INTELLIGENT TRANSPORTATION SYSTEMS STRATEGIC DEPLOYMENT PLAN

Alternative Technologies Report

prepared for

Nevada Department of Transportation Regional Transportation Commission of Clark County, NV

by

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Section 1 - Introduction

1.1 Project Overview

The Las Vegas Valley Intelligent Transportation System (ITS) Strategic Deployment Plan Project examines the transportation needs and opportunities for ITS. This effort is led by the Nevada Department of Transportation (NDOT), the Regional Transportation Commission of Clark County and the Las Vegas Valley ITS Strategic Deployment Plan Steering Committee. Through the identification of transportation problems and needs. solutions utilizing ITS technologies will be provided in a Strategic Deployment Plan.

The Federal Highway Administration (FHWA) utilizes a ten-step process in developing a strategic deployment plan. As illustrated in Figure 1-1, the process begins by defining the existing systems with respect to the framework in which they operate and the problems they encounter. Through the usage of the ITS User Services, solutions to these problems are proposed across short-, medium-, and long-term phasings. System functionality and its framework are defined along with their implementing alternative technologies. This process concludes with a Strategic Deployment Plan and identification of deployment projects.

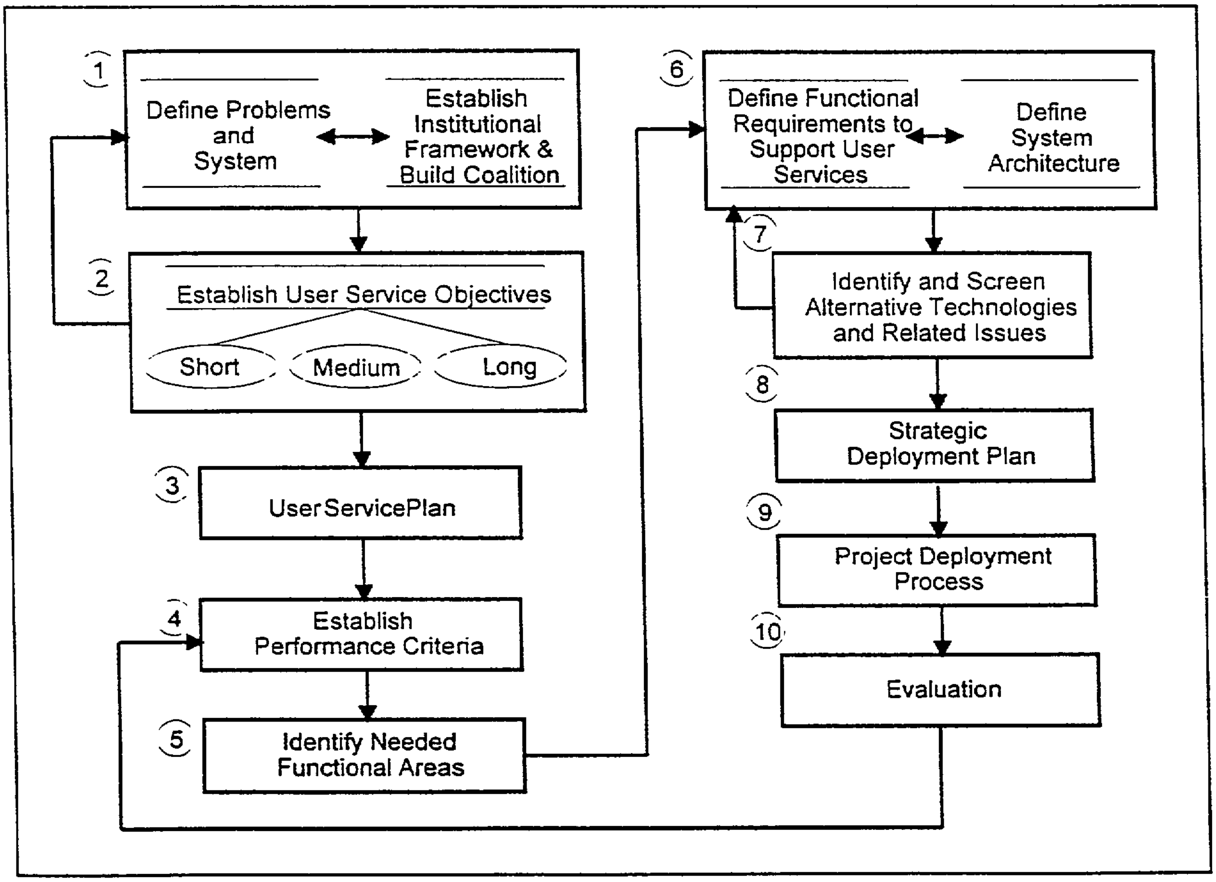

Figure 1.1-1. ITS Planning Process.

1.2 Technology Assessment Process

The Technical Memorandum *on the Functional Area Plan* described functions necessary for ITS deployment for the Las Vegas Area. By examining each alternative system configuration, the required functionality of the technology areas are described. That is, the Functional Area Plan identifies the general functions that ITS technologies provide.

The Technical Memorandum on the *System Architecture* established the framework in which different system elements interact. It defines where the functions are performed and the protocol of how each element functions within the overall framework.

This technical memorandum documents the seventh step of the ITS Planning Process -- the technology assessment. Given that we know the technology categories, what each system elements are to perform, how they connect with each other, and how users will interact with them, technology assessments are conducted. These assessments evaluate technology options which effect deployment strategies. These characteristics include performance, maintainability, life-cycle cost, expandability, compatibility, openness, and proprietariness. System components evaluated are:

- Communications
- Traveler Interface
- Navigation Guidance
- In-Vehicle Sensors
- Traffic Surveillance
- Vehicle Surveillance
- Transit Vehicle Sensor
- Routing System
- Traffic Signal Control
- Traffic Prediction Data Processing
- Signalized Traffic Control Algorithm
- Database Processing

Each assessment steps through an evaluation process which identifies alternate technologies and classifies the technologies into "proven" and "maturing".

All technologies transition from research and development into deployment Some technologies are applied to different applications and require testing. The Federal Highway Administration (FHWA) utilizes the Field Operation Test (FOT) as an ITS program delivery mechanism to evaluate technologies. Although many FOTs appear identical, each is unique and tests different technologies, different applications of technologies. and different environments. For each of the technology areas, FOTs that are relevant to Las Vegas Area and the alternative system configuration are identified and described.

Thus, each technology area section of this technical memorandum screens and evaluates technologies required to enable the alternative system configurations within the proposed Las Vegas Area system architecture. In addition. each section provides a list of FOTs that gives insight and perhaps some lessons learned for consideration prior to Las Vegas Area deployment.

This technical memorandum is intended to be a reference handbook to guide the development of the Strategic Plan and select the appropriate technology for each deployment scenario.

Section 2 - Communications Technologies

Communications technologies in Las Vegas Valley to perform 1-way mobile communications, 2-way mobile communications. and stationary communications are assessed. l-way mobile communications is classified as broadcast communications to a mobile receiver. 2-way mobile communications is interactive communications between at least one mobile transceiver. Stationary communications is communications between fixed sites.

Specific installation A major cost driver in implementing an ITS system can be attributed to the communications infrastructure and O&M costs must be analyzed along with technology bandwidth and expansion capabilities.

Bandwidth capacities directly affect the supportability of data types. Use of distributed processing techniques reduce data rate requirements considerably. However, video distribution at operational resolutions and frame rates still require equivalent bandwidths of 6-9 MHz for each video distribution channel.

The following analyses evaluate potential use of various communications technologies for digital and video data. Characteristics for evaluated technologies are compiled and then separate analyses were conducted for digital and video data types.

In the Las Vegas Valley, some examples of the existing communications system include the LVACTS traffic signal control systema using dedicated data lines to each signal location with the use of hard wire cable to interconnect each signal in the system.

2.1 Alternate Communications Technologies

Various communications technologies are evaluated to determine the most cost effective and expandable sy stem. Communications technologies and their maturity levels are shown in Table 2.1. Communications technologies more directly linked with traveler interface are discussed in section 3 of this technical memorandum.

Voice Grade Channel

Voice grade channels are currently being used to communicate between remote and central computers. At each end of the communications link resides a data modem. Modems are used to provide audio communications between hvo devices. The modem can generate either of two separate audible carrier tones. One end of the link is designated as the host (i.e. central computer when connected to remotes) and transmits one of the carrier tones and the other unit transmits on the other carrier tone. In this configuration, data can be transmitted simultaneously from both sides (full duplex). Usable bandwidth of a typical voice grade line is approximately 2700 Hz and data rates of 9600 bps and above can be achieved using various data compression and modulation techniques.

Table 2.1 Communications Technologies and Maturity Levels.

Technology	Maturity Level
Voice Grade Channel	Proven
Twisted Pair Wire	Proven
Coaxial Cable	Proven
Fiber Optics	Proven
Power Line Carrier	Proven
Packet Radio	Proven
Trunked Radio	Proven
Microwave	Proven
High speed digital line	Proven
Spread spectrum radio	Proven
Cellular Telephone	Proven

A separate connection is required for each point-to-point link. Typically, a voice grade line is connected from remote computers to the host after being routed through a regional telephone company (telco) facility. If numerous connections are returned to the host system, a line multiplexer can be used at the telco facility to reduce the number of input/output ports required at the host and to reduce operating costs. The data is multiplexed together and transmitted to the host input/output port sequentially. This approach requires special multiplexers and demultiplexers at both the telco and host facilities.

Twisted Pair Wire

Twisted pair wires can be used to provide serial connectivity in point-to-point or point-to-multipoint communications topologies. The pair of wires typically operate in a “balanced” mode such as RS-432 or RS-485. Both types of circuits provide digital communications with the pair of wires operating in opposing polarities. In other words, digital data is sensed by monitoring the voltage difference between the pair of wires. This method is highly immune to noise since the induced noise signal is seen on both wires simultaneously, however. the voltage difference between the two wires remain the same.

Differential twisted pair wires can operate at data rates up to 10 megabits per second, depending on the quality of the cable and cable length. As the length of cable increases, additional line capacitance somewhat degrades the signal properties such as rise and fall times. The maximum recommended distance between two points is 4000 feet at 19,200 bps without intermediate amplifiers or signal conditioners.

System operation using RS-422 drivers limits the communications architecture to point-to-point applications. Multiple devices cannot be connected onto one link unless special circuit isolators are used for each device. However, RS-485 drivers are tri-state (on, off, and high impedance) devices which allow multiple devices to share a single communications line. In this manner, each device is polled and the device with the matching unit address can respond. By using a round robin master-slave polling scheme. data from all of the devices on the communications line can be received. Multiplexing schemes similar to the one described in voice grade channels can aIso be used to reduce the number of wires returning to the host system.

Coaxial Cable

Coaxial cable systems, commonly known as “coax”, operate with a carrier frequency of 5-350 MHz. Data signals, either analog or digital, are modulated and transmitted along the length of the cable. Various carrier frequencies can be applied to one coax cable providing multiple channels on a single line. Typical channel bandwidths are 6 MHz and may be further subdivided for digital data transmission. Data rates of up to 7.5

MHz can be achieved based on channel subdivision. Frequency Division Multiplexing (FDM) techniques are used for channels and Time Division Multiplexing (TDM) is used for data on a channel. Various types of data can be accommodated by coax systems including digital data, voice, analog data, full motion video, and compressed video.

Several Community Access Television Channel (CATV) systems use coax as a video transmission and distribution medium. In some cases, excess CATV system capacity is available for lease from the CATV providers. The use of the excess bandwidth is beneficial since the communications infrastructure already exists; however, existing coax cable may not be easily accessible from each of the widely distributed remote computer/controller locations.

If CATV cable access is not available. the coax infrastructure can be installed by the user; however, costs of approximately $26 per foot for trenching, conduit, and installation will be incurred, excluding the cost of the cable itself.

Fiber Optics

Fiber optics communications systems use a beam of light, which is generated by a laser diode or gas laser, transmitted through a glass fiber in a serial manner. The pulses of light with wave lengths between 850 and 1550 nanometers turn on or off depending upon the logic state of the transmitted data bits. Fiber optic cables are typically bundled with multiple fibers, providing several data channels. Data rates of up to 2.1 giga bits (3.4 billion bits) per second can be accommodated by using time division multiplexing. Multiple channels of digital data can be transmitted at high speeds providing extraordinary through-put capabilities. Data can be transmitted over several miles (25 to 30 miles) and the transmission range is rarely a limitation provided communications hubs or fiber optic repeaters are installed.

Optical fibers are immune to electrical disturbances and noise. Since this technology uses no metallic conductors or shields, noise and other electrical disturbances such a magnetic fields cannot be coupled onto the optical fiber. Additionally, optical fibers with diameters as small as human hair can be used providing a small cable bundle with the capability to handle hundreds of data channels.

Many CATV subscription providers and telecommunications companies are currently installing several miles of fiber optic backbone. Spare fibers are typically available for other uses under a leasing agreement; however, not all locations have fiber optic capabilities. A dual ring communications topology usually provides redundancy and a backup data path.

Power Line Carrier

Power line carrier communications use existing AC or DC power cables as the communications medium. Advanced power line carrier equipment uses spread spectrum techniques to couple data onto power lines. The low signal levels do not effect the purity of the power line and can be operated at data rates up to 5 Mbps. Data can be transmitted at distances of up to 4000 feet provided that the entire transmission path is on the same side of a power transformer. Many metropolitan areas use multiple power transformers to reduce line losses throughout the area of coverage. Therefore, long distance communications between devices cannot be accommodated.

Packet Radio (Area Wide Radio)

Packet radio data transmission has been used over the past several years to transmit data from one point to another over a wireless medium. Various radio bands such as HF, VHF, UHF. and microwave have been used to transmit messages. Data bytes are packetized into a serial stream and transmitted using modulation techniques such as Frequency Shift Keying (FSK). Data error checking is accommodated by either firmware or by software. Data can be transmitted at rates of up to 256,000 bits per second depending on the operating frequency band and can accommodate voice, digital data, and compressed video. However, state and local government frequency bands for VHF and UHF limit the data rate to 9600 bps.

Packet transmissions may use a request-response protocol, or they may be initiated by a remote unit when there is new data to send which has exceeded a pre-defined block size. Each packet sent is acknowledged by the receiving node. Individual remote units are uniquely addressed, and can be configured to respond only when requested to do so from the master. This polled mode does induce cause extra link turn-around times since there are actually 4 transmissions required -- one request, an acknowledge of the request packet, one response, and an acknowledge of the response. The radio transmitters also have a minimum key-up time (similar to push to talk -- PTT on voice radios) of approximately 20 milliseconds before data can be sent. This reduces packet turn-around time by a small amount at 300 baud, but much larger amounts at higher data rates (a 128 byte packet with overhead takes about 3.5 seconds to send at 300 bps but only 0.46 seconds at 2400 baud). UHF frequencies can generally be obtained for use by local governments with a range of 20 to 30 miles using low power (less than 2.5 watts) units and simple antennas with a central antenna placed about 100 feet above average terrain and direct line-of-sight access.

Trunked Radio

Trunked radio service (also known as Special Mobile Radio (SMR)) operates similar to packet radio in transmitting data. However, the turn around time is significantly longer due to the method of operation of trunked radio services. Trunked radio systems multiplex 5 to 20 frequencies in a round robin fashion. One channel is allocated as a control channel and as a unit is keyed up, the control channel digitally synchronizes group identifications, and selects an available frequency for the group to use. This method allows multiple users to be assigned to an identical frequency group without disturbing operations of other users. However. the channel select sequence can take up to 0.75 seconds to synchronize.

Microwave

Microwave communications systems operate at high frequencies (928 MHz to 40 GHz) and are normally used for high speed and live video applications. Multiple channels can be supported at a microwave site of which each channel is operating at data rates of up to 7.5 Mbps depending on channel allocation. Typical uses for a microwave system include multiplexing analog voice circuits and live video. Data transmission range varies and may extend to over 30 miles depending on the frequency and environmental variables.

