tag is read. The tag record, along with any other tag records that have collected during the time that the telephone connection is made, are sent to the AVI host computer. The ADP then hangs up the connection so the central line can be used by another ADP.

The specifications required that the system transmit tag reads to the AVI host computer within one minute of the time that they are read in the field. The majority of tag reads are actually received within 20 seconds. This is the time that it takes to dial, connect, and transmit the tag read to the host. If ADPs receive a busy signal, they must re-dial which adds to the time required to transmit the record. As the number of tags deployed in the system grows, the average time to transmit tag records must be monitored. If average transmission times grow too large, more modems may be added at the central site. To monitor these times, the AVIcalc software is used to periodically log the transmission time of each tag record to a file for analysis.



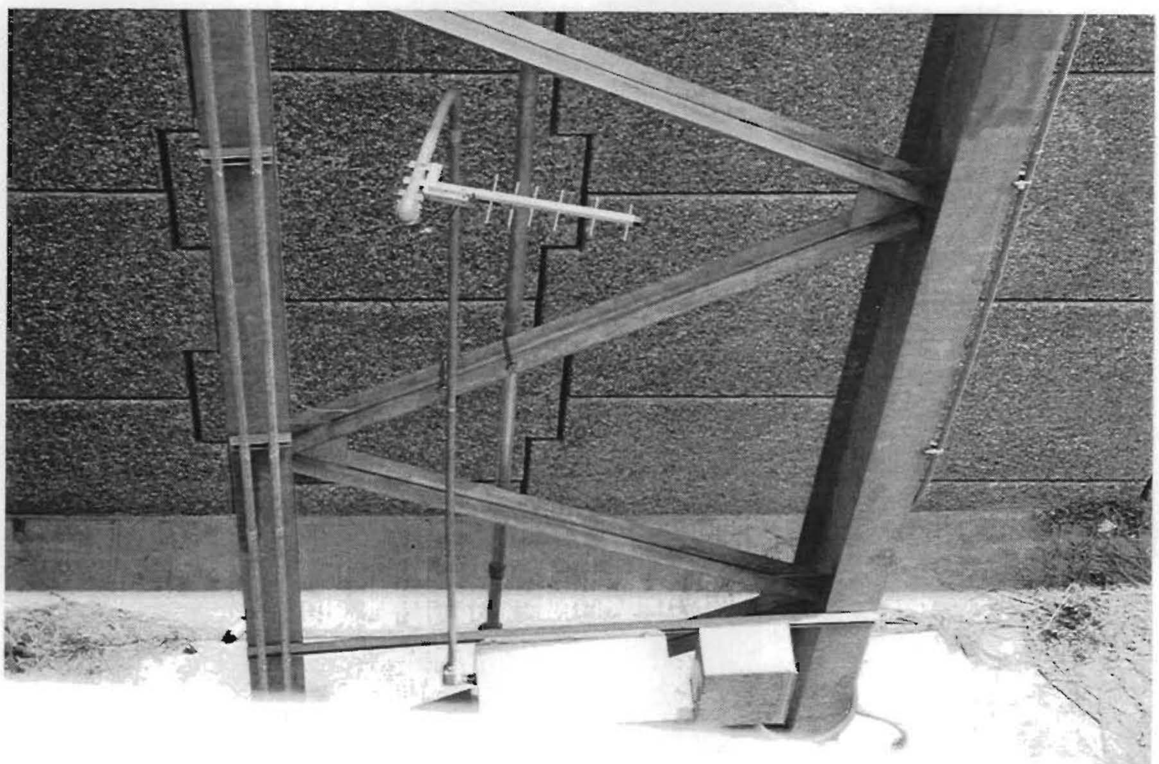


Figure 10. Wireless Modem Antennas

DATA PROCESSING SYSTEMS

Software Components

The AVI system uses various software elements to automatically gather tag data, compare tag data at successive reader locations to measure the progress of the probes along the roadways, and display the resulting data representing current travel conditions. Most software used in the system was developed specifically for use in this system, although it could be configured to work in similar AVI systems. TTI and Amtech developed separate software elements for TxDOT. Although the development tasks were segmented by function, coordination between Amtech and TTI was critical in developing software systems that correctly communicate system data. The following sections describe each software component's basic functionality. Figure 11 shows the data flow between each of these components.

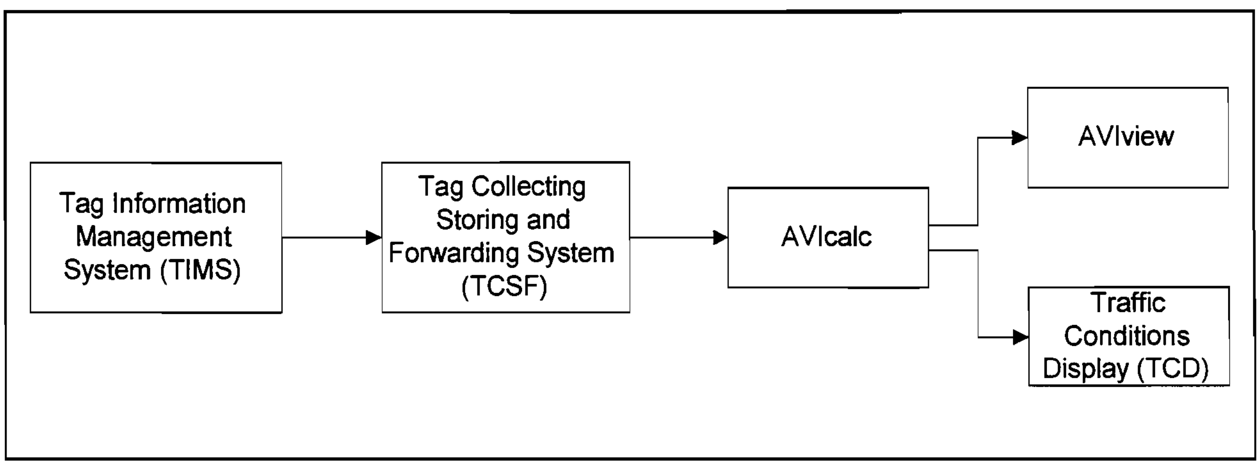


Figure 11. AVI System Data Flow

Tag Information Management System (TIMS)

At each tag reader station the ADP computer is used to recognize each tag, add a time and date stamp to the tag record, and communicate the record to the central site. Amtech used its existing tag information management system (TIMS) software within the ADPs with minor changes. TIMS is the same software used in many of Amtech's automatic toll collection facilities.

Tag Collecting, Storing, and Forwarding System (TCSF)

Amtech was responsible for providing a system to bring each tag read record from the field reader stations to a centralized point and transfer the data to the TxDOT computer systems. The computer system responsible for performing these tasks is called the AVI host computer. This host computer is a Sun SPARCstation 20 running the Solaris (unix) operating system. This computer executes Amtech's tag collecting, storing, and forwarding (TCSF) software package.

The TCSF software is responsible for processing and storing each tag read record as it is received from the ADPs. Tag information is stored within the AVI host computer within a local database, as well as on shared disk drive storage. This storage of information on the shared disk enables data access by the AVIcalc program described in the next section. The TCSF software also monitors connections to the ADPs and issues status messages if communications are lost or error messages are received from an ADP.

AVIcalc

AVIcalc is responsible for receiving tag read data from the AVI host computer (described above), processing the data to produce vehicle travel times, identifying and discarding any "bad" or "invalid" data, and forwarding this information to the AVIview programs for display.

Each time a probe vehicle passes a checkpoint in the system, a tag record is produced. Each tag record consists of the tag's identification number, the identification number of the antenna that detected the tag, and the exact date and time the tag was detected. As tag records are received from the AVI host computer, AVIcalc searches through older tag records to find when the vehicle passed the previous checkpoint. The travel time of the vehicle is calculated by determining the difference between the two tag record time stamps.

AVIcalc calculates a vehicle's average speed by dividing the measured travel time into the known distance between checkpoints. The travel time and speed data are stored in a data file on the network from which the AVIview software (described below) accesses the data for viewing. Since April 1996, AVIcalc has also stored the speed and travel time data in an Oracle relational database management system within the Houston TranStar Center. This allows the TranStar Traffic Conditions Display (described below) access to the data.

Invalid Data Screening Algorithm

One inherent problem with using AVI systems to collect travel time data is the possibility of collecting invalid data. If a probe vehicle passes a checkpoint, then stops or takes a detour before passing the next checkpoint, a travel time that is longer than the expected travel time will be reported. An algorithm is used within AVIcalc to attempt to identify this invalid data. This algorithm will only work if there are vehicles traveling the section with tags so that there will be current data to compare. The algorithm has proven successful in screening out most invalid data, given the large amount of data collected by the system. The technique and algorithm are described below.

Assume that two vehicles traveling on a section of roadway at the same time will always travel at the same speed and that no speeds are too fast. Given this, if vehicle A and vehicle B start at the same time and vehicle B finishes after vehicle A then vehicle B had to have gotten off the roadway or stopped for some period of time. Of course, we know that the two vehicles will not travel at the exact same speed, so a time buffer is introduced which will allow for the difference in their speeds. The minimum and maximum speeds of the vehicles are estimated from current conditions. From these minimum and maximum speeds, minimum and maximum travel times are calculated. The difference between these travel times should be the maximum amount of time variation between two vehicles traveling the roadway segment at the same time. If the travel time difference between vehicle A and vehicle B is greater than this buffer, then the data from vehicle B is considered invalid.

The following is the algorithm used to implement this technique using a buffer of ±20 percent.

```
get next data record (called match1)
match2 is a previous data record for the section of roadway
if (StartTime1 < StartTime2) and (EndTime1 > EndTime2) then
 begin
  TimeDif = (StartTime2 - StartTime1) + (EndTime1 - EndTime2)
  MinSpeed = 0.80 * CurrentSpeed;
  MaxSpeed = 1.20 * CurrentSpeed;
  MinTravelTime = (Dist / MaxSpeed) * 3600;
  MaxTravelTime = (Dist / MinSpeed) * 3600;
  TimeBuffer = MaxTravelTime - MinTravelTime;
  if (TimeDif > TravelBuffer) then
   read 1 is invalid
 end
```

Variable Descriptions
StartTime - time that the first checkpoint was passed
EndTime - time that the second checkpoint was passed
TimeDif - total travel time difference between vehicle1 and vehicle2
CurrentSpeed - current speed on roadway (from current AVI data)
MinSpeed - estimated minimum speed on roadway segment
MaxSpeed - estimated maximum speed on roadway segment
Dist - distance of current roadway segment
MinTravelTime - estimated minimum travel time on roadway segment
MaxTravelTime - estimated maximum travel time on roadway segment
TimeBuffer - estimated maximum allowable travel time difference between vehicle1 and vehicle2

AVIview

The AVIview program(s) takes the travel time information provided by the AVIcalc program and presents the information to a user in two formats. Data are shown in data tables that present travel times, speeds, and a historical plot of data by roadway section. A color-coded map of Houston area freeways presents average speeds, by section, for quick identification of travel conditions.