Microwave systems are typically used in long haul video surveillance and data transmission. The cost of one point-to-point link can be as much as $75,000. Due to the high cost of a single link, the use of microwave communication for remote-central applications is not recommended unless some method of regional multiplexing is provided to reduce the number of dedicated links back to the central facility. However, if video surveillance is required at strategic locations, the excess bandwidth of a channel can be used to transmit data from regional to central facilities.

High Speed Digital Line

High speed digital communications lines are available from most local communications providers and are available at various data rates. Data is transmitted over these dedicated lines using Pulse Code Modulation (PCM) techniques. There are many advantages to using PCM systems.

- Signals may be regularly reshaped or regenerated during transmission since information is no longer carried by continuously varying pulse amplitudes but by discrete symbols.
- All-digital circuitry may be used throughout the system.
- Signals may be digitally processed as desired.
- Noise and interference may be minimized by appropriate coding of the signals.

High speed digital lines can be used to accommodate multiplexed sfreams of serial data. Several 64 Kbps lines can be multiplexed at a central location to allow one high speed digital link between two locations. Up to twenty four 6-F Kbps lines can be time division multiplexed, sampled, and coded onto one 1.544 Mbps (also known as Tl) PCM for carrier transmission, or for further multiplexing for longer distance communications. Multiplexing schemes used to support high speed communications can accommodate input lines of varying bit rates. 64 Kbps lines can be multiplexed to one 1.554 Mbps line, and then four 1.544 Mbps lines can be multiplexed to one 6.312 Mbps (T2) line. The multiplexing of these signals allows a given transmission channel to be shared by a number of users, thus reducing costs.

By using multiplexing techniques, the number of communications lines back to each central computer can be reduced. The reduction in the number of lines can provide significant cost savings to system operations. In order to gain maximum benefit of this technique, other IVHS components should share the communications link whenever possible.

Spread Spectrum Radio

Available spread spectrum radios which operate in the 902 MHz and 74 GHz range in an FCC unlicensed mode contain the logic needed to handle nehvork protocol including relay among nodes (where required). These units are designed to work in "cells" where there is a "headend" radio connected to the central facility. one for each cell. Adjacent cells use different frequency channels and each remote controller requires a radio.

Frames are used for transmit / receive / network join functions, with a typical frame time of 1 second. During the top of frame time, the central site sends all polls, etc. to its headend radio for all controllers in the cell. The headend then initiates outbound transmission of all bundled traffic in a single packet. Each radio receives the transmission and removes the message for its controller (passing it to the controller over an RS-422 or RS-732 serial link of selected data rate). If the radio is also providing relay service for other nodes (who cannot receive the headend directly), it builds a new packet containing the messages for its "customers" and sends it. This process repeats until all radios have received outbound messages. When a response comes from a local controller, it is placed into a new packet by the radio and combined with responses from other "customers" of the radio before being sent in a burst back to the headend. The process repeats until the headend has collected all inbound messages, which are then forwarded to the central facility.

This system is similar in concept to packet radio. No additional infrastructure is required (beyond supplying power for the units). Approximately 30 nodes couId be accommodated on a single frequency.

Disadvantages include the cost of the units and the uncertainty of future use of the 902 MHz band (which could interfere with radio operation).

Cellular Telephone

Cellular telephones have been widely used for personal and business communications. Use of communicating digital information over the cellular infrastructure have increased significantly over the past two years. Cellular telephone communications is accomplished using techniques similar to trunked radio service. Several channels are available for use in the 850 MHz frequency range and is allocated to a user in a round robin fashion. However connections using cellular telephone systems can only be accomplished by dial-up techniques. Each time a connection between two devices are required, the requesting system must dial-up the remote units assigned telephone number. This interaction can take up to 15 seconds. Additionally, modems must be used in establishing a digital communication link and takes an additional 7-10 seconds.

Digital information can reliably be exchanged at rates of 9600 bits per second, and some special modems can provide 14,400 bits per second transfer rates using data compression. Charges for cellular phone use range from a standard rate of approximately 20 cents a minute (minimum of one minute). The use of cellular telephones to exchange mainline detector data is not cost effective. However, cellular telephones can be used effectively for highway advisory radio message generation and changeable message sign control.

Cellular telephone usage is not only limited as a potential for traffic management. The Cellular Telecommunications Industry Association reported that in 1993 90% of the 13 million subscribers had cellular service access to traffic information. Typically this information is provided free of charge incurring only the air time charge. In addition to being a viable dissemination method of traffic information, cellular telephone is a high volume source of incident reports and is usually a specified interface for any incident management system.

Communications Technology Summary

Table 2-1 summarize characteristics and system capabilities of the discussed communication technologies.

Table 2.1-2. Summary of Communications Characteristics.

Technology	Expansion Capability	Max. Data Rate per Channel	information Types Supported	Transmission Range	Comments
Voice Grade Channel	Additional channels can be easily added	9600 bps	Data, voice, Slow Scan N (SSTV)	Several miles (10-100 miles)	High recurring lease costs
Twisted Pair WIRE	Additional construction required	9600 bps	Data, voice, SSTV	9-15 miles w/repeaters	Construction is key cost driver
Coaxial Cable	Bandwidth available, additional construction required	7.5 Mbps	Data, voice, live video	Several miles (10-12) miles)	Construction is key cost driver
Fiber Optics	Bandwidth available, additional construction required	2.4 Gbps	Data, voice, live video	Rarely a limitation with repeaters (ZO-30 miles without repeaters	Construction is key cost driver
Power Line Carrier	Expansion limited to single side of power transformer	100 Kbps	Data, voice, SSTV compressed video	4,000 feet	Limited to single side of power transformer or 4000 ft. w/ bridge
Packet Radio	H/W expansion easily accommodated, frequencies can be added for data volume	9600 bps	Data, SSN, voice	Several miles with repeaters (30 miles without repeaters)	FCC license required for each channel used
Trunked Radio	H/W expansion easily accommodated, frequencies can be added for data volume	9600 bps	Data, SSN, voice	Several miles (25-50 miles)	Protocol used does not lend ta fast response
Microwave	Extensive construction needed for additional sites	7.5 Mbps	Data, voice, live video	Several miles, range varies (up to 30 miles)	Line of sight availability, weather, multipath sensitivity
High Speed Digital	Additional channels can be easily added	DSO 64 Kbps	Data, voice, compressed video	Several miles (10 - 50 miles)	High recurring costs
Spread Spectrum Radio	H/W expansion easily accommodated	256+ Kbps	Data, voice, SSN, compressed video, live video	Several miles (up to 50 miles)	No FCC license required

Cellular Phone	Infrastructure exists for expansion	9600 bps	Data, voice	Several miles Point-to-point	No FCC license required High recurring costs

Comparisons of the life-cycle costs for both digital data communications and video communications are provided in Figures 2-1 and 2-2.

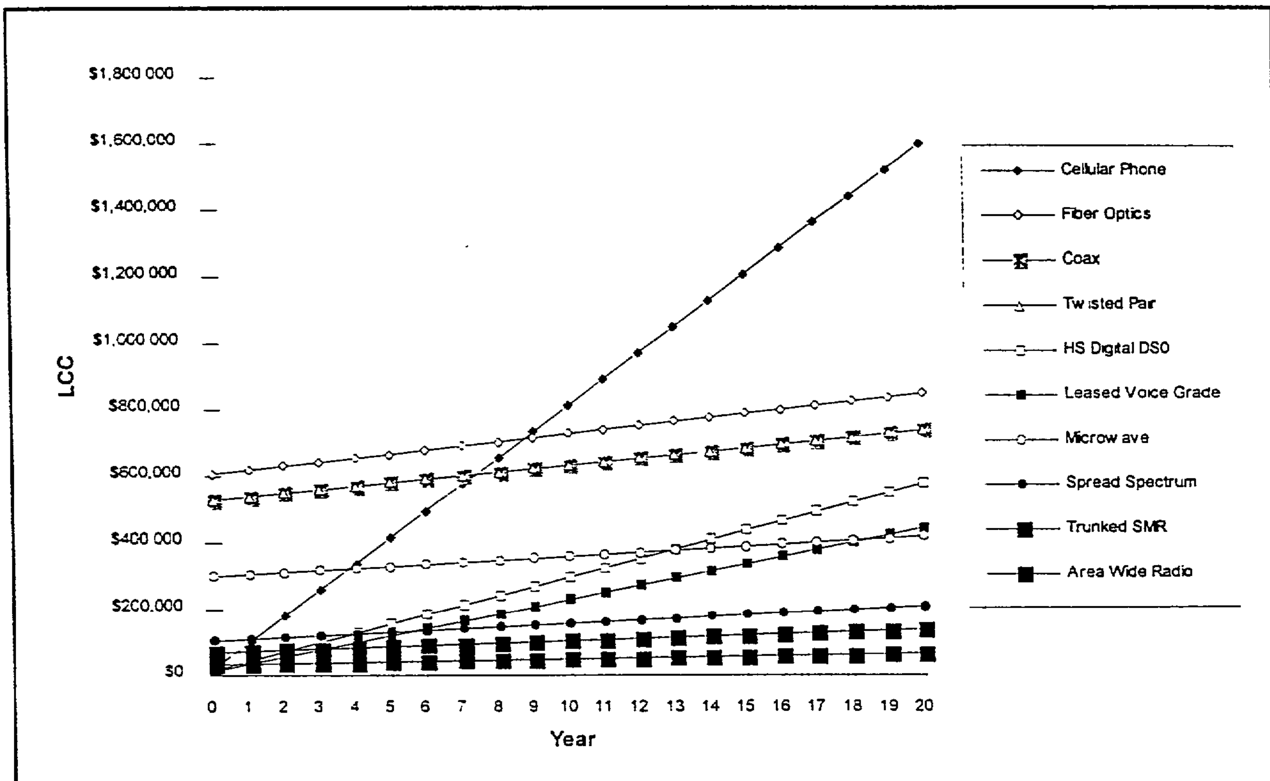

Figure 2.1-1. Digital Data Communications Life Cycle Cost Comparison

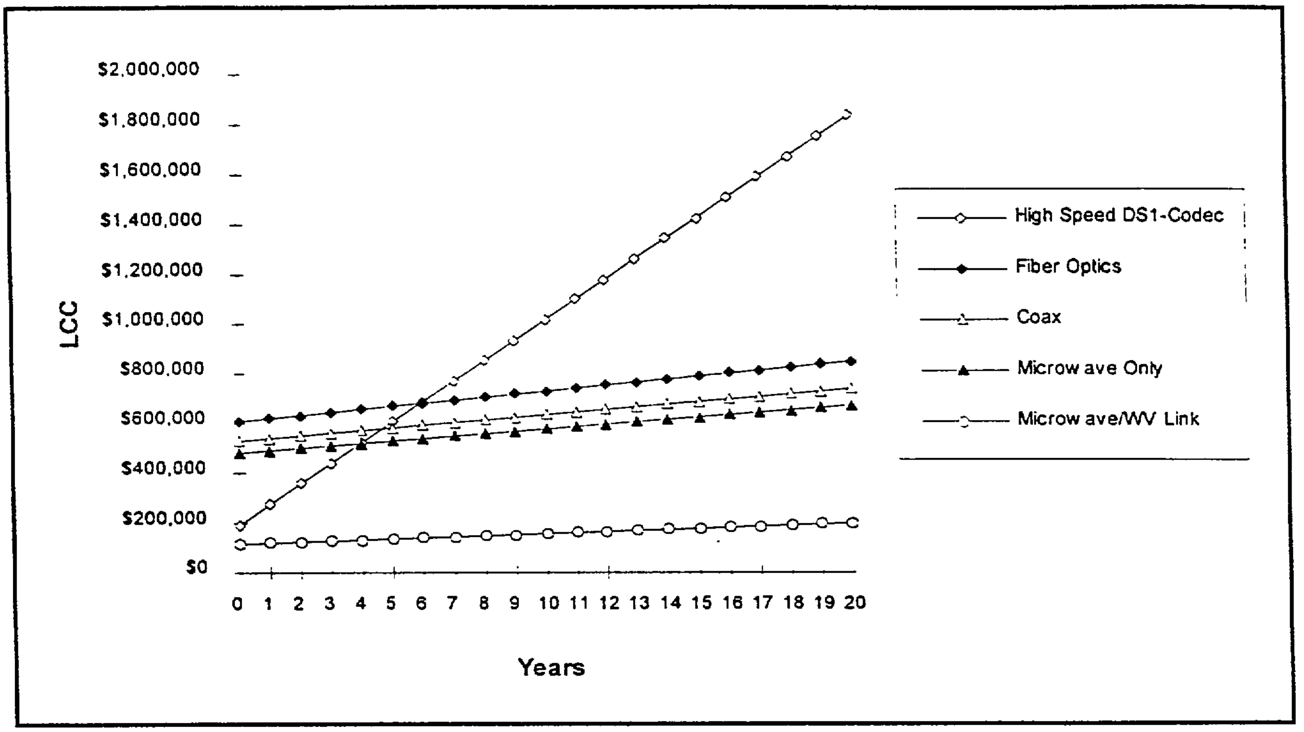

Figure 2.1-2. Video Communications Life Cycle Cost Comparison

2.2 Communications Related Field Operational Tests (FOTs)

FHWA FOTs nearly all involve some aspect of communications. Following are those FOTs that have specifically called out a communications technology. The following information is from the U.S. Department of Transportation Project Book.

Seattle Smart Traveler FOT

An FOT dealing with mobile communications is the Seattle Smart Traveler FOT located in Metropolitan Seattle. The partners involved with this project are the Federal Transit Administration (FTA). Bellevue Transportation Management Association (TransManage), University of Washington, City of Bellevue, and Washington State DOT. Its start date was October 1991 with an end date of August 1995. Its estimated total project cost is S535K.

This project examines ways in which mobile communications, such as cellular phones, and information kiosks can be used to make ridesharing (carpooling and vanpooling) more attractive and is evaluating a Traveler Information System. A set of information-based service for ridematching was developed in Phase I in cooperation with the mobile telecommunications industry in an effort to increase the use of HOV facilities. The initial focus advised private auto drivers of rideshare possibilities using mobile communications. A second phase operationally tested a prototype computer-based, interactive commuter information center in an office building in downtown Bellevue. The center provided computerized transit information, rideshare matching, and a method to schedule occasional carpool or vanpool trips. In addition to cellular telephone, the technological applications include voice mail, computer-based ridematching, traffic monitoring computers and electronic maps,

Phase I determined that there is a potential for the use of cellular telecommunications and voice mail ridesharing, although there was no incentive found for existing carpools/vanpools. It was found that 42 percent of "drive alone" commuters would consider "instant sharing." A final report of Phase I is available from FTX. Phase 11. recently completed, developed and operationally tested a prototype traveler information center at a major downtown Bellevue office complex and tested the use of pagers to assist single trip ride matching. A final report is being prepared. Phase III was selected as a part of a National ITS Operational Test Program. The project is now defining roles in relationships of the various partners. Future developments: An expanded operational test to include travelers from additional kiosk locations, additional employers and an expanded geographic coverage is a probable future development prior to deployment.

Seattle Wide-Area Information for Travelers (SWIFT) FOTs

An FOT focusing on FM subcarrier communications is the Seattle Wide-Area Information for Travelers (SWIFT) FOT located in Seattle, Washington. The partners involved with this project are Federal Highway Administration (FHWA), Washington State Department of Transportation (WSDOT). Seiko Communications Systems, IBM Corporation, Delco, Etak, Metro Traffic, King County (Washington) Metro Transit, and University of Washington. Its start date is December 1994, with an end date of December 1997. The expected total project cost is $7.2M.