A sample map image is shown in Figure 12. The map display uses six different colors to identify speed ranges. The display shows speeds in both freeway directions as well as on the HOV lane. The two outer lines represent the freeway lanes in each direction. If three lines are present for a roadway, the middle line represents the HOV lane. Data for the HOV lane changes direction as the HOV lane operation changes direction. Roadway segments are marked as "Not Available" using a gray line if no information has been collected in the past 30 minutes.

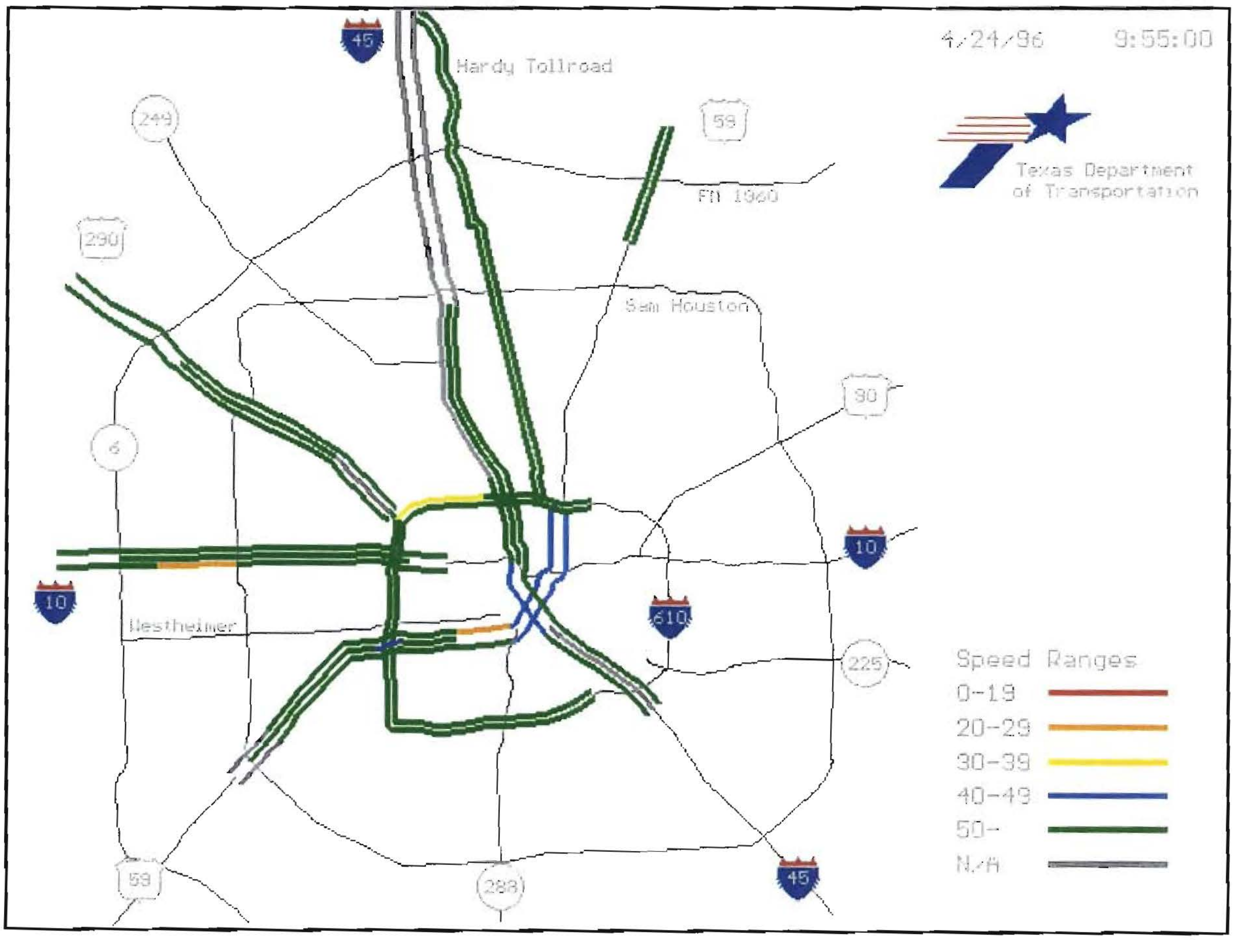


Figure 12. Sample Color-Coded Map Image

Traffic Conditions Display (TCD)

The Traffic Conditions Display (TCD) is a multi-purpose mapping system developed for the Houston TranStar Center by Lockheed Martin (formerly Loral Space Information Systems). The TCD allows traffic operators within TranStar to view travel data including the AVI data and loop detector data using a color-coded display similar to that of AVIview. The TCD also shows locations of various TranStar devices including cameras, changeable message signs, and lane control signals.

Original System Architecture

In the original system design, the AVIcalc program executed on a single IBM compatible 386DX computer connected to a Novell Netware 3.11 network. AVIcalc received information from the AVI host computer through a shared file which was accessed through the Novell Netware file server. This access was made possible by connecting the AVI host computer to the Novell Netware server using a software package called Netware NFS Gateway that allows computers connected to the Novell file server to access files on the AVI host computer.

The Netware network was also used to transmit the travel time information from the AVIcalc computer to the AVIview programs using a shared file on the Netware server. AVIview was a DOS based program that could execute on personal computers with at least a 386 processor. Figure 13 shows the network configuration and data flow of the original system.

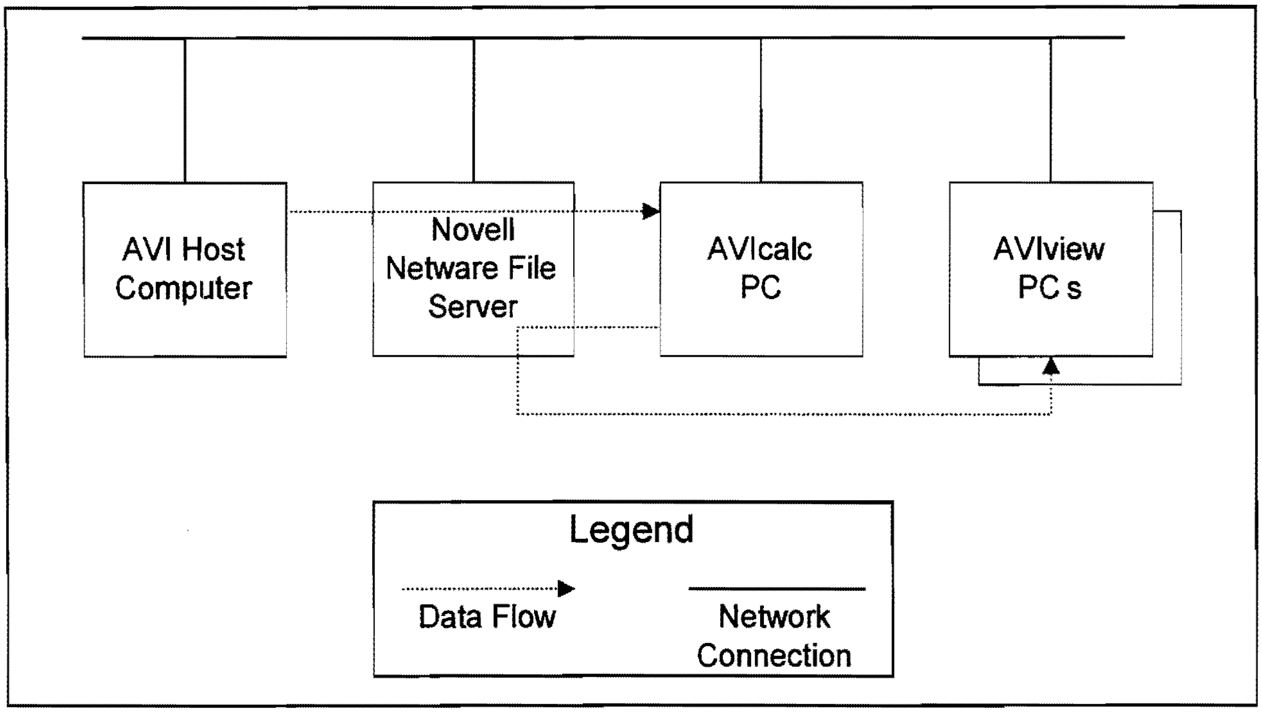


Figure 13. Original Network Setup and Data Flow

Current System Architecture

With the development of the Houston TranStar Center, there was a need to integrate the AVI system into the Houston TranStar systems that use an Oracle relational database management system instead of files to store and manage the real-time data. Utilizing this database would make sharing and management of the data much easier. TranStar includes an Integrated Traffic Management (ITM) server that is a Hewlett-Packard brand server running the HP-UX (unix) operating system. The AVIcalc program was modified to execute on the ITM server and store the travel time and speed data into the Oracle database, which also contains the general configuration data about the AVI checkpoints and roadway segments for access by AVIcalc. Software forms were developed for entering, deleting, and modifying this configuration data.

A network file system (NFS) connection is used to transmit the raw AVI tag read records from the AVI host computer to the ITM server where AVIcalc processes the information. Figure 14 shows the network configuration and data flow of the current system.