This project will test delivery of traveler information via three devices: the Seiko Receptor Message Watch, an in-vehicle FM subcarrier radio, and a palm-top computer. This project will also expand service currently available under the Bellevue Smart Traveler project.

Partnership agreement signed in August 1994. Draft evaluation plan prepared in November 1994. Awaiting contractual documents between WSDOT and project partnership consortium, estimated to be completed in December 1994

Atlanta Driver Advisory System (ADAS) FOT

Another FOT dealing with FM subcarrier communications is the Atlanta Driver Advisory System (ADAS) FOT located in the Atlanta Metropolitan Area. The partners involved with this FOT are Scientific-Atlanta, Federal Express. TRW, Concord Associates, Georgia Tech Research Institute, Georgia Tech., Clark Atlanta University, Georgia DOT, Oak Ridge National Lab, and the Atlanta Committee for the Olympic Games. No specific date information was available, although an estimated total project cost is $8.6M.

The primary objective of this test is to evaluate the benefits of en-route traveler advisory and traveler services information using FM subcarrier wide area communications systems and applications of the 220 MHz frequency pairs. All elements are planned to be integrated into Atlanta's advanced traffic management system.

Herald En-Route Driver Advisory System Via AM Subcarrier FOT

An AM subcarrier communications FOT is the Herald En-Route Driver Advisory System Via AM Subcarrier FOT located in Colorado and Iowa. Sponsoring partners include Modulation Sciences (subcontractor-private) and members of the ENTERPRISE group (Departments of Transportation from the States of Arizona, Colorado, Iowa, Michigan, Minnesota, North Carolina and Washington State, and the Dutch Ministry of Transport, Ministry of Transportation of Ontario, and Transport). This project is expected to start in January 1995 and end in December 1995. Its estimated total project cost is $375K.

The main concept of this project is to disseminate important traveler information in difficult to reach, remote, rural areas using a subcarrier on an AM broadcast station. The three basic components of Herald - message generation. message transmission and message reception - have been developed under an effort by the multi-state organization called ENTERPRISE. This project will determine the performance of the system and analyze the impacts on broadcasters. travelers and equipment manufacturers. The primary objective of this test will be to assess real world impacts of the system related to transmission of traveler information in challenging terrain (Colorado) and potentially interfering environmental conditions (Iowa), improvements to safety, and the overall marketability of the system.

Berman Expressway Advanced Traffic Management Systems FOT

An FOT dealing with spread spectrum radio communications is the Borman Expressway Advanced Traffic Management Systems FOT located on the Borman Expressway (I80/94) in northwest Indiana. Involved partners include Federal Highway Administration (FHWA) and the Indiana Department of Transportation (INDOT). Its start date was July 1993, with end date scheduled for April 1995. The estimated total project cost was $1,750,000

INDOT, in conjunction with Hughes Transportation Systems/JHK/Avilla, is developing and installing a functioning prototype Advanced Traffic Management Systems (ATMS) deploying several of the more promising electronic sensors and integrating them into the prototype using spread spectrum radio communications. The equipment will be independently evaluated for dependability and cost effectiveness by Purdue University before being incorporated into the permanent ATMS that will be constructed in a later phase. The Borman ATMS will become an essential component of the Gary-Chicago-Milwaukee, Midwest Priority ITS Corridor.

Electronic sensors are being installed and Purdue University has started preliminary work on the evaluation phase.

Mobile Communications System FOT

Another spread spectrum radio communications FOT is the Mobile Communications System located in Orange County, California. The partners involved with this FOT are the California Department of Transportation (Caltrans). City of Anaheim, City of Irvine, Hughes Aircraft, CalPoly University, PATH, and FHWA. Its start date is May 1993 with a completion date of December 1996. Its estimated total project cost is $4M.

This project will test and evaluate the use of a portable detection and surveillance system for highway construction, special events, and incident locations. Specially-equipped trailers will be placed at temporary traffic congestion locations throughout Orange County. Trailer-mounted video image detectors will use spread spectrum radio for transmission of real-time information to a Caltrans control center.

Spread Spectrum Radio Traffic Interconnect FOT

Another FOT dealing with spread spectrum radio communications is the Spread Spectrum Radio Traffic Interconnect FOT located in Los Angeles, California. Involved partners include the City of Los Angeles, Hughes Aircraft. JHK & Associates, and California Department of Transportation (Caltrans). The project start date was in the summer of 1991 with a completion date for the summer of 1996. Its estimated total project cost is $3.5M.

This operational test will evaluate the use of spread spectrum radio as a naffic signal communications devices within the Los Angeles ATSAC signal system. The radios will be tested in a nehvork of signals to determine their ability to reliably reroute communications links. their ability to work in a variety of geographies, their ability to provide for large-scale once-per-second communications, and to determine the cost-effectiveness of using this technology.

"Capital" - ***Washington DC Area Operational Test***

An FOT dealing with cellular communications is the "Capital" - Washington, DC Area Operational Test located in the Washington, D.C. metropolitan area. Sponsoring partners are the Federal Highway Administration (FHWA). Virginia Department of Transportation (VDOT). Maryland State Highway Administration (MSHA), Engineering Research Associates, Bell Atlantic Mobile and Farradyne Systems Inc. The start date was August 1993 with an end date scheduled for March 1995. The estimated total project cost was $7,169,420

This ITS Operational Test makes extensive use of the existing cellular infrastructure for both areawide surveillance and communications. ERA equipment is being collocated on Bell Mobile towers to collect cellular usage and geolocate phones on designated roadways. Specific evaluation goals include to determine the: accuracy of geolocation data; accuracy in completeness of traffic information; usefulness of passive statistical processing for measuring volume and incidents; criteria for selecting roadways that can be monitored by these techniques; systems' capabilities; costs for deployment; public acceptance; and usefulness of information dissemination to fleet vehicles.

Project Northstar FO T

Another cellular communications FOT is the Project Northstar located in the states of New York, Connecticut, and New Jersey. Partners involved with this FOT are Federal Highway Administration (FHWA), NYNEX. New York State Department of Transportation, New York State Police, Metro Traffic Control, WBLS F M and Westchester County (New York). Its start date was September 1994 with an date of April 1995. Its estimated total project cost was $9.6M.

Project Northstar will integrate cellular communications, FM subcarrier communications, Global Positioning System (GPS) and pager technology to provide Advanced Traveler Information in a real-time environment. The primary goals of the project include:

Evaluating the benefits of using FM subcarrier communications, combined with cellular telephony, a portable digital assistant and speech synthesis to provide en-route driver advisories and traveler information services; and implement and assess the benefits of an emergency notification and personal security service.

DIRECT FOT

An FOT dealing with multiple Communications technologies is the DIRECT FOT located along sections of I-75, I-94 and M-10 within the city of Detroit. Sponsoring partners are the Michigan DOT, Federal Highway Administration (FHWA). General Motors, Ford, Chrysler, Delco, Ericsson/GE, AA of Michigan, Ameritech, Orbacom, TELETRAC, Metro Traffic Control, Navigation Technologies, and Whalen. Its start date was May 199 1, with an end date scheduled for April 1996. Its estimated total project costs is $5M.

DIRECT (Driver Information Radio Experimenting with Communication Technology) is a 36-month Operational Field Test that will deploy and evaluate several alternative low cost methods of communicating advisory information to motorists. These include use of the Radio Data System (RDS), television subcarrier, Automatic Highway Adv isory Radio (AHAR), Low Power Highway Advisory Radio (HAR), and cellular phones.

The Michigan Intelligent Transportation Systems (MITS) Center will collect traffic information from various sources, fuse the information and provide trafftc advisory updates to travelers on an exception basis. Initial experimental testing will involve 30 specially-equipped vehicles; subsequent testing will involve additional vehicles using conventional equipment (HAR and cellular phones).

San Antonio TransGuide FOT

An FOT dealing with fiber optics communications is the San Antonio TransGuide located in San Antonio. Texas. The partners involved with this FOT are the Texas Department of Transportation (TxDOT), AlliedSignal Technical Services Corporation, Southwest Research Institute (SwRI), Texas Transportation Institute (TTl), and Federal Highway Administration (FHWA). Its start date November 1993 with a completion date of December 1995. The estimated total project cost is $1.3M.

The TxDOT is installing the first phase of an advanced traffic management system (TransGuide) in San Antonio at an estimated cost of $33 million. Upon completion of this first project, the three story control center and twenty-five (25) miles of the one hundred ninety (190) mile proposed ATMS will be operational. TransGuide will provide:

- Complete digital communication network (voice, data, and video):
- Communication standard "SONET";
- Fully redundant fiber optic network;
- Fault tolerant computer system;
- Software developed to "POSIX" standards;
- Fully developed Central Control facility with a test-bed development computer;
- Field equipment consisting of changeable message signs, lane control signals, loop detectors, and surveillance cameras;
- Incident detection goal of 2 minutes; and,
- System response goal of under 1 minute after detection.

This Operational Test will document the San Antonio TransGuide system design rationale and goals, evaluate the system's success in meeting the design goals, and evaluate the digital communication network for cost effectiveness and benefits versus "traditional" transportation data communication systems. An additional element of this Operational Test is the on-line evaluation and comparison of several incident detection algorithms.

Satellite Communications Feasibility FOT

An FOT dealing with satellite communications is the Satellite Communications Feasibility FOT located along the I-95 in Philadelphia, Pennsylvania. Involved partners include the Federal Highway Administration (FE-WA) and Pennsylvania Department of Transportation (PennDOT). The project dates are from 1991 to 1995. The estimated total project cost is $2.2M.

This project will evaluate the use of VSAT (very small aperture terminal) satellite as the communications medium for four stationary closed-circuit television (CCTV) cameras and a mobile CCTV camera and communication platform. Specific objectives of the project are to: 1) develop and evaluate the feasibility of remote switching of multiple cameras through a single satellite channel, 2) develop and evaluate the feasibility of a mobile CCTV camera and communication platform, 3) determine the impact of weather conditions and other factors that degrade the VSAT signal integrity, 4) determine the limitation of VSAT for video surveillance by examining image clarity, pan-tilt-zoom controls and other factors associated with day-to-day CCTV freeway surveillance, 5) test the security of VSAT remote equipment with respect to vandalism and theft, and 6) compare VSAT video quality with other communications medium including leased T-l service and direct fiber optic cable.

Trilogy FOT

An RBDS FOT is the Triligy FOT located in the Twin Cities Metropolitan Area. Involved partners include the Minnesota DOT, AB Volvo, University of Minnesota, Indikta Displays, and Minneapolis Public Schools Radio. Its start date is August 199-t with an end date of September 1997. Its estimated total project cost is $4M.

The Trilogy project is part of the Minnesota statewide ITS program, Guidestar. Trilogy will provide traveler information through three different communications techniques: the Radio Broadcast Data System-Traffic Message Channel (RBDS-TMC), a FM subcarrier, and a high-speed RF subcarrier similar to STIC system. These devices will provide end users with area and route-specific en-route advisories on the highway operating conditions in the Twin Cities Metropolitan Area. The primary objective of Trilogy is to test and compare a range of user devices and evaluate the improvement in efficiency of the existing transportation network.

Section 3 - Traveler Interface

The traveler interface technologies for the Las Vegas Valley include display technologies for motorists and travelers as well as the individual traveler interfaces to information systems. Examples of potential locations for traveler interfaces the hotels and casinos along the Strip and within the downtown area. In addition, McCarran International Airport, Las Vegas Convention Center, Cashman Field, University of Nevada, Las Vegas and Las Vegas Silver Bowl Regional Park

3.1 Alternate Traveler Interface Technologies

Various traveler interface technologies were evaluated. These technology areas and their maturity levels are provided in Table 3.1-l.

Table 3.1-1. Traveler Interface Technologies and Maturity Levels.

Technology Area	Technology	Maturity Level
Broadcast Audio	AM/FM Radio	Proven
	Radio Broadcast Data System	Proven
	HAR/AHAR	Proven
	TV SAP	Proven
Interactive	Pager	Proven
	SMR/ESMR	Proven
	Kiosk	Proven
Display	LCD	Proven
	HUD	Maturing
	LED	Proven
Automated Announcement and Passenger Information System		Proven

Broadcast Audio

Broadcast Audio technologies such as the radio (AM/FM) provides one way information voice transmission using conventional AM/FM frequencies. This technology is a standard with a long technology development history, ease-of-use, and traffic information currently uses it. Traffic reports are included as part of regular programming during rush hour periods of the day and reaches a large segment of vehicles, with no additional cost for specialized in-vehicle equipment. However, it is reliant on broadcaster, is only a one way communications. and has limited information and timeliness.

Another Broadcast Audio technology is the Radio Broadcast Data System (RBDS). This technology provides information via radiotext program service displays, alternate frequency switching, and traffic announcements. An international RBDS standard has been around since 1985 with a U.S. standard since 1992. There are fewer restrictions on the programming or technical nature of the broadcast with more available frequencies and a widespread availability of low cost hardware. Long warranties exist and re repair service is readily available. If the signal becomes weak, techniques such as alternate frequency tuning are used. In addition, error detection and correction ensure reception of correct data. An example product is the RDS-X2 Data Receiver, priced at $895 with enclosure and power supply

A third Broadcast Audio technology is HAR/AHAR. HAR/AHAR provides voice transmission from broadcast to vehicIe. It includes an automatic capability to tune to AHAR channels, monitors for special transmissions, and is the ability to mute car radios for the duration of the AHAR message. The HAR/AHAR usually includes a battery backup to keep the system on the air during extended power outages. while solar power and cellular phone options allow systems to be installed in areas where utilities are not readily available. There are no direct costs to users as it uses a standard AM radio to receive signals. Analyses indicate that it more than doubles the effectiveness of using variable message signs alone as the VMSs have an average exposure time of only 9 seconds while HARs can communicate with motorists throughout the work tone and beyond.

Still another Broadcast Audio technology is TV/TV Second Audio Program (SAP) that can receive voice information in the vehicle or at fixed locations using TV SAP frequencies. In the vehicle, its characteristics are similar to current mobile radio units and requires a licensing agent for TV/ TV SAP usage. The in-vehicle units are approximately $200 usually accompanied with a monthly access fee. TV/TV SAP has stronger signals than Frequency Modulation stations and also more have better coverage. In addition, its easy to install, compatible with most AM/FM auto-stereo systems, and provides immediately accessible, regionally specific traffic information. However, it does not operate as well as RBDS receivers and requires substantial effort to create a provider data broadcast system.

Interactive

An interactive traveler interface technology is the Pager that provides text and data in non real-time via the paging network Depending upon the paging service, regional or nationwide support can be provided at costs around an initial fee $50 with monthly services of around $10. Pagers allow for text transmission as a slow - pager nenvork is definitely not real-time. However, its low cost, existing infrastructure, and widely used equipment make this technology very viable.

Another interactive traveler interface technology is SMR/ESMR providin, wide-area analog voice dispatch service. ESMR provides cellular-like mobile phone service, dispatch service, and alphanumeric paging and messaging. The SMR is an old, analog system that is used mainly for dispatching buses and taxis, while the newer ESMR is currently being tested in Los Angeles with a nationwide ESMR network planned to be built. While the cells are larger than cellular telephone cell. SMR is generally regarded as less user friendly than cellular. However, ESMR is expected to have service costs 10-15% less than cellular. Unfortunately. the equipment is not necessarily in the form desired by potential information providers and handsets are more expensive and bulkier than current cellular phones. The mobile units are priced between $400 to $1000 with small monthly service charges.

Another interactive traveler interface technology using a fixed wireline communication is a kiosk system. A kiosk system is defined to be a computer-based information system, located in public areas, with which, through an intuitive user interface. from most anonymous users, predominantly while standing and for a relatively short time, information can be recalled or transactions can be triggered. The primary goals of a kiosk are to present information on a wide range of topics using the most appropriate media, to sell products by direct ordering. to fill out an electronic form for any kind of further transactions, in order to substitute and alleviate staff at counters. For ITS applications, these include traveler information, traffic information, electronic payment, etc. Their easy installation and use are weighed a nominal $10K cost plus installation and integration and fixed location.