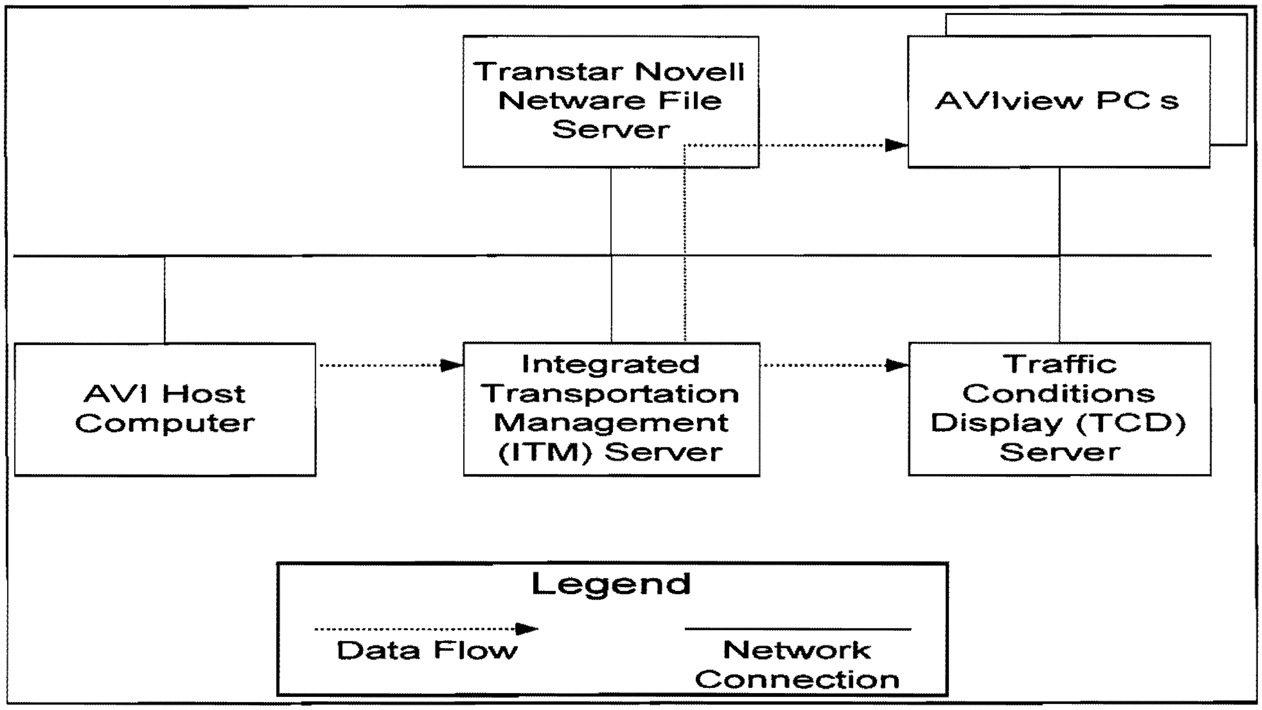


Figure 14. Current Network Setup and Data Flow

To allow TranStar operators to execute the AVIview software on the operator consoles, AVIview is currently being modified to execute as a Windows program. AVIview will be used in the future (primarily for the AVI Phase 4 project) to provide additional displays of the AVI data.

III. SYSTEM OPERATIONS

GENERAL OPERATION

The AVI system requires a limited amount of daily system operation. Some areas, though, need regular attention.

TxDOT personnel at TranStar are responsible for keeping the AVIcalc software operational on the ITM server. Normally, AVIcalc executes continuously on the ITM server with no need for operator interaction. Error and warning messages are stored in a common status log in the TranStar database. TxDOT personnel monitor this log for AVI and other messages that may need attention. TTI personnel are also on call to assist TxDOT personnel in solving problems that may occur.

TTI is responsible for the management and storage of all data collected by the AVI system. Each night at midnight, the AVIcalc program archives the raw data that has been collected that day. The data is then transmitted to a data management computer at TTI. An automated program on this computer calculates summary statistics and archives the raw data and summary data on long-term magnetic tape and CD-ROM storage.

TTI personnel are also responsible for monitoring the AVI system for field and computer equipment malfunctions detected at the central site. In addition, Amtech maintenance personnel monitor these malfunction reports and are responsible for correcting the problems. Amtech is required to correct any problem within 24 hours. Most malfunctions have dealt with communications, although there have been instances of equipment damage due to rain, ice storms, and vehicle accidents. To date, Amtech's response in correcting malfunctions has been very good.

INFORMATION DISTRIBUTION

Houston TranStar

Travel time and speed information collected by the AVI system is provided, in real time, to personnel within the Houston TranStar Center (Figure 15). TranStar personnel in the control center (Figure 16) have access to the AVI data through the traffic conditions display (TCD) on individual operator consoles. A computer with a high resolution 37" monitor that provides a continuous display of the AVI map is installed in the control center. This display provides quick viewing by control center personnel. Personnel throughout the TranStar Center can access the AVI data, by personal computer, using the AVIview program provided by TranStar's Novell Netware network.

Internet

In December of 1994, TTI developed a system that provides the AVI map display and data reports to the public through the World Wide Web portion of the Internet, the international network of computers. The site allows commuters with Internet access to view travel information at work or at home to better plan their commute. Data on the site is updated once every minute so that people get a current view of traffic conditions. The site includes a general description of the AVI system design and operation. This allows commuters and other transportation agencies around the world to learn about Houston's AVI system.

TTI's Internet server, at address *http://traffic.tamu.edu/traffic.html*, is used to serve out the AVI map. This site has been one of the most popular Internet sites in the Houston area. A front page article on the site was published in the Houston *Chronicle* on March 10, 1995, and the site has been featured in numerous local television news reports. The number of users of the site has steadily grown during the past year: 10,000 monthly users in May 1996 and 16,148 in May 1997. These 16,148 users accessed the site 231,247 times during that month.

Figure 15. Houston TranStar

Figure 16. Control Center

The system provides four views of the AVI data. The primary view is the color-coded map display, previously shown in Figure 12. The AVIview program is used to create this map and is the same map seen by TranStar personnel using the AVIview program.

Three additional features are included that allow the user to access more detailed information about roadway segments. The "clickable map" feature allows the user to select a specific roadway segment on the map display with their mouse. The system then provides them with detailed information about the roadway segment including the roadway name, the beginning and ending cross street names, the length of the segment, and the last collected travel time and average speed. A sample of this information is shown in Figure 17.

Houston Real-Time Traffic Report

You Selected The Following Roadway Segment :

Roadway	I-45 North Freeway	**Traveling**	Northbound
From	I-10	**To**	Crosstimbers
Distance		2.90 Miles	
Last Data Sample taken at		16:12:10	
Last Travel Time Sample		8 minutes, 22 seconds	
Last Speed Sample		20 mph	

Figure 17. Sample Segment Data Report

Another feature allows the user to view the detailed information in tabular format for a complete freeway that allows users to view travel time and distance information for a complete freeway so they can better plan the length of an upcoming trip. A sample of this information is shown in Figure 18. The far right column shows a graphic that is color-coded based on the speed using the same legend as the color-coded map image (Figure 12). This allows users to quickly locate problem areas.

I-45 Gulf Detailed Data

Freeway Northbound						
From	**To**	**Data Age**	**Dist (miles)**	**Travel Time**	**Speed (mph)**	.
Broadway	Woodridge	16:10:30	1.30	1:17	60	
Woodridge	Wayside	16:12:04	1.60	1:35	60	
Wayside	Scott Street	16:12:43	2.55	6:12	24	
Scott Street	I-10	16:12:00	4.20	7:56	31	

Figure 18. Sample Tabular Data Report

The detailed information, along with a description of how the system works, may help users better understand the type of data that the system collects, thus allowing them to better interpret the information.

The latest feature added to the Internet system is the Route Builder Utility. This utility lets Internet users define a route from one point in the freeway system to another using the AVI checkpoints to define the route. As users define the route, they are shown a travel report for the sections of the route and the total route. To implement the Route Builder Utility, special pairings of checkpoints were defined for the AVIcalc software to time vehicles between. These new pairs allow AVIcalc to calculate travel times of vehicles that exit from one freeway to another freeway. For example, the report in Figure 19 shows a route that proceeds northbound on the I 610 West Loop, then takes US 290 westbound.

Sensor Locations	Last Data Time	Dist. (miles)	Travel Time	Speed (mph)
I-610 West Loop Freeway, Northbound				
US-59 Southwest				
Westheimer	11:36	0.90	0:53	61
Woodway	11:36	1.80	1:50	58
I-10 Katy Freeway	11:36	1.65	1:41	58
US-290 Northwest Freeway, Westbound				
Dacoma	11:36	1.25	1:10	64
34th Street	11:35	1.10	1:06	60
Pinemont	11:36	2.45	2:20	63
Fairbanks	11:35	2.90	2:43	64
Sam Houston Tlwy	11:35	1.55	1:28	63
Route Totals :		13.60	13:11	62

Figure 19. Route Builder Report

Public Displays

Government employees and visitors may view the travel information at several remote kiosk-type displays that have been installed in the lobby areas of county, city, and TxDOT offices in Houston. The computer displays show the AVI map display for commuters as they leave the workplace.

Smart Commuter Information Delivery System

The TranStar Smart Commuter Information Delivery System (CIDS) is a Federal Highway Administration (FHWA) sponsored field operational test which is intended to disseminate real-time traffic, and static bus schedule information to 700 commuters in the I 45 North Freeway Corridor. The participants will be provided the information using two methods: (1) an interactive telephone system (ITS) to hear the information, and (2) a portable personal digital assistant (PDA) to view the information. The project is being used to evaluate the usefulness of this information in affecting commuters' driving habits, with emphasis on converting commuters to carpooling and transit.

The AVI system is the main traffic data source for the CIDS. TRW is under contract by the Metropolitan Transit Authority of Houston (Metro) to develop the computer and communication systems to provide the data to the participants. The CIDS accesses updated AVI data from the TranStar Oracle database once every 10 seconds. This data is then made available to the ITS and PDAs. When users access the ITS, they can hear voice reports of current travel times along various routes in the corridor including I 45 North Freeway and HOV, and an alternate route of the Hardy Toll Road. On the PDAs, users may view the travel times as heard on the ITS and may also view a map of the corridor that shows icons representing current roadway conditions.

Cable Access Channel

Plans are currently underway to develop a system to show the AVIview map display on the City of Houston Municipal Channel. This television channel, which is available through most Houston area cable television services, will display the travel speed map at timed intervals during peak travel hours. Persons with access to the channel can check roadway conditions before beginning their commute trip.

The system will use a remote display similar to the public displays described above at the Municipal Channel office to create the map display. A scan converter device will convert the computer graphic image to a TV signal for broadcast by the channel.

Houston Traffic/Transit Kiosk Information System

Houston TranStar is pursuing a priority corridor project that will develop and install 10 publicly accessible kiosks throughout Houston. Each kiosk system will use the AVI data to present the user with a color-coded map of freeway speeds. The kiosks will also show general information about Houston TranStar, METRO bus route information, and incident and construction conditions.

Metro SmartCar

TTI is conducting a project for the Metropolitan Transit Authority of Houston (METRO) to equip one or more METRO police cars with computer and communications systems that provide the officer access to information collected by the Houston TranStar Center. One of the main capabilities of this system will be the AVI map display on the computer screen within the vehicle. The officer will use the information to determine problem areas and the best route to approach any destination.

SYSTEM MODIFICATIONS

TranStar Communications

The Houston TranStar Center became operational during the spring of 1996. The original plan was to move the AVI system operations from the TTI offices at 701 N. Post Oak into the TranStar Center. However, the cost of moving the communications telephone lines to TranStar was greater than anticipated because the "Centrex" system used for the central phone lines would not be available at TranStar. Changes in the Texas tariff laws allowed telephone companies to stop providing this low-cost billing package to customers. Customers may keep and add lines to their existing system, but may not purchase a new system and may not move an existing system unless in the same central switching office. Unfortunately, even though TranStar and TTI's offices are only 2 kilometers apart, they are in different Southwestern Bell telephone offices.

If the change was made from the Centrex system to regular business rate telephone lines at $40 per line per month at TranStar, the communication costs for the central site would increase by $25,000 per year to operate Phases 1, 2, 3, and 4. It was decided that this system would stay at the TTI office site and an existing fiber-optic cable would be used to transmit the data to TranStar. This fiber link was made operational in March of 1996. Ultimately, the system will be moved to TranStar when other communications options become available.