Using this same multimedia technology, the personal computer and cable TV perform similar functions as the kiosk system. While the communications costs of a kiosk system are often borne by the deploying agency, personal computers and cable TV require communications investments. For the personal computer, modems are usually used for data transmissions; however, for high bandwidth requirements such as video, extra investment including increased monthly communications fees may be required. The cable TV system requires the cable system connection and monthly service fees. Current application of interactive cable TV is very limited, however market tests have indicated possible consumer acceptance and pilot programs are anticipated.

Still another technology is the Personal Communications Device (PCD). These are essentially personal computers for field applications using wireless technology for transmission of data. Costs range from $400 to $1500. Portable and interactive are assets for these devices, yet models are quick to become obsolete with the rapid CPU changes making each previous version not powerful enough. The recent allocation of additional communications frequencies and manufacturer push to upgrade processing capabilities are expected to make PCDs more prevalent.

Another technology embedded in many route guidance systems is voice instructions and voice recognition. Voice instructions often augment display systems to minimize driver distraction. Voice recognition technology augment keypad of other input devices to allow drivers to enter information with minimal distraction.

Display

Display technologies include LCD screen, Heads-Up Display (HUD). and Light Emitting Diode (LED). These technologies provide displays of traveler information in terms of textual, graphical, or icon-based images. The information can be formatted in conjunction with a GIS and map database such as in a route guidance system. The LCD screens can also provide television and video display, while the HUD would project information onto windshield, and an LED would illuminate display indicators.

The display units are generally a module in a system such as route guidance, but for TV and video applications, interfaces would require NTSC compatibility. Those that interface with on-board processors such as for route guidance might standardize on a PCMCLA interface. The LCD expected reliability is to be virtually the same as comparable usage for laptop computers and televisions, with HUD reliability estimates uncertain and LED reliability remaining high. Already manufacturers such as Clarion and Sharp provide slide in/out of dash LCD display units with technology prevalence expected to provide easy access to service centers although HUD maintainability uncertain.

An entire route guidance system including display is approximately $2000. The display units should be around the $ 1000 level, while the HUD units require an interface to the dash and would add a couple hundred dollars to any system. Route guidance with visual display is marketed as a safety feature as well as for convenience punctuated by a HUD that by design allows the driver to keep his eyes on the road for more safety at a higher cost. It is reminded that car video is illegal in some states, thus television and video applications may face liability issues.

Two applications of these display technoIogies are the pathfinder and variable message signs (VMS). These systems communicate with drivers in real-time using visual words, numbers, or symbols to electronically display traffic roadway, or environmental conditions. The pathfinder signs are used to direct traffic on arterials as a congestion mitigation tool by using on/off arrow illumination with LED technology. These signs have greater than normal viewing distance and visible in poor visibility conditions.

The Variable Message Sign technology displays traveler information including decoding and display formatting. The widely deployed versions are the “flip disk” modules, while other technologies (liquid crystal, flat panel, etc.) are possible. This technology is a more accurate communication than operator announcements, and includes the ability to incorporate complex messages and graphics if beneficial to the system. Another benefit is its clear, concise graphical communications of information using clear presentation with silent operation that does not intrude on passengers. The cost is around $200 to $400 per character. less for larger signs and greater if graphics display or multi-color capability is required.

Automated Announcement and Passenger Information System

The Automated Announcement and Passenger Information System technologies can be self-contained as an all on-board system with manual triggering. These systems store pre-recorded messages, displays code for next message to operator (allows skipping and/or jumping to other locations in the sequence), allows selection of alternate message (option, manually selected), and outputs the message. This technology eliminates dependence on driver announcements but still requires driver control action. It is not reconfigurable. rendered not usable on alternate routes unless its been preprogrammed. This is an existing technology at some level. where more elaborate development requires only software in existing design mobile computers. It has proven vehicle compatible technology with minimum reliability issues. The designs are modular for field service, with low cost modules probably replaced in place of repair. The prices are variable depending on capability, probably around $500 for simple recorder and $6000 for computerized re-configurable storage versions.

Another version of the Automated Announcement and Passenger Information System technology include using GPS or another satellite navigation system to determine location and direction. These are developed, but in limited deployment. Due to the GPS or other satellite navigation system, the reliability and maintainability of these technologies are lowered. However, it does eliminate the dependence on driver announcements, ensures timely announcements, standardizes information delivered, and is operable on any route for which standard message exist. The costs for these systems are in the range of $5000 to $10000 depending on display data capacity and re-configurability options (and operator display is required).

Still another version of the Automated Announcement and Passenger Information System technology includes a beacon based location with on-board message generation. This system stores pre-recorded messages. determines location and direction using road side beacons. selects proper message, and outputs message. This is a propose. and not developed technology and is expected to cost in the range of $3000 to $5000 depending on display data capacity and options for vehicle system. The infrastructure cost depends on route. distance, and usability by other programs.

3.2 Traveler Interface Related Field Operational Tests (FOTs)

As with communications. the traveIer interface to ITS is a critical element. Following are those FHWA FOTs that specifically examine a traveler interface technology The following information is from the U.S. Department of Transportation Project Book.

Denver, CO Hogback Multi-Modal Transfer Center, I-70 West at Morrison Road FOT

A kiosk technology FOT is the Denver, CO Hogback Multi-Modal Transfer Center, I-70 West at hforrison Road FOT. This FOT is a Joint Operational Action Program Project between FHWA and the Federal Transit Authority (FTA). Partners included in this FOT are Westinghouse Electric and Jefferson County. Its start date was Xray 1993 with completion expected in September 1996. The estimated total project cost is $600K.

This unique project proposes to provide a multi-modal transfer center on I-70 near the western edge of the metro area for travelers bound for the rural recreational areas west of Denver as well as downtown Denver. Electronic methods will be used to provide real-time or near-real-time information to a Kiosk for the travelers' use. The project goals/objectives are to (1) provide a convenient, attractive, secure, and "user-friendly" parking facility for increased parking by transit users, carpoolers, and recreational users; and (2) to test Advanced Public Transportation Systems and Advanced Traveler Information Systems in a specially-designed information kiosk within 18 months of Regional Transportation District's implementation of the AVL/GPS technology. Unfortunately this FOT was suspended due to problems with the implementation of the AVL/GPS technology.

Los Angeles Smart Traveler FOT

Another kiosk technology FOT is the Los Angeles Smart Traveler FOT. Partners included in this FOT are the Division of New Technology and Research of the California Department of Transportation (Caltrans). Los Angeles Xletropolitan Transportation Authority (LAMTA), Commuter Transportation Services Inc.. California Health and Welfare Agency Data Center (HWDC), IBM Corporation, Volpe National Transportation Systems Center (VNTSC), and Federal Transit Administration (FTA). This FOT started in July 1992 and is expected to be completed by December 1995. Its estimated total project cost is $3.3M.

The Los Angeles Smart Traveler project will demonstrate access to real-time and other reliable sources of transportation information that can be used to examine high-occupancy vehicle travel options. Kiosks using audiotex and videotex will be used to provide the information which will include transit, paratransit and rideshare options. The availability of additional travel options is expected to decrease single-occupant vehicle travel by providing alternative modes of travel which are more reasonable, safe, convenient, and economical.

Audio/video text map database, and transmission line linkages were developed and installed in over 70 information kiosks. Site locations include shopping malls and public buildings. Information provided includes public transit itineraries to allow a traveler to know how to get to the intended destination. on-line ridesharing opportunities, and real-time freeway conditions in Los Angeles.

TravLink FOT

Still another kiosk technology FOT is the TravLink FOT located in Minneapolis/St. Paul, Minnesota. Partners include the Minnesota Department of Transportation, Metropolitan Council Operations. US West-3M/Renix, City of Minneapolis University of Minnesota, and FHWA. Its start date was in 1993 with an end estimated for sometime in 1996. Its estimated total project cost is $5.8M.

TravLink is a 3-year project that will implement an Advanced Traveler Information System and Advanced Public Transportation System along the I-394 corridor extending from downtown Minneapolis. approximately 12 miles to the west. TravLink will provide real-time transit schedule and traffic information through a combination of kiosks and terminals at work, home, shopping centers. and transit stations. The test is in full scale operation with data collection expected to be completed by November 1995.

Genesis FOT

A personal communications device FOT is the Genesis FOT located in Minneapolis/St. Paul, Minnesota Partners included in this FOT are the Federal Highway Administration (FHWA), Minnesota Department of Transportation (MnDOT), Motorola Center for Transportation Studies, and the University of Minnesota. Its start date was September 1992 with an end date of December 1996. The estimated total project cost is $4M.

Genesis is an advanced traveler information system (ATIS) that uses PCDs to distribute information. Timely delivery means gathering the data in real-time and distributing the data to travelers when they need it, where they need it and how they need it. Genesis is one of the principle elements in the Minnesota Guidestar integrated transportation system. With transit and traffic data, Genesis is able to provide the urban traveler with current data relevant to a chosen trip mode and route. The Genesis PCD is portable and transit information is fully accessible to the user.

Boston Smart Traveler FOT

An interactive telephone technology FOT was the Boston Smart Traveler FOT. The project contributors included the FHWA the Massachusetts Highway Department, and SmartRoute Systems. Several local radio and television stations donated advertising and promotion for the project. The FOT was started in September 1993 and completed in December 1994. Its estimated total project cost was $3M. This FOT is an example of a public/private partnership where public monies were used to jump-start a project and subsequent control granted to a private enterprise.

The project tested the public acceptance and potential traffic impacts of a telephone-based audiotext traffic information service. An independent evaluation of the project was done and the final report available. The state and FHWA determined that the project needed more time to achieve wider-scale public acceptance and the project was continued for another year with State Planning and Research (SPR) funding.

Denver, Colorado Rapid Transit District (RTD) Passenger Information Display System FOT

A transit passenger information display system technology FOT is the Denver, Colorado Rapid Transit District (RTD) Passenger Information Display System. Partners included in this FOT are the Federal Highway Administration (FHWA). Colorado Department of Transportation (CDOT), Denver RTD, and Westinghouse Electric. Its start date was September 1993 with completion expected by September 1997. The estimated total project cost is $2M.

This project will utilize the data gathered from the Automatic Vehicle Locator (AVL) system, currently being installed on all RTD buses, to provide information to video monitors at selected locations throughout the District and at selected Ecopass companies regarding estimated bus departures for waiting bus passengers.

Section 4 - Navigation/Guidance

Navigation provides information on location through the usage of a variety of competing technologies. Applications include private vehicle travel, fleet management such as for transit systems like publicly owned and operated citizen's Area Transit (CAT) system. Additionally, CAT offers a new paratransit. Service which provide on-demand service with shuttle buss for curb-to-curb transportation. CAT currently operates 171 buses with an estimated 1.5 million passengers per month.

Guidance provides routing information especially in Las Vegas with its extensive interstate and interregional travel such as its role as a I-95 alternate, along I-91 and I-84 and CVO traffic)

4.1 Alternate Navigation/Guidance Technologies

Various navigation and guidance technologies were evaluated. These technology areas and their maturity levels are shown in Table 4.l-1.

Table 4.1-l. Navigation/Guidance Technology Areas and Maturity Levels.

Technoloay Areas	Maturity Level
Satellite Based Location	Proven
Land Based Location	Proven
Inertial Navigation	Proven
Vehicle Transponders	Proven
Map Database Matching	Proven
Dead Reckoning	Proven

Satellite Based Location

One technique for automatic vehicle location is through the use of GPS. which utilizes a system of I6 earth-orbiting satellites (the complete system will include 20 satellites) to determine a vehicle's location. A GPS-based system requires that a vehicle be equipped with at least a receiver so that the vehicle can pick up the satellite signals, and calculate the vehicle location. An AVL or mayday system based on GPS would also require a transmitter to transmit the vehicle's location to a central monitoring facility.

Global Positioning System (GPS) and other satellite based locations systems are part of a broader classification of autonomous navigation systems. These technologies are used for ITS to provide position (and optionally velocity) determination from a satellite fix, plotting the position on an internal map base. display, and optionally can include route advice (where to turn based on position, remaining distance or travel time, map base information such as one-way streets). These technologies are continually being developed as well as being deployed.

Satellite-based systems allow minimum atmospheric interference with satellite signals in most cases. Concerns about shadowing from building in urban areas and signal interruptions (bridges, etc.) exist; otherwise these systems are fully self contained. These technologies are complex, but mature providing a moderate but predictable failure rate. The module replacement is typically in the field, as these expensive modules require lower level (board or component) repair with needs specialized repair personnel and equipment. The GPS-based systems benefit from a full defined GPS interface and while vehicle and operator interfaces require development. it is not perceived that standardization is required. In quantities, cost estimates are $1000 per unit.

Quite a few manufacturers offer GPS-based AVL systems, most of which are part of fleet management systems. Fleet-trac V, from Auto-Trac, employs radio-based GPS in the framework of a fleet management system. The mobile element of the system is tracked on a computerized map. Ball Systems is installing an AVL system as part of a service patrol implementation in the San Francisco Bay Area. This system is also based on existing two-way radio communications with a fleet of vehicles. Fleet-Trak AVL, from Navigation Data Systems, uses GPS plus dead reckoning for automatic vehicle location.

Chicago's ADVANCE system will test a fleet of vehicles and will also test a much larger group of private and commercial vehicles (ultimately 5,000 cars) for the second phase of the project. Montgomery County, Maryland is including GPS-based AVL for county vehicles in an ATMS system. TravLink, in Minneapolis, Minnesota, will include GPS on the region's transit vehicles. The TravTek system in Orlando, Florida used GPS and dead reckoning (sees Below) for automatic vehicle location for mayday alarms on its rental test fleet.

ORBCOMM, a location and communications system, will use its own satellites in low earth orbit to determine user position. Although the ORBCOMM system does not use GPS for vehicle location, the ORBCOMM satellites will determine their own position using GPS. Vehicle location is computed by measuring the Doppler shift on signals sent from the satellites to the users. ORBCOMM anticipates that the full satellite system (26 satellites) will be in orbit by this year. After full deployment, it is projected that most of the United States will have communications available more than 95 percent of the time.

Land Based Location

Land Based Location technologies include Beacon Based Navigation, Data Packet Based Navigation, and Pager Data Based Navigation. These technologies for ITS applications would determine the current vehicle location (including direction), compare to destination, integrate traffic data (optional but generally included). and recommend route. A limiting factor is the deployment areas as well as environmental factors such as a very short range beacon communications subject to local effects (dust or fog on infrared, magnetic interference on radio), and the area communications subject to all normal limiting factors (noise, multi-path, other sources, etc.).

Some systems are fully developed, while other technologies are under development. Still, no standard interface to infrastructure exists. While the in-vehicle equipment can be minimized, communications requirement limits the overall reliability. It is expected that the in-vehicle equipment could be a modular replacement, and that the central control equipment will be easily accessible, however, field deployed communications and/or processors (if utilized) may be difficult to access for maintenance. Various distributions of vehicle equipment versus fixed equipment complicates the cost issue. Vehicle systems from $100 to $300 are generally possible. with a potential major deployment cost of fixed sites if it can only be distributed over a minimum number of users.

KSI, Inc. is developing DFLS (Direction Finding Localization System), a system which locates vehicles using cellular telephone signals.

Pinpoint Communications, Inc. Uses radio positioning for the AVL portion of their intelligent mobile data communications network. Mobile subscribers to the network, using in-vehicle terminals, communicate with the central facility through an array of ground-based antennas. Vehicle locations are determined from the data transmissions of users.

Inertial Navigation

Inertial Navigation technology for ITS applications utilizes inertial sensors through the integration of gyro and accelerometer data to determine changes in location over time, determines change from known initial coordinates to indicate heading and distance to final desired coordinates, no map used, driver must make all route choices. In short, these technologies are used to determine attitude and acceleration, integrate to vector velocity, integrate to delta position, calculate distance and direction to destination, and then display it to the traveler. The technology is highly developed, but the required accuracy is beyond an affordable cost for most vehicle uses.

Attributes of these technoIogies are the lack of outside interfaces and usable in all areas, plus a moderate but predictable failure rate is available. Maintenance is expected to involve module replacement in the field, as these expensive modules will require lower level (board or component) repair and needs specialized repair personnel and equipment. It is noted that the operator interface requires development. Depending entirely on the accuracy required. systems with errors of 1000 feet per hour are probably obtainable for $5000 in large production quantities, while systems with very high accuracy requirements will cost much higher.

Vehicle Transponders

Vehicle transponders provide a vehicle navigation/guidance capability defined similar to the beacon-based systems. This technology can determine current vehicle location (including direction), compare to destination. integrate traffic data (optional but generally included), and recommend routes. There exists only limited development.

This technology would include minimal in-vehicle equipment with the communications requirement being the overall reliability limiting factor. The vehicle equipment could be modular replacement with the central control equipment easily accessible. The field deployed communications and/or processors (if utilized) may be difficult to access for maintenance. The system would provide accurate route guidance, minimization of travel time. and an avoidance of many of the risk areas associated with similar systems. But, like the other land based systems, there exists a potential major deployment cost of fixed sites. Vehicle equipment are expected to cost in the range of $100 to $300.

Map Database Matching

The technology of Map Database Matching use the measurement of turning and travel distance to calculate approximate route and makes a comparison with available routes to correct for errors. The systems would record the starting map position, monitor turning (or heading, etc.) and distance traveled, compare projected route to available routes in map data base, correct location to remain on viable routes (e.g., generally on a street). calculate remaining route required and provide turning directions. This is a technology that is developed and deployed. However some drawbacks include the distance and turn errors with poor road conditions or vehicle maintenance and outside route modifications (detours, etc.) that can induce hard to recover from errors (loss of route requiring manual operator reset). And although the product specific standards are developed, there exists no general industry standards.

The operational reliability is good due to the simple design, with functional reliability limited by route selection errors (system placing indicated position on wrong route requiring manual reset). The distance sensors are widely utilized and maintainable, and the other components would be simple and subject to complete module replacement. The cost is controlled by the map storage system and display costs, which are currently $500 in production quantities for a full featured system.

Dead Reckoning

The Dead Reckoning technology uses accumulated heading and distance based position changes from known initial coordinates to indicate heading and distance to final desired coordinates. There are no maps used and the driver must make all route choices. This system is not commercially used, but the basic component technology is well developed although specific applications have not been developed. It is a simple design subject to minimum failure modes, and requires maintenance only if mechanical distance sensors are used. The distance sensors are widely utilized and maintainable, while other components would be simple and subject to complete module replacement. The expected costs are very low at less than $100 in large quantities. In actual implementation, this technology would probably supplement maps if they incorporate latitude/longitude or other coordinates.

1.2 Navigation/Guidance Related Field Operational Tests (FOTs)

Many navigation/guidance FOTs have been and are being performed, especially in the area of Automatic Vehicle Location (AVL). Following are those FHWA FOTs that specifically examine the navigation and guidance technologies. The following information is from the U.S. Department of Transportation Project Book.

Nothern Virginia Integrated Route Deviation/Fixed Route FOT

One satellite based location FOT is the Northern Virginia Integrated Route Deviation/Fixed Route FOT. Partners in this FOT include the Potomac Rappahannock Transportation Commission (PRTC). Northern Virginia Planning District Commission, Virginia Department of Rail and Public Transportation (VDRPT). Gandalf Mobile Systems. UMA Engineering, SG Associates, Federal Transit Administration (FTA), and Federal Highway Administration (FHWA) Its start date was in January 1994 with an date scheduled for July 1996. The expected total project cost is $3.2M.

This FOT will evaluate an enhanced, ridesharing-route deviation transportation system integrated with conventional transit and ridesharing in the Northern Virginia suburbs of Washington, D.C. including Prince William and Stafford Counties. The system will provide on-demand service through an audiotex request system which uses scheduling software similar to the taxi industry. Depending on the needs and preferences of the system user, door-to-door transportation would be provided using both public and privately owned vehicles operated by paid volunteer drivers using vans, minibuses, specialized public vehicles, fixed-route buses, and taxicabs. Users would be charged a standard per-mile rate regardless of the type of vehicle used. System cost not recovered by these fares would be covered by local agencies. Smart cards will be used to process transactions. It is hypothesized that this service could be provided at a much lower cost than conventional transit service. It is expected that a dispatch center will be established and 50 vehicles will be equipped. Technologies are expected to include Automatic Vehicle Location (AVL) and Global Positioning System (GPS) satellites, interactive cable TV, and electronic bulletin boards.

ADVANCE FOT

Another GPS technology FOT is the ADVANCE FOT in the northwest suburbs of Chicago, Illinois. This FOT includes the Illinois Department of Transportation (IDOT), Motorola Inc., Illinois Universities Transportation Research Consortium (IUTRC), American Automobile Association and Federal Highway Administration (FHWA). It started in July 1991 and will continue until December 1997. The estimated total project cost is $52M.

ADVANCE (Advanced Driver and Vehicle Advisory Navigation Concept) is a cooperative effort to evaluate the performance of the first large-scale dynamic route guidance system in the United States, At least 3,000 private, commercial and public agency vehicles in the northwestern suburbs of Chicago will be equipped with in-vehicle navigation and route guidance systems. Vehicles will serve as probes, providing real-time traffic information to a Traffic Information Center. This information will be processed and then transmitted to the equipped vehicles and used to develop a preferred route. The routing information will be presented to the driver in the form of dynamic routing instructions.

Unfortunately the vast deployment aspect of this project appears to be delayed if not canceled. It was anticipated that the large number of probe vehicles would finally validate analysis indicating requirements of 1-2% vehicle penetration for adequate coverage.

FAST- TRAC FOT

A land based location FOT is the FAST - TRAC FOT in Oakland County, Michigan. Partners included in this FOT are the Federal Highway Administration (FHWA), Michigan DOT, Siemens Automotive, GM, Ford, Chrysler, Road Commission for Oakland County (RCOC), County of Oakland, AWA Traffic System - America, and the University of Michigan. The project began in April 1992 and ends in January 1996. The estimated total project cost $70M.

FAST-TRAC (Faster and Safer Travel through Traffic Routing and Advanced Controls) will combine Advanced Trafftc Management Systems and Advanced Traveler Information Systems technologies in Oakland County Michigan. The Australian SCATS traffic adaptive control system will be installed throughout Oakland Count);, Michigan. Traffic detection for real time traffic control will be provided using Autoscope video image processing technology. For the Advanced Traveler Information Systems part of the test, vehicles will be equipped with the Siemens Ali-Scout route guidance and driver information system. Infrared beacons will be installed at critical locations in the network to provide for a continuous exchange of real time traffic and route guidance information. A Traffic Operations Center has been established. not only as the heart of FAST-TRAC operations. but also as the focus for systems integration.

Two hundred intersections are under SCATS control with 120 more anticipated to be in operation by December 1995. Testing of the Ah-Scout system has begun with 40 beacons now in place, and 60 more anticipated to be operational by December 1995.

Montgomery County Advanced Traffic Management System FOT

One of many FOTs investigating the Automatic Vehicle Location (AVL) technology is the Montgomery County Advanced Traffic Management FOT located in Montgomery County, Maryland. Partners included in this FOT are the Federal Highway Administration (FHWA), Montgomery County Office of Traffic, Montgomery County Transit, Maryland State Highway Administration (MSHA), Orbital Sciences Corporation, Automatic Signal/Eagle Signal, and RGA Inc. The start date was September 1994 with completion expected by September 1996. The estimate total project cost is $1.6M.

This project will enhance Montgomery County's ATMS to provide integrated transit and traffic capabilities. The system will include an AVL equipped bus fleet, intelligent in-vehicle units, two-way communications, real-time graphics, relational database, monitoring, and control software, transit priority and system information dissemination.

Santa Clara County Smart Vehicle FOT

Another AVL FOT using GPS technology is the Santa Clara County Smart Vehicle FOT located in Santa Clara County, California. Partners included in this FOT are the Division of New Technology and Research of the California Department of Transportation (Caltrans), Santa Clara County Transportation Authority, Outreach Paratransit Broker, Trimble Navigation, UMA Engineering, Navigation Technologies, Volpe National Transportation systems Center (VNTSC), and Federal Transit Administration (FTA). The start date is November 1993 with completion by October 1995. Its estimated total project cost is $850K.

This project will use GPS technology for AVL operation of a paratransit system in conjunction with bus, light-rail, and train operation. The service provided will allow disabled travelers to request specific transportation service. A vehicle will be routed and, where appropriate, the traveler would be transferred to a fixed-route mode. Use is made of AVL technology, demand-responsive dispatching software, and a navigable map database which allows the closest available vehicle nearest a requester to be dispatched.

TravTek FOT

A highly publicized and successful FOT was the TravTek FOT in Orlando, Florida. The partners included the City of Orlando, Florida DOT, Federal Highway Administration (FHWA), General Motors/Hughes, and American Automobile Association. The FOT started in 1990 and concluded in 1994. Its estimated total project cost was $ 12M.

TravTek (Travel Technology provided traffic congestion information, motorist services ("yellow pages") information, tourist information and route guidance to operators of 100 test vehicles, rented through AVIS. that were equipped with in-vehicle TravTek devices. Route guidance reflected real time traffic conditions in the TravTek traffic nehvork. A Traffic Management Center obtained traffic congestion information from various sources and provided this integrated information, via digital data radio broadcasts, to the test vehicles and the data sources.

TravTek rental operations began in March 1993. The operations phase ended in March 1993. The data collection for project evaluation is completed. The final evaluation reports were scheduled to be available in early 1995. In addition to the TravTek partners, the National Highway Traffic Safety Administration (NHTSA) participated in the TravTek evaluation.

Pathfinder FOT

Another FOT using in-vehicle navigation was the Pathfinder FOT located in Los Angeles, California. Partners in this FOT included the FHWA, California Department of Transportation (Caltrans), and General Motors. The FOT started in 1990 and concluded in 1992. Its estimated total project cost was $2.5M.

Pathfinder was a cooperative effort by Caltrans, FHWA and General Motors. It was the first U.S. test of the use of an in-vehicle navigation system to provide real-time traffic information to drivers. Pathfinder provided drivers of 25 specially equipped cars with up-to-date information about accidents, congestions, highway construction, and alternate routes in the Los Angeles Smart corridor. A control center managed the communication, detected traffic density and vehicle speeds (via detectors and by using the Pathfinder vehicles as probes) and transmitted congestion information to equipped vehicles. The information was then presented to the driver in the form of an electronic map on a display screen or digital voice.

The project is completed. The project's evaluation report, titled "Pathfinder," is available.

Baltimore Smart Vehicle FOT

Yet another FOT examining AVL is the Baltimore Smart Vehicle FOT located in Baltimore, Maryland. The partners involved include the FTA and Mass Transit Administration (MTA) Baltimore. Its start date was May 1988 in the research and development phase with completion in May 1994. The estimated total project cost was over $10M for both phase.

MTA implemented an Automatic Vehicle Location (AVL) system that provided bus status information to the public while simultaneously improving bus schedule adherence and labor productivity. A prototype system involving 50 buses was tested with LORAN-C receivers and 800-MHz radios. The buses' location is determined by the receiver and the information is transmitted to a central dispatch center. Off-schedule buses are identified so corrective action can be taken. The system was to expand to include all 900 Baltimore transit buses and Global Positioning System (GPS) inputs are replacing LORAN-C for vehicle location. A new trunked communication system was also to be installed.

Chicago Smart Intermodal System FOT

AVL was also tested in the Chicago Smart Intermodal System FOT in Chicago, Illinois. Partners included the FTX. City of Chicago Department of Public Works and Department of Streets and Sanitation. The start date was July 1991 with completion set for December 1995. Its estimated total project cost was $3.6M.

This cooperative agreement supports data collection and evaluation of an operational test of a Bus Service Management System (BSMS) by the Chicago Transit Authority (CTA). The CTA is in the process of creating a BSMS which includes procuring an Automatic Vehicle Location (AVL) system, a computer assisted dispatch and control system, real-time passenger information signs, and a traffic signal preemtion system. The initial demonstration phase is being funded locally by the Regional Transportation Authority (RTA). In addition to supporting data collection and evaluation, this cooperative agreement is to document the implementation of the BSMS and to analyze the BSMS human factors element to assess the effects of introducing video terminals and information systems into the transit dispatching environment.

Dallas Smart Vehicle Operational Test FOT

Another FOT that examined AVL and GPS technology was the Dallas Smart Vehicle Operational Test located in Dallas, Texas. The partners for this FOT included the University of Texas at Arlington, Texas Southern University, and Dallas Area Rapid Transit (DART). Its start date is set for 1995 with completion by 1996. The estimated total project cost including evaluation is $560K.

Dallas Area Rapid Transit (DART) has installed an Integrated Radio System that includes automatic vehicle location on 823 transit buses, 200 mobility impaired vans and 142 supervisory and support vehicles. The Global Positioning System (GPS), a satellite navigation system developed by the Department of Defense, is generating vehicle location information.
The Federal Transit Administration is sponsoring an evaluation of this system to determine its effectiveness in controlling bus schedules and position accuracy determinations. The evaluation is part of a national evaluation plan for all FTA sponsored demonstration activities. All projects will be evaluated on an equal basis through a common evaluation format. This approach will permit other areas to judge the effectiveness of a new technology or operational approach on a comparative basis to determine which technologies have the greatest potential in their own context.

The evaluation plan has been prepared by the Volpe National Transportation Systems Center and will be used as the foundation for this operational test. The Integrated Radio System is presently being installed; approximately 300 vehicles are presently involved in system polling tests. Under the DOT ITS Operation Test Program, this system will be used to test Flexibly Routed Transit Operations, which will involve routing buses off fixed routes so passengers outside the route's services area can be served.

Denver Smart Vehicle FOT

Still another FOT looking at AVL with GPS technology is the Denver Smart Vehicle FOT located in Denver, Colorado. Partners for this FOT included the FTA and the Regional Transportation District (RTD) Denver. Its start date was September 199 1 with completion in February 1995. The estimated total project cost is $10.5M

The RTD installed an Automatic Vehicle Location (AVL) system, as part of an upgraded communications system, to provide bus location information to transit dispatchers to increase efficiency, ridership and passenger safety. Location information is supplied by a Global Positioning System (GPS), which uses a series of navigation satellites. The location of each bus is determined by a GPS receiver on the buses and is transmitted to a central dispatch center. Off-schedule buses are identified so corrective action can be taken to reroute buses when needed.

The contract issued for an upgraded Communications and Automatic Vehicle Location System for RTD's fleet of 788 buses and 28 supervisory vehicles. Map displays showing each vehicle's location will permit the dispatcher to control the buses and their schedules. In the event of an on-bus emergency, the driver can summon help through a silent alarm that identifies the bus and its location so that police can be directed to the bus. An evaluation of the system was initiated by the FTA in close cooperation with the RTD. Installation of equipment on all buses is completed with new control heads being retro-fitted to improve readability in bright light; approximately 400 vehicles are in full AVL operation. System acceptance was scheduled in early 1995

A future expansion will include passenger information and interactive displays has been funded under the ITS Program for impIementation in the next year.

Colorado Mayday System FOT

An FOT that is looking at GPS for an emergency application is the Colorado Mayday System FOT located in Central - Northeast Colorado. Partners in this FOT include the NAVSYS Corporation, ESRI, CeIIular Inc.. Colorado State Patrol, Castle Rock Consultants, and members of the ENTERPRISE group (Departments of Transportation from the States of Arizona, Colorado, Iowa, Michigan, Minnesota North Carolina, and Washington State, and the Dutch Ministry of Transport, Ministry of Transportation of Ontario, and Transport). The start date was October 1994 with completion set for December 1997. The estimated total project cost is $3.8M.

This project will evaluate the use of GPS for vehicle location and cellular phone for two-way communications in order to provide emergency and non-emergency assistance to travelers operating in an area of over 12,000 square miles in north-central Colorado. The test will involve up to 2,000 vehicles equipped with a low-cost location device called TIDGET. The TIDGET sensor uses GPS satellite signals to the control center which can then determine the location of the vehicle. The primary objective of this test will be to evaluate the impact of an infrastructure-based GPS system and response network on emergency response activities, time and public safety. Additionally, this test will identify the necessary structure, responsibilities and service levels of a traveler assistance center necessary to commercially operate such a system and to eventually return control of the system to the center.

Section 5 - In-Vehicle Sensors

The in-vehicle sensors are technologies that provide the monitoring of various systems within a vehicle, as well as monitoring vehicle and driver performance. With the slight exception of lane control and radar frequency allocations, infrastructure interface with the in-vehicle sensors is non-existent. Hence, the in-vehicle sensors technologies do not impact the Las Vegas infrastructure and will be implemented independent of the Las Vegas system architecture. They will, however, affect the drivers of the Las Vegas Area

5.1 Alternate In-Vehicle Sensors Technologies

Various in-vehicle sensors technologies are evaluated. These technology areas and their maturity levels are provided in Table 5.1-1.

Table 5.1-1. In-Vehicle Sensors Technology Areas and Maturity Levels.

Technology Area	Maturity Level
Restraint Systems (Active)	Proven
Restraint Systems (Occupancy Detection)	Maturing
Collision Avoidance (ABS)	Proven
Collision Avoidance (Detection)	Maturing
Lane Control	Maturing
Driver Performance Monitoring	Maturing
Vehicle Performance Monitoring	Maturing

Most Federal Highway Administration sponsored projects involving in-vehicle sensor technologies are or have been research and development projects. The Automated Highway System Consortium is actively moving towards a 1997 demonstration project that is expected to field many elements involved with in-vehicle sensors.

Restraint System (Active)

Active restraint system include airbags for both front and side, and seatbelts. These technologies sense severe conditions to either deploy airbags to protect the occupant when an impact occurs or they lock the seat belt adjustment mechanisms when impact occurs. Front and some side airbags offered now as standard or optional equipment on consumer automobiles and trucks, while seat belts are standard equipment required by federal regulation.

Technology advancements include new polymer acceleration sensors such as those developed by AMP, Inc. to reduce cost and improve sensitivity for faster deployment. Passive Restraint Systems (PARS) is using a pressure sensor to trigger deployment of its head rest integrated airbag.

These airbag devices must meet electromagnetic interference (EMT) and radio frequency interference (RFI) constraints for solid-state devices. All restraint systems are either standalone components in the vehicle subsystem or would require interface with an automotive bus architecture. The interface to the system architecture is critical as the Las Vegas system architecture did not address interfaces required for an Automated Highway System, or other ITS user services with vehicle safety and infrastructure interfaces such as intersection collision avoidance.

Active restraint system technologies have high reliability based upon proven technology with easy maintenance requiring certified servicing available from many sources and includes a high degree of built-in test. Current costs for conventional electromagnetic types are approximately $12. The PARS headrest airbag system is estimated at $ I77 each, with TRW electronics and sensors OEM costing roughly $70 to $90

The technologies include simpler designs, are smaller in size, and provide faster response for active restraint systems. Side impact have even shorter sensing/deployment times of 10 milliseconds.

Restraint System (Occupancy Detection)

Occupancy detection for restraint systems include technologies such as infrared sensors, machine-vision sensors, acoustic sensors. and heating elements. Vehicle seat occupancy detection is performed in conjunction with air bag deployment system and are being specifically designed for the application of rear-facing child seat or heavy object in passenger-side seat. The applications are expected to expand to driver's and then rear-seat positions. The United States government and automakers have agreed for an active switch effective 1998 cars and 1999 trucks.

In addition to EMI and RFI considerations, the internal vehicle cabin considerations are required in the design. As with active restraint systems, occupancy detection will be either standalone components in the vehicle subsystem or would require interface with any automotive bus architecture. As this technology for this specific application is still evolving, reliability data is not yet available, although it is being designed for 0.99999. As well. cost data is not yet available. Maintenance issues are expected to be similar as those for air bags.

The occupancy detection is a logical extension to current air bag systems providing information for deployment decision as well as the potential to eliminate triggering of air bags unnecessarily, or propel contents of the seat when located too close to air bag deployment system. Concerns with this technology are that errors can result in ineffective air bag deployment and the increased susceptibility to high false alarm rates.

Collision Avoidance -Anti-Lock Braking System (ABS)

Collision avoidance using the Anti-Lock Braking System (ABS) prevents the wheel from locking during a sudden stopping event. It allows for controlled braking in several vehicle safety scenarios and is now offered as standard or optional equipment on consumer automobiles and trucks. The ABS provides maximum braking without wheel lock by controlling slip ratios for each whee1.

In theory. the ABS provides enhanced vehicle safety due to minimizing the wheel slippage; however. current field data is yet to prove this theory. Much of the initial field data had been based upon comparing same modeI/different year vehicles with and without ABS. Other variables such as driver usage and driving environments have made the data difficult to utilize. Hence. debate still exists whether the cost of system is worth its perceived benefits. Nevertheless, the perception of safety continues to make it a consumer demand.

As with all solid state device, EMI and RFI constraints must be considered. The ABS is either a standalone component in the vehicle subsystem or would require interface with any automotive bus architecture. As reliability of these devices are generally embedded in cost relative to liability issues, no such data is readily available. Servicing from certified sources is required. The typical ABS packages retail at about $500 for the 4-wheel ABS.

Collision Avoidance (Detection)

Detection for collision avoidance involves many technologies such as acoustic obstacle detection, ultrasonic obstacle detection. microwave radar, millimeter-wave (MMW) radar, laser radar, and wide-band radar. These technologies are used to detect the position and velocity of obstructions and other vehicles in the headway (roadway in front of the vehicle), to detect the presence of obstruction in the blind spots, and to detect the presence of obstruction in other area surrounding the vehicle. The collision avoidance systems automate sensing previously left to drivers by first detecting and alerting drivers of obstacles, then providing direct input into vehicle control system. In addition, these systems are designed to prevent accidents or minimize their impact. Eventually these systems will automatically detect objects and in conjunction with the cruise control and steering systems, provide automatic braking and automatic maneuvering. There are many issues to be resolved including the fact that the system can be distracting and is susceptible to high false alarm fates. Concern also exists regarding potential conflict with external environment as well as that it may make drivers too reliable upon sensors that are not yet foolproof.

Operational systems have been developed by various companies with these different technologies demonstrating the ability to detect objects. How the data is used is the next step in developing a vehicle safety sensor system which is acceptable to the drivers of these vehicles. These technologies require design for automotive environment including EMI and RFI. In addition to inside the vehicle, external environmental considerations including weather, other vehicles, clutter, and vehicle kinematics must be considered. Another item that might affect the Capitol Region, as it might all jurisdictions, is the FCC allocated frequency for the radar systems.

These systems usually require interface to a display unit, the vehicle cruise control unit, and either a data bus such as J1850 or a RS-232 serial port. System reliability data from U.S. manufacturers difficult to obtain as reliability is generally embedded in liability issues. Maintenance is provided through certified servicing. Cost estimates include $2000 for Delco’s Forewarn system including installation, the Ford and Delco at $1200 each, VORAD radar systems at $500 to $2000, Daimler-Benz MMW system at $600, and Siemens SideMinder OEM cost of $50.

Lane Control

Lane control includes technologies such as magnets, visual TV, infrared imaging, radar and reflectors. These technologies are used to detect the position of vehicles in a lane or automatically detects lane departure and lane edges for vehicle lateral control. Detection can be defined by magnetic nails in the road bed as lane markers, and image processing using visual TV images or infrared images. Magnet nail lane marker detection has been demonstrated by Partners for Advanced Transit and Highways (PATH) at their Richmond Field Station. Lane/Lock is in development by GM using visual TV images to determine road edges and lane markers. Infrared is mentioned because it can distinguish road edges and lane marker which have different emissivities relative to the road bed in daylight or at night. The imaging technologies also have the added advantage of providing the driver with vision enhanced images.

Many vehicle and roadway environmental considerations exist. As with most vehicle reliability data, these technologies also are not readily available and are generally embedded in the cost relative to liability. As lane control technologies are associated with infrastructure -- tightly associated in the case of magnetic nails and loosely associated in the case of lane markings, Las Vegas would be highly involved with technologies deployed in the area of vehicle sensors. Within the vehicle, it is expected that an interface to a display unit will be required, as well as interfaces with the vehicle cruise control unit, and either a data bus such as J1850 or a RS-232 serial port. The expected costs range from $100 to $500 for equipment based upon radar technology. with imaging systems expected to be slightly higher in cost.

Driver Performance Monitoring

Driver performance technologies are still in early development, with no standard designation yet defined. These technologies will monitor vehicle parameters (steering wheel motion, braking action, accelerator position. other operator controls, seat position and occupancy sensors), analyze data, produce assessment of alertness of driver, assume control and/or disable vehicle as required. Many techniques are being studied with methods of non-intrusive, non-contact driver assessment in early stages of development. The assumption of vehicle control for moving vehicles remains a major issue as it is with the Automated Highway Systems.

Basic component reliability is not an issue as driver performance technologies are based on otherwise proven component technology. However, operational reliability is viewed as a major issue. In addition, concern exists that the system design utilize module replacement for maintenance, as the critical nature of some system components would favor module replacement over repair. Driver performance may also require legal enforcement to prevent disabling by drivers that do not desire this protection and may require override capability by emergency personnel.

The only existing technology is drunk driving lockout which requires direct driver cooperation and is only effective at start-up This technology operates at all times and detects any type of impairment, responding to all types of driver disablements, and capable of taking control at any time. Correct algorithm development is expected to offer sensitivity to more driver conditions with the critical issue of lockout or assumption of control that can create an unsafe condition.

The costs of these technologies are highly variable depending on implementation method and level of functionality provided. The sensors may be shared with other systems to reduce the cost, with estimated implementation cost in high production in the range of $100~$300.

Vehicle Performance Monitoring

Vehicle performance technologies include vehicle condition sensors that monitor vehicle components and systems (engine. transmission, component temperatures, brake performance and temperature, tire pressure, vibration, steering, safety systems (air bag, wipers, lights), comfort systems (heater), assess overall and individual performances. warn drivers of impending problems and recommend actions. A wide range of vehicle sensors are available; sensor technologies developed for other industries may also be applicable. The current vehicle computers perform similar monitoring for some of these systems, and given that display systems already exist, development should only require processing algorithms to integrate the additional data.

Most components should or are available in designs suitable for the vehicle environment. Their interfaces are defined by their suppliers, with standards existing for many parts of the system. Additional development of standard methods of assessment and uniform driver notification are required in for vehicle performance. Component level reliability is not expected to be an issue based on proven technology available, although processing reliability (false alarms) is critical to public acceptance of the warnings provided. Most components would be replaced and modules discarded as distribution of components throughout vehicle will require complex and difficult to maintain cabling unless alternative methods of communications are utilized (vehicle data bus, integrated power and data wire, fiber optics).

Depending on how extensively the vehicle is instrumented, costs should be $I00-$500 in high production.

Section 6 - Traffic Surveillance

For the Las Vegas Valley, traffic surveillance is being implemented with the LVACTS upgrades traffic surveillance systems provide a range of traffic flow information by using different technologies. This information includes speed, volume, density, travel time, queue length, occupancy, and vehicle position. These data are used in real-time for making traffic management decisions, such as selecting traveler information displays, implementing appropriate control strategies, incident detection, coordinating route, diversion, and establishing ramp metering rates. The data may also be stored as a historical record of traffic flow conditions.

Las Vegas Valley computer Traffic System (LVACTS) is currently being upgraded to include approximately 43 CCTV cameras throughout the valley. In addition, the desert Inn Super Arterial is being constructed to include CCTV cameras and traffic vehicle detections.

6.1 Alternate Traffic Surveillance Technologies

Some of the surveillance technologies have already been used in various ITS projects, and many more are being developed. The technologies identified and their maturity levels are shown in Table 6.1-1.

Table 6.1-1 Traffic Surveillance Technologies and Maturity Levels

Technology Area	Maturity Level
Inductive Loop Detectors	Proven
Radar Detectors	Proven
Microwave Detectors	Proven
Acoustic Detectors	Proven
Infrared Detectors	Proven
Machine Vision/Video Image Detection	Maturing
Closed Circuit Television (CCTV)	Proven

It should be noted that some of these technologies are currently used only in limited applications and some are undergoing operational test.

Inductive Loop Detectors

Inductive loop detectors are by far the most commonly used detector today and are the standard form of detection in many agencies. Essentially, this detector installation consists of one or more turns of insulated loop wire buried in a saw-cut slot in the road surface. The ends of this loop are connected by cable to an electronic sensor unit, usually located in a traffic controller cabinet. A vehicle passing over or resting on the loop will change the resonant Frequency of a tuned circuit which is recognized by the sensor unit. Loops are a means to measure volume and occupancy, and when installed in pairs, can provide speed and classification (length) information as well.

Although loops are a proven, versatile technology and can provide all necessary detection functions, there have been some concerns about reliability maintenance effort and the disruption of traffic associated with installing and repairing a loop. How-ever, there is evidence that suggests that many loop detector problems are the result of poor design or improper installation, and not an inherent deficiency in the technology itself. New installation techniques, such as loop wire encased in plastic tubing, use of better sealants, and embedding of pre-formed, conduit encased loops, have dramatically improved loop reliability.

Radar Detectors

Radar detectors operate by directing a beam of low power microwaves toward the roadway. When a vehicle passes through the beam, the microwaves are reflected back to the detector unit at a different frequency. The detector senses the change in frequency and measures the speed of the vehicle based on the magnitude of the change, a principle known as the Doppler shit?.

There are two types of radar units available for vehicle detection - wide beam and narrow beam. As the name implies, wide beam detectors direct a broad stream of microwaves that can collect speed information from several lanes. They can be mounted over the center of the roadway or off to the side. If multiple vehicles enter the beam within the same one-second interval, the speed of the largest vehicle is typically recorded. Wide beam radar detectors are predominantly used when only the general speed of traffic flow is required.

Narrow beam detectors operate similarly to wide beam detectors, except they use a smaller microwave beam to cover one lane only. An individual detector unit is mounted directly above the center of each lane. These detectors are installed at locations where lane-specific traffic volumes and individual speed measurements are necessary.

Radar detectors would not be appropriate for intersection control, since they are capable of measuring volume and speed only, and not presence. The radar detector could be used for a traffic counting station.

Microwave Detectors

Essentially, microwave detectors operate in a manner similar to radar detectors in that they transmit microwave energy toward an area of roadway from an overhead or side-mounted device. The difference in the two detectors is in the way the information is processed.

The microwave detector measures the amount of time it takes for a microwave pulse to reach the road or vehicle and then reflect back to the detector. Vehicles are detected by an observed difference in the time a pulse takes to reach the roadway and reflect back, as compared to the time to reach a vehicle and reflect back.

Microwave detectors are generally insensitive to adverse weather conditions and operate in both day or night conditions. A primary drawback to microwave detectors is that the sampling rate (four times per second) does not provide accurate presence readings, especially at low speeds, therefore microwave detectors do not provide the “true” presence information that is obtained with loops.

A microwave detector has been developed by a Canadian firm (Electronic Integrated Systems or EIS) in response to the sampling rate problem, that is capable of true presence detection. The detector, which has been available since 1992, has a specified sampling rate of 100 times per second. This detector can be mounted in either a side-fire or a forward-looking configuration. The side-fire configuration reportedly can provide lane-specific count and presence data and, if installed in pairs, can obtain speed and classification information as well.

A microwave detector mounted to the side of the roadway offers easier maintenance since lane closures are not required for its repair. The only disadvantage of this configuration is that large vehicles passing the detector in the outer lanes, nearest the detector, inhibit the detector's ability to detect traffic in the inner lanes, a phenomenon known as occlusion.

In a forward-looking installation, occlusion is completely eliminated by mounting the detector units directly over each lane of the roadway. This configuration uses multiple detection zones to measure volume, speed, presence and classification from a single installation. However, there is an increased effort associated with the installation or repair of an overhead unit, since lane closures may be necessary.

Acoustic Detectors

Acoustic detectors use an array of small microphones and state-of-the-art signal processing technology to "listen" for passing vehicles. The sensors "hear" sounds from vehicle engines, tires and transmissions. The acoustic detector can distinguish automobiles from trucks or buses if classification information is desired. Enhancements of this technology could lead to the detector being capable of identifying vehicles from one detector location to another detector location. This information could be used to determine travel times along an arterial.

The acoustic detector can be mounted overhead or side mounted and requires less than 2 hours for installation, with minimum disruption of traffic. The performance of the detector is not affected by rain, snow, fog, temperature, humidity or ambient light conditions. The acoustic detector is capable of presence detection for use at signalized intersections. In addition to classification information, the acoustic detector also provides volume and occupancy information.

The acoustic detector is similar in cost to the installation of a 6'x 6' embedded loop detector and. depending on placement, can represent the larger loop necessary for intersection control. Up to four sensors can be connected to one detector card.

Currently. there are no applications of the acoustic detector for intersection control, however, the technology is available.

Infrared Detectors

Infrared detectors consist of a transmitter and a receiver mounted two to four feet apart above each lane of the roadway. The transmitter transmits an infrared beam which is reflected by the roadway pavement and received by the receiver. When a vehicle passes, the beam is disrupted. indicating vehicle presence. Infrared detectors can operate day or night, and are capable of measuring volume and presence. When installed in a paired configuration, they can also provide speed and classification information.

Infrared detectors are vulnerable to fog, mist, rain and snow, which can scatter and attenuate the infrared energy emitted by the transmitter.

Machine Vision/Video Image Detection (VID)

Machine vision technology also widely known as Video Image Detection (VID), uses microprocessor hardware and software to extract real time traffic flow data through an analysis of video images collected by a series of cameras mounted over the roadway. The microprocessor hardware may be located in a controller cabinet in the field. or at the Traffic Control Center where the video images may be monitored in real time. Up to 64 detection zones can be defined on a video image by the user using interactive graphics. These zones can easily be redefined to adapt to changing lane positions or to implement more advanced control strategies. VID provides all traffic flow information (volume, speed, occupancy and vehicle length), and multiple detection zones covering several lanes can be defined within a single camera's viewing area. Therefore, this technology becomes more economical as the number of required detection zones increases.

To use this technology at an intersection, either more than one unit would be necessary to cover all approaches or one unit would have to be strategically placed where all approaches could be observed from the one unit. It is more likely that more than one unit would be necessary for intersection control, which significantly increases the cost to control each intersection.

There are other concerns about this detection technology, including:

- Current VID systems function at night by identifying the movement of headlights. While this method provides accurate volume and speed information, it precludes the processing of occupancy and length data. This could also affect the use of this technology for intersection control. In order to obtain this presence-driven information during the nighttime, it is necessary to utilize low-light sensitive cameras.

- The accuracy of VID is very sensitive to camera placement and may be subject to occlusion. Positioning the camera well above the center of the roadway will resolve the occlusion problems, but this may not always be feasible.

- The initial cost of a VID system (including the camera, microprocessor and interconnecting cabling) is relatively expensive. The average cost of a single VID installation is about $35,000. As mentioned earlier, for intersection control, two camera units will probably be necessary for each intersection. It is anticipated that this cost will begin to drop in the near future as more vendors enter the market.

Closed Circuit Television (CCTV)

Historically, traffic surveillance cameras have been used primarily to monitor freeway conditions; however, as more cities become interested in achieving peak performance of their computerized traffic signal systems, there is increasing interest in using wide-area surveillance cameras to monitor traffic conditions on surface streets. The use of cameras in these environments is quite different. Freeway surveillance systems are typically used to identify and monitor incidents while aiding emergency personnel in clearance activities and advising motorists of delays. In addition to these activities, wide-area surveillance can be used to monitor traffic conditions along primary surface streets and diversion routes, and to assess the effect of signal timing adjustments aimed at improving intersection capacity and queue lengths in reaI time.

A variety of surveillance video cameras are currently available from a number of manufacturers. Cameras are distinguished by a number of characteristics and features, some of which, including camera control, and environmental protection, are discussed below. Also presented is a discussion of general camera technologies and a comparison of color versus monochrome (black and white) cameras.

Camera Technology - The most significant improvement in camera imaging technology occurred in the late 1970's with the introduction of Charged Coupled Device (CCD) solid-state imaging Integrated Circuits (IC's) or "chips"). Costs for solid-state cameras have decreased significantly and quality improved so much that modem solid-state "chip" cameras have almost completely replaced older electron tube technologies, the most common of which was the vidicon system. Generally, solid-state cameras consume less power, dissipate less heat and provide better reliability and improved resolution. Further improvements in the associated electronics have produced features enhancing the picture quality during both daytime and nighttime operation. Interline transfer circuitry reduces the effects of video trails and smears from vehicle lights. Automatic gain control (AGC) provides increased sensitivity at low-light levels.

Camera Control - The camera control equipment and communications hardware is located in a field cabinet at each camera site. From this cabinet the video signal is transmitted, via a communications medium such as fiber optic cable, microwave or twisted-pair copper cable, to the Traffic Control Center (TCC) for observation and evaluation. The field control equipment receives camera control commands (including pan, tilt and zoom) from, and transmit confirmation to, the TCC Another control feature of interest is preset pan and tilt positions, where multiple preset viewing perspectives can be easily recalled and viewed in succession.

Environmental Protection - The camera unit, although hardened to cope with the outdoor environment, is not made for direct contact with the elements. Dust, vehicle emissions, sunlight and precipitation can affect the performance of the camera, therefore a weatherproof camera housing with a sun visor is recommended to protect the camera and lens. Most manufacturers provide a variety of housing sizes with options including cooling fans, window wipers and heating units. However, these units do require periodic maintenance and cleaning.

Camera Lens - The camera lens must also be given consideration in the selection of system components. Zoom lenses are commonly used in freeway and arterial surveillance applications to enhance the capability to identify incidents. congestion and traffic signal malfunctions. A ten power, 5.8 - 58 mm, remotely controlled zoom lens will allow operators to monitor locations up to one mile away. Automatic iris and spectral filtering are lens options available to prevent optical effects that can degrade image resolution.

Color Versus Monochrome Cameras - Traditionally. surveillance systems have used monochrome rather than color cameras. Although color cameras are more pleasing to the eye, in the past, monochrome cameras have typically provided greater resolution and sensitivity than color cameras, especially during nighttime operations under low-light conditions.

This trend has begun to change with the recent introduction of several high resolution color cameras designed specifically for surveillance applications. With the advent of such color cameras, monochrome cameras are now generally used only for applications calling for extreme low-light sensitivity.

6.2 Traffic Surveillance Related Field Operational Tests (FOTs)

A number of FOTs have been conducted in the area of Traffic Surveillance. Following are those FHWA FOTS that specifically examine the traffic surveillance technology The following information is from the U.S. Department of Transportation Project Book.

Connecticut Freeway Advanced Traffic Management System (ATMS)

An FOT dealing with radar detectors and closed circuit television (CCTV) is the Connective Freeway Advanced Traffic Management Systems FOT located in Connecticut. The partners involved in this project are the Federal Highway Administration (FHWA) and the Connecticut DOT. The project start date was 1992 with an end date of 1994 The estimated total project cost is $ 1.3 million.

This ATMS project will evaluate the use of roadside mounted radar detectors in combination with closed circuit television (CCTV) for incident detection and verification. The ATMS utilizes 44 radar detectors (wide- and narrow-beam) and compressed video.

Idaho Storm Warning System FOT

An FOT directed at examining sensor systems to provide visibility and weather data is the Idaho Storm Warning System located along Interstate 81 in southeastern Idaho. Partners in this project are the FHWA, Idaho Transportation Department (ITD), CH2M Hill, Handar Incorporated, Santa Fe Technologies and Surface Systems Incorporated (SSI). The project starting date was June 1993 and a projected ending date of June 1996. The estimated project cost is $1,231,000.

The purpose of the Idaho Storm Warning Operational Test is to investigate various sensor systems that could provide accurate and reliable visibility and weather date, and to use that data to provide general warnings, speed advisories and possible road closure information to travelers on a section of I-84 in southeast Idaho that is highly prone to reduced visibility from blowing snow and dust. The primary goal of such a system is a major reduction in visibility related multi-vehicle accidents in rural areas. Information will be transmitted to the motorist via changeable message signs.

Documents completed and accepted by FHWA include Revised Scope of Work, Evaluation Plan and Individual Evaluation Test Plans for Phase I of the Operational Test Plan. IT'D has prepared the Phase I test site with guard rail, fence, concrete foundations for sensor equipment towers, and power and telephone hook-ups. As of February 1994, two of three equipment suppliers (Handar and SSI) have installed a complete complement of their equipment at the site and collecting weather and visibility data. ITD personnel have been trained on how to use and conduct routine maintenance on the equipment. The computer system with related software to collect the sensor data format for evaluation, and notify ITD personnel of specific events is being installed at the Cotterell Port of Entry.

Multi-Jurisdictional Live Aerial Video Surveillance System, I FOT

A live video transmission FOT is the Multi-Jurisdictional Live Aerial Video Surveillance System, I FOT located in Fairfax County, Virginia. Sponsoring partners are the FHWA, Fairfax County Police, Virginia Department of Transportation (VDOT) and the Virginia State Police. Its start date is January 1992 with a completion date of January 1995. The estimated total project cost is $355K.

This is an ITS operational test project to procure, install and evaluate live video transmission from a gyto-stabilized camera mounted on helicopters for use in observing, evaluating and properly managing major highway incidents and situations of a public safety nature. The live color video is transmitted to police and state highway traffic management centers and to mobile command centers at incident sites. Communications technologies include microwave, Community Access TV (CATV) and state owned coaxial cable. It is expected that the use of real-time airborne video will serve as a valuable component of an Advanced Traffic Management System (ATMS) particularly in major incident management.

Multi-Jurisdictional Live Aerial Video Surveillance System, II FOT

Another live video transmission FOT is the Multi-Jurisdictional Live Aerial Video Surveillance System, II FOT in Montgomery County in Maryland. Partners in this FOT are the FHWA, Montgomery County Office of Traffic and the Maryland State Highway Administration (MSHA). The project start date was in 1992 with a completion date of 1994. The project cost estimate is $400K.

Similar in concept to the project in Fairfax County, Virginia, this operational test project will evaluate live video transmission from fixed-wing aircraft to county and state traffic management centers. Maryland and Virginia will cooperate in this effort and will transmit video to traffic management centers in both states. Maryland, like Virginia, will also test the feasibility of transmitting live video to mobile command centers.

The system has been operational using a manual operated video camera. The system is currently being upgraded by mounting a gyro-stabilized camera to the aircraft. A six month evaluation period will follow.

Section 7 - Vehicle Surveillance

Vehicle surveillance systems involve the collection of individual vehicle information including vehicle location, weight, identification for various ITS related services such as transit and commercial fleet operations, electronic toll collections, truck weight law enforcement, and border crossing, etc.

7.1 Alternate Vehicle Surveillance Technologies

Several relevant technologies have been developed and applied in the vehicle surveillance area as part of ITS. Table 7. l-l shows the vehicle surveillance systems and their maturity levels.

Table 7.1.1 Vehicle Surveillance Technology Areas and Maturity Levels

Technology Area	Maturity
Vehicle Position	Proven
MAYDAY	Proven
Weigh-in-Motion	Proven
Electronic Vehicle Tag	Proven

It is noted that some of the systems may share the same technologies. For example, the vehicle position system and the MAYDAY system both use the global positioning system (GPS).

Vehicle Position System

Vehicle Position Systems are also known as Automatic Vehicle Location (AVL) systems. They provide not only the basis of the functional elements of the route guidance and the traveler advisory system, but also the automatic MAYDAY system. Detail evaluation of vehicle position systems are provided in Section 4.1

MAYDAY Systems

MAYDAY systems encompass a series of traveler emergency services such as emergency medical assistance. stranded motorist roadside assistance, and security response. All automatic mayday systems rely on some form of automatic vehicle location systems. Data collection requirements for emergency services include vehicle location and nature of the emergency. By using geographical information system (GIS) and GPS technologies, the MAYDAY systems can identify precise geographic location of the requesting vehicles. A MAYDAY alarm could be transmitted from the vehicle automatically by in-vehicle crash sensors. Other alarms could be initiated by the traveler and call for help to other vehicles, police, or an emergency management services. These alarms can be realized by one-way communication systems such as a panic button, an integrated part of an on-board system, or by two way communication systems such as pager application and extended power cellular service.

The emergency services with MAYDAY systems have been available in the United States, and in Europe with such systems as Datatrak, used in Great Britain. Datatrak's vehicle location and communication capabilities are used in an emergency situation when the vehicle sends a special message. The system covers 90 percent of Britain's roads. both rural and urban.

In a MAYDAY situation. an emergency message is reported more frequently than in a normal situation. PacTel's Teletrac Roadside Service only requires a driver to push a button in the vehicle, notifying the control center that automotive assistance is needed. However, the push-button program is limited to the cellular coverage area: in other areas a telephone must be used to request the service. The II Morrow Vehicle Tracking System has a MAYDAY function. In this system, a vehicle position sensor calculates the vehicle's position based on broadcast radio signals and reports the position to the central facility.

Weigh-In-Motion System

High speed mainline weigh-in-motion (WIM) systems have been proposed in the national ITS program to provide highway truck statistics data and decrease the delay of the weight enforcement process. The U.S. Department of Transportation (US DOT) views WIM as the first goal of ITS in the field of commercial vehicle operations (CVO). With high speed WIM, those that are in compliance with legal weight status can bypass the inspection site on the mainline with no more than one stop on their whole trip. The US DOT believes that with high speed WIM. both states and carriers will increase their productivity levels.

Many states have been using WlM as a vehicle sorter for more than ten years. But at present, the practice of WIM in weight enforcement is limited to medium speed WIM systems, which usually accommodate speeds of 20-35 mph, and are located on the entrance ramp of weigh stations. Commercial vehicles are still required to enter the weigh station, then they are further sorted to either a bypass route or to the scale house based on their weight status. So, delay still exists even for vehicles taking the bypass route because of the speed loss in the facility.

One high speed WIM system. along with AVI, is being tested in the HELP (Heavy Vehicle Electronic License Plate)/Crescent and ADVANTAGE I-75 projects. With the Crescent system, a vehicle with an on-bumper electronic license plate is weighed and identified by the on-road high speed WIM and AVI reader. The information is transmitted to the computer system in the scale house, and the vehicle's credentials, recorded in the computer data base, are checked. If the vehicle is qualified with every enforcement detail, a "go" signal is transmitted to the on-board receiver, and the vehicle is granted permission to stay on the mainline; otherwise a "not go" signal is given to the vehicle, and it has to enter the weigh facility for futher inspection.

International Road Dynamics (IRD) developed the following budgetary prices for the system and installation costs for a typical mainline and ramp sorting system (including axle, axle group. and gross weight) as shown on Table 7.1-2.

Table 7.1-2 Budgetary Pricing for Typical Sorting System

Mainline WIM Sorting		Ramp WIM Sorting
System	$210,000	$160,000
Installation	$110,000	$100,000

Electronic Vehicle Tag System

Electronic vehicle tag systems are also known as AVI. They provide electronic reading and recording of a vehicle's identity as it passes specific points, without requiring any action by the driver. Information that identifies a vehicle is encoded onto a vehicle-mounted transponder (or toll-tag). As the vehicle passes a site with an AVI antenna/reader, the tag is activated to transmit the coded data to the antenna, and then to an adjacent roadside reader or processor. Several different technologies and procedures are used in AVl systems, for example:

- Tags may be bar coded, and then scanned using optical lasers or infrared; but these systems suffer from limitations in dealing with harsh environments found in many transportation applications. The most versatile systems use RF or microwave transmissions to energize and read the encoded tag.

- Antennas can be mounted above or to the side of the roadway; while some systems utilize an inductive loop embedded in the roadway as an antenna. The antenna mounting obviously impacts the placement of the vehicle tag.

- Some AVI systems are "read-only"; while others provide two-way data transmission between the reader and the tag (e.g., the reader can also transmit data to the tag which is encoded in a "scratch pad" for subsequent reading by a downstream antenna).

The primary applications for AVl are to automate toll collection without stopping (known as electronic toll collection - ETC): automatic equipment identification to identify rolling stock and inventory assets (e.g., rail cars, highway trailers) in the rail, shipping, and motor freight industries; for truck weight and safety enforcement regulation; and for commercial vehicle revenue collection and curb usage regulation at airports.

As noted above. AVl technology is being implemented to aid in electronic toll collection in numerous areas in North America, Europe, and Asia. In the United States, there are currently over a dozen electronic toll collection systems in operation or under procurement including the Tobin Bridge, the Dallas North Tollway, the Delaware River Bridges in Philadelphia, the Verrazano and Goethals Bridges in New York, and the Oklahoma Turnpike. Electronic toll collection enables roughly three times as many transactions per lane per hour as is currently done with manual toil collection. Therefore, traveler delays (and air pollution) can be significantly reduced, along with a concomitant reduction in the labor resources needed for toll payment transactions.

Another ITS-related use of AVI involves commercial vehicle operations. An example of this application is the ADVANTAGE I-75 project, in which AVI will be tested along the I-75 corridor between Canada and Florida.

Certain trucks will be equipped with identification transponders or tags, which can be read at highway speeds to automatically identify the vehicle. As a tagged truck approaches a weigh station on I-75, it will be directed into the rightmost lane by existing signing. In advance of the weigh station, a roadside AVI reader will automatically read the truck tag and identify the specific truck. The truck ID will be forwarded to a computer in the weigh station which will check to see if the truck has previously been weighed. Whenever a tagged truck is weighed at any station in the corridor, a trip data packet is transmitted to the next downstream weigh station and is ready for recall when the truck arrives at that location. A parallel project in the western region is known as the Crescent/HELP program.

Major AVI hardware and equipment vendors include Amtech, Vapor (a division of Mark IV), AT&T (with Lockheed). and SAAB (Europe). Xmtech has by far the largest installed AVI base, owing largely to its early entry into the market and its initiatives with standard setting organizations. Amrech's installed systems include an estimated 200,000 AVI tags on North American cars and 60,000 AVI tags in Europe for electronic toll collection; and an estimated 8,000-15,000 AVI tags installed on commercial vehicles for revenue and curb space control at airports. AT&T has been selected to provide its smart card electronic toll system for the Orange County Transportation Corridors Authority in California 3/4 a project expected to ultimately require 150,000 tags.

7.2 Vehicle Surveillance Related Field Operational Tests (FOTs)

As with traffic surveillance, a few FOTs have been conducted in the area of Vehicle Surveillance. Follow-ing are the FOTs that examine this technology. The following information is from the U.S. Department of Transportation Project Book.

Ada County Travel Demand Management Emissions Detection FOT

Monitoring vehicle emissions is the focus of the ADA County Travel Demand Management Emissions Detection FOT located in Xda County Boise Idaho. Involved partners are the FHWA, Idaho Transportation Department, Ada Planning Association and the Ada Air Quality Board. This project has a start date of September 1993 and an end date of October 1995. Total project cost is estimated at $319K.

The primary objective of this test is to evaluate the feasibility of using remote sensing technology to monitor vehicle emissions. Active infrared roadside emissions detection technology will be used to determine the relative contributions of in-county and out-of-county vehicles to mobile-source emissions.

Dynamic Truck Speed Warning for Long Downgrades FOT

An FOT focusing on the safe descent speed for trucks is the Dynamic Truck Speed Warning for Long Downgrades FOT conducted in Colorado. This FOT is a joint project of the Colorado DOT, the Colorado Motor Carriers' Association and the International Road Dynamics. The project start date is June 1993 with an end date of September 1995. Total estimated project cost is $250K.

This project provides for the installation of weigh-in-motion station to determine the weight of each truck passing the site, ignoring the vehicles under 30,000 pounds GVW, and installation of loops to determine vehicle speed. Using the weight and speed, the safe descent speed will be computed from the algorithm published in FHWA-RD-79-116 "Feasibility of a Grade Severity Rating System" as modified by "The Development and

Evaluation of a Prototype Grade Severity Rating System". The vehicles will be advised of the safe speed using variable message signs.

Evaluating Environmental Impacts of ITS Using LIDAR FOT

An FOT dealing with improvements in air quality is Evaluating Environmental Impacts of ITS Using LIDAR FOT located in Minneapolis and St. Paul in Minnesota. Involved partners include the Minnesota Department of Transportation (MnDOT) Santa Fe Technologies, IBM Federal Systems Company and the University of Minnesota. The project start date was June 1994 with a completion date of February 1995. Estimated total project cost is $795K.

This test will combine Light Detection and Ranging (LIDAR) technology for wide area emissions detection with active infrared technology for roadside emissions detection to evaluate any improvements in air quality due to implementing traffic responsive control strategies for events at a sports complex. The objectives are to: (1) measure the effect of MnDOT's portable Traffic Management System on air quality, (20 determine the ability of LIDAR technology to provide quantitative and qualitative air quality date, and (3) assess the overall effectiveness of LIDAR as an evaluation tool.

SMART Call Box FOT

The SMART Call Box FOT, located in San Diego, California, focuses on increasing the functionality of the existing call box system. Joint partners in this FOT are the San Diego Service Authority for Freeway Emergencies (SDSAFE), California Department of Transportation (Caltrans) and the California Highway Patrol (CHP). The Project start date was September 1993 and the end date was December 1995. The estimated total project cost was $2,260,200.

This operational test takes advantage of the extensive call box system installed on California freeways and will attempt to increase their functionality by adding interface to traffic management devices. The project will include testing the feasibility of using the Smart Call Boxes to collect traffic census data; obtain traffic counts. flows and speeds for incident detection; report information from roadside weather information systems; control changeable message signs: and control roadside closed-circuit television cameras.

Section 8 -Transit Vehicle Sensors

Transit sensors include all in-vehicle devices that monitor the individual vehicle and driver, and those elements of the external driving environment that pertain to individual vehicle operation.

This service can provide the Las Vegas CAT operators with real time vehicle and facility status to improve transit operation and maintenance, Integrating this service with the traffic control services can help maintain transit schedules, assure transfer connection information and assist travelers with accurate real-time transit information as needed while a trip is underway.

8.1 Alternate Transit Vehicle Sensors Technologies

The application of in-vehicle sensors in transit vehicles focuses on the passenger boarding and alighting, driver's performance, and vehicle status monitoring.

8.1.1 Passenger Boarding And Alighting

Automatic Passenger Counters

Automatic Passenger Counters (APCs) provide scheduling personnel with data necessary for planning transit operations. Information regarding the maximum load points, distribution of the load along a route, and total number of passengers served can provide scheduling personnel with information needed to determine the number of vehicles necessary to meet maximum loads and optimal head ways between buses. Information on the actual number of passengers on individual buses can allow control centers to reschedule buses to meet unexpected demands. Besides improved service quality, such data provides travelers with information about the status of a transit vehicle (e.g.. empty or crowded).

Many systems have been used to determine the number of passengers boarding or alighting transit vehicles. These include infrared beam systems. pressure sensitive mats. ultrasonic beam systems, multi-switch treadle mats, acoustic echo ranging systems and smart cards, which are briefly discussed below.

> ***Infrared Beam Systems*** - The infrared beam system consists of two infrared light sources and photo diode detectors placed on one side of the doorway, and reflectors placed on the other side. When a passenger passes through the bus doorway, the light beams sent from infrared light sources are broken down in a unique sequence. depending upon whether the passengers are boarding or alighting, and then transmitted back to their respective sensors by reflectors, Information from sensors is then processed electronically, and passenger counts are produced.
>
> ***Pressure Sensitive Mats*** - In pressure sensitive mats, shin-sensitive magnetostrictive wire is embedded in standard bus stair treads. When a passenger enters or leaves the bus, the impedance variations of the mat inductance is converted into electrical signals. These signals are then converted to on/off digital signals and used to generate boarding or alighting pulses. The mats are usually placed on the upper and lower steps of a stairwell.

Ultrasonic Beam System - The ultrasonic beam system consists of an emitter, a receiver, and a control logic device. The emitter generates a highly directional 50kHz sound wave. When a passenger boards or alights the vehicle, the receiver detects the interruption of the sound wave. The pulses from the receiver are then fed to a control logic device that provides a signal for each passenger who leaves the bus, and a different signal for each passenger who enters the bus.

Multi-Switch Treadle Mats - With multi-switch treadle mats, each switch mat contains 16 ribbon switches oriented parallel to the direction flow. A logic unit accepts the switch inputs from four treadle mats, determines the change in the number of feet per step from the pattern of switch closures, and generates boarding or alighting signal pulses from the patterns of footstep changes. The mats are placed on the upper and lower steps of a stairwell.

Acoustic Echo Ranging Systems - In the acoustic echo ranging system, passenger counts are determined by the detection and measurement of the transit time of 40-kHz acoustic pulses reflected by passengers that are entering and leaving the bus steps. The direction of motion is then determined through logic circuitry.

Automatic Ticketing and Payment

Automation of ticketing and trip payment can benefit both transit operators and riders. It improves transit operations by providing the controllers/managers with data on revenue, passengers, and origins and destinations. This increases the speed of entry and processing of passengers, and improves the security of operators and riders due to reduced cash handling. Such automation also reduces the inconveniences of fare payment.

Many vendors are developing ticketing machines that accept different payment methods. For example, the new TVM 5000 machine developed by Schlumberger can accept bills, coins. credit cards, and debit cards. It allows the rider to pay for an open ticket or multiple tickets, upgrade his/her ticket, purchase a transfer, or purchase a ticket for an origin other than the location of the TVM.

Different methods have been investigated to improve the efficiency of ticketing and fare collection. Payment through credit cards, magnetic cards and smart cards, and automatic passenger identification speeds up passenger entry and processing.

Credit cards can be used to purchase tickets eliminating the need to have change for tickets. When special readers are installed at gates or fare boxes, credit cards can be used to allow riders to enter and exit rail stations and buses. A demonstration project done by the Merrimack Valley Regional Transportation Authority (MVRTA) in the City of Haverhill, Massachusetts in 1983, was successful in establishing a credit system, and implementing automated collection of charged fares. The project demonstrated the technical feasibility of the past-payment concept.

Smart cards can also improve the efficiency of ticketing and payment. These are plastic cards with a programmable memory chip that can be used for identification, trip payment, and other travel-related functions. Smart cards are being used by the Milton Keynes City Bus in the U.K. The card carries the holders' account balance, which is debited with a discounted fare each time the traveler uses the bus.

Magnetic strip cards that carry the holder's bank account number are used for trip payment in Oldenberg and Lueneberg, Germany. The account number is recorded by a reader unit on-board the bus. Each month the fares due are debited from the traveler's account without exceeding the cost of a monthly pass, regardless of the number of journeys.

The automatic passenger identification concept can be used for post-payment of a trip. The traveler carries a small microwave or radio frequency tag which is read as the individual enters and exits the transit vehicle. The fares are then calculated and billed to the traveler's account.

8.1.2 Driver's Performance and Vehicle Status Monitoring

On-board computers (OBCs) are employed to continually monitor operations of the transit vehicle to reduce the deviations from desired performance. They are used to collect and store data on speed, distance traveled, engine revolutions per minute, oil pressure. water temperature, turn signals on/off, ignition on/off, etc. An analysis of gathered data allows monitoring of vehicle performance and driver behavior.

OBCs consist of a computer attached to a number of sensors. The sensors are linked to different parts of the vehicle, such as engine, air-conditioning, brake, oil pressure, etc. On-board computers collect vehicle data (oil pressure, water, and engine temperature, vehicle speed, signals, etc.), which can be used by the driver and transit operators to monitor vehicle performance, and to respond quickly to breakdowns.

8.2 Transit Vehicle Related Field Operation Tests (FOTs)

Following are FHWA FOTs that involve some aspect of Transit Vehicle Technology. The following information is from the U.S. Department of Transportation Project Book.

Santa Clara County Smart Vehicle FOT

The Santa Clara County Smart Vehicle FOT implemented in Santa Clara County, California focuses on the operation of a paratransit system. This FOT is a joint project of the Division of New Technology and Research of the California Department of Transportation (Caltrans), Santa Clara County Transportation Authority Outreach Paratransit Broker, Trimble Navigation, UMA Engineering, Navigation Technologies, Volpe National Transportation Systems Center (VNTSC) and the Federal Transit Administration (FTA). The project start date was November 1993 and the completion date was October 1995.

Those project will use global positioning system (GPS) technology for automatic vehicle location (AVL) operation of a paratransit system in conjunction with bus, light-rail and train operation. The service provided will allow disabled travelers to request specific transportation service. A vehicle will be routed and where appropriate, the traveler would be transferred to a fixed-route mode. Use is made of AVL technology demand-responsive dispatching software, and a navigable map database which allows the closest available vehicle nearest a requester to be dispatched.

TRANSMIT FOT

An FOT dealing with the use of automatic vehicle identification (AVI) as an incident detection tool is the Transmit FOT implemented in Rockland County and Bergen County, both in New Jersey. Joint partners in this FOT are the FHWA, New Jersey Department of Transportation (NJDOT), New York State Thruway Authority, New Jersey Highway Authority and TRANSCOM. The project start date was January 1991 with a completion date of December 1994. The estimated total project cost is $2,550,000.

The "TRANSMIT" (TRANSCOM's System for Managing Incidents and Traffic) Operational Test will evaluate the use of automatic vehicles identification (AVI)) technology as an incident detection tool. A consultant team (headed by Farradyne, Inc.) has finalized design for a system of AVI "tag" readers which allow vehicles equipped with transponders to serve as traffic probes. Tag-equipped probe vehicles will be assigned a random identification number as they enter a system populated with AVI readers spaced approximately 2 km apart. Software analysis will be used to help identify potential incidents by comparing actual to predicted travel times behveen readers. in addition to determining real-time traffic information such as speed and travel time.

Northern Virginia Integrated Route Deviation/Fired Route FOT

An FOT dealing with an enhanced ridesharing-route deviation transportation system is the Northern Virginia Integrated Route Deviation/Fixed Route FOT implemented in Northern Virginia. Partners in this FOT include the Potomac Rappahannock Transportation Commission (PRTC), Northern Virginia