Communication Migration

Currently, 35 of the 88 sites in Phases 1 and 2 are on roadways that have TxDOT owned fiber-optic communications. These sites could be moved to fiber communications that would remove 35 field telephone lines and 23 central telephone lines from the system and result in a savings of approximately $24,000 per year. To accomplish this change, a project would be developed to acquire the necessary equipment and to make the necessary installation. Changes in Amtech's TIMS software and TCSF software packages may also be required. No cost estimates of this work have been developed at this time.

INSTALLATION COSTS

Field Installation Cost

Table 5 identifies the total field installation cost for Phase 2, along with the number of reader stations, average cost per station, and average cost per freeway centerline kilometer. The contract to install the field equipment was let in November 1993. Field tests began in August 1994. The system was operational on all four freeways (I 610, US 59, I 45, Hardy Toll Road) by December 1994.

Table 5. Project Cost–Phase 2

Total Cost	$2,362,797
Freeway One Direction Reader Stations	79
HOVL Bi-Direction Reader Stations	7
Total Reader Stations	86
Average Cost Per Reader Station	$27,474
Freeway Centerline (kilometers)	157.2
Cost Per Kilometer	$15,031
Average Distance Between Stations (kilometers)	4.7

OPERATIONS/MAINTENANCE COSTS

Communications Cost

The cost of telephone lines for the system is a major operational cost of the system. The cost of maintaining the 164 telephone lines for Phase 1 and Phase 2 combined is approximately $65,000 per year, which is approximately $40 per month per line for field lines and $25 per month per line for office lines.

One telephone line is needed for each auxiliary data processor (ADP) in the field and approximately two telephone lines are needed at the central site for every three ADPs in the field. Some sites that would normally incur long distance charges for calls to the central site were priced at a higher rate, allowing them to make the calls as local calls.

Since the central telephone lines were all at one location, they could be provided as part of a "Centrex" system that averages about $25 per month per line. This saves greatly in the cost of the central telephone lines. Table 7 shows the current monthly operational costs for both the Phase 1 and Phase 2 AVI projects.

Table 6. Telephone Communication Costs

	Phase 1		Phase 2	
	Number of Lines	Cost	Number of Lines	Cost
Central Lines	*46	$1125	30	$ 765
Field Lines	36	$1535	52	$1940
Monthly Total	82	$2660	82	$2705

*Sixteen of these lines are used for non-tag communication purposes (networking and dial-in data access).

The current configuration with all four AVI phases implemented will require approximately 200 telephone lines at an annual cost of $96,000. Overhead charges increase this to $129,600 per year.

Staffing Requirements

Minimum staffing requirements are based on 0.25 man-years and provide the following services:

- Computer support staff (daily monitoring of system);
- Coordination of maintenance activities;
- Maintenance of database; and
- Administration of AVI accounts.

Estimated annual salary cost for this activity is $12,800 and includes a 60 percent overhead and fringe benefit factor. This estimate accommodates all four phases of the project.

Staffing requirements to provide enhancements to the system are based on 0.25 to 0.50 man-years and would provide the following additional services:

- Develop software modifications to enhance the system operations;
- Expand the dissemination of information by coordinating applications of the database;
- Promote the use of AVI in other transportation management applications; and
- Investigate modifications in hardware and software designs for extended use of the AVI system.

Estimated annual salary cost for this enhanced operation is $30,400 and includes the 60 percent overhead factor.

Estimated clerical support staff is 0.10 man-years at an annual cost of $3,200 with the overhead factor. This estimate applies to both the minimum and enhanced staffing cost estimates.

The total estimated salary cost for a minimum staffing operation is $16,000 per year. The total estimated salary cost that would also provide system enhancement programs is $46,400 per year.

Total Operations Cost

The total estimated operations cost for all four phases of the program is $176,000 per year. This is based on accounting procedures and rates used by TTI for contracts with TxDOT.

Maintenance Cost

The current maintenance agreement between TTI and Amtech has a monthly charge of $133 per AVI station. With the completion of the installation of Phases 3 and 4, the total number of stations in the system will be 167 for an annual cost of $266,537.

The annual maintenance contracts for the computer system for Phases 1 and 2 is approximately $1,500. For the total system, the annual cost is expected to be approximately $2,500.

Total annual maintenance cost for all four AVI phases is $269,037.

Total Annual Operations and Maintenance Cost for AVI

Based on the current design and maintenance agreements, the total annual operating and maintenance cost for the AVI system will be approximately $445,037. The total cost of installation for the four phases is $8.44 million. Therefore, the annual operating and maintenance cost represents approximately 5.27 percent of the estimated installation cost.

Summary

As noted in the staffing discussion, $30,000 is designated for improvement and enhancements to the system. These may be deleted from the analysis of requirements for operating the existing AVI system.

The communications cost of $96,000 is based on 200 leased telephone lines. Studies will be conducted on alternative forms of communication, such as connection to the TxDOT or RCTSS communication network and wireless communications. Also, an analysis on modifications to the AVI design that would reduce the communications cost will be conducted, such as reducing the number of receiving lines in the central office, storing more data at the field sites before initiating calls, collecting data from AVI stations at communication hubs for transmission to the central computer, and polling sites versus field site initiated calls.

The major cost is the maintenance of the field sites. TxDOT has a negotiated contract with Amtech to maintain all of the field equipment. The cost is based on a standard charge per month for each field station. An examination of the maintenance records may determine if there is a more cost-efficient method of contracting for this service. The use of TxDOT technicians will be considered. This may be an important factor because of the large area over which the AVI is installed. Much of the maintenance cost can be attributed to the time required to travel to each of the sites.

Although the annual maintenance cost is only approximately 5 percent of the installation costs, which would appear to be in line with other similar types of electronic systems, there are two things to consider. More than half of the cost of the system was construction costs, which included some traffic handling costs. Approximately $175,000 of the costs were for transponder tags, which are not included in the maintenance costs. Each AVI site is equipped with essentially the same electronic devices, so that the technical requirements for troubleshooting and repairs are simplified.

Finally, it should be noted that TxDOT has been supporting the operation and evaluation of the AVI systems as they has been developed and implemented over the last five years. The level of support have been approximately $250,000 per year. The funding sources for this support have been varied, including 100 percent state funds for Phase 1, CMAQ funds for Phases 2 and 3, and Priority Corridor Funds for Phase 4. TxDOT has also committed state funds to the maintenance of the field equipment.

IV. CLOSURE

SUMMARY

Implementation of the AVI traffic monitoring system presented several challenges, the foremost being to select a technology that would provide a reliable measure of the traffic flow on the freeway/toll road/HOVL system at a reasonable cost. To date, Amtech Corporation's technology is providing this reliability. The 95 percent read accuracy requirement is being met as reflected by the tag read rates of three to six reads per minute in the peak hours of operation and three to five reads per minute during the off-peak periods. The cost of $15,031 per centerline kilometer for Phase 2 is considered a relatively low cost for a traffic management system.

Reader stations were placed on existing roadway bridges, overhead, and side-mount sign structures, therefore, it was not necessary to erect any separate reader station structures. Enough existing structures were in place to meet the project goal of four to five kilometer station spacings.

The existing structures served as platforms for AVI antennas and supports for equipment cabinets. Antennas were mounted with adjustable brackets to achieve maximum reception and read accuracy.

The communication system utilizes leased telephone lines to transmit the message (reads) from the reader stations to TranStar. The communication from the reader station equipment cabinet to the telephone service drop is provided by wireless modems at most locations. This provided a cost savings in lieu of placing conduit under freeway service roads. Conversion of the lease line to fiber-optic communications is an option to be considered in the future.

The reluctance of the general public to serve as traffic probes was surprising. The concerns that the transponder tag would be used for law enforcement or that their vehicles could be traced were difficult to overcome. Project staff had to continually explain how this information could not and would not be used for that purpose.

The technology compatibility with the Harris County Toll Road Authority's (HCTRA) EZ tag toll collection program has been the major contributing factor in the increase of total reads and read rates on the freeway mainlanes. The issuance of EZ tags by HCTRA has increased threefold (40,000 to 120,000) since the AVI program began in 1993. With the recent completion of the South Sam Houston Tollway and as more EZ tags are issued, the combination toll road and freeway trips by the EZ tag user will preclude the need for the issuances by TxDOT of tags for traffic monitoring functions only.

The reduction of TxDOT tags being read on the freeway system (4,200 to 1,765) at the time of this report cannot be explained. Upon completion of all phases of the program, the study staff will try to contact participants to determine their status in the program. Some participants have contacted the study office and asked for a replacement tag because they left the tag on the windshield when they traded vehicles. This could be a major reason for the tag read reduction. Other participants may have moved away or tired of the program and have thrown their tags away. Others may have changed their trip routes.

Without the EZ tag program, it would seem that ongoing tag distribution would be necessary to maintain adequate tag reads in the program.

BENEFITS

Benefits of the AVI system are difficult to measure directly because the purpose is to provide information to the public so that they can make decisions as to the trip route or the time to start their trips. The AVI system demonstrates that it can be a good source of information about the location of problems such as stalled vehicles and accidents that cause slow speeds. Early detection of these events can save hundreds of hours of travel time for each incident.

Another benefit is the availability of true travel time information for planning and design functions. This information is historically collected one or two times per year by driving each section of roadway three or four times each peak period. The AVI system provides continuous travel time information for all peak periods, for every day of the year.

Cost constraints have limited implementation of previous methods of traffic management systems to small sections of the freeway system. This would delay implementation on some freeways as much as 10 to 15 years. The AVI system design enables a traffic management system to be implemented on the entire freeway/toll road/HOVL system in a short period of time (two to three years) at a relatively low cost (approximately $20,000 per centerline kilometer).

FUTURE PLANS

As of April 1997, AVI Phases 1 and 2 are operational and Phases 3 and 4 are being installed and are expected to be operational by June 1997. A Phase 5 is tentatively scheduled for implementation by 1998, and would expand the AVI system on the Sam Houston Tollway.

Phase 4 places additional reader stations on US 290 to reduce the spacing between stations. This section of freeway will be used to evaluate the ability to more quickly identify and better locate incidents. If this proves successful, stations may be added throughout the system.

Other applications of AVI are scheduled to be tested under the Priority Corridors Program. The main application is to use a "smarter" transponder that provides read/write capabilities and two-way communications from the roadside to the motorists. The first application will be with large trucks traveling through freeway to freeway interchanges that have reduced speed limits. The AVI system will be used to activate a warning device in the driver's compartment if the truck's speed is too high. Other applications will be investigated to provide general traffic conditions for persons that have the AVI transponders on their vehicle.

Finally, greater emphasis will be placed on the dissemination of the AVI information to the general public in forms that can be received anywhere and that can be easily understood.

REFERENCES

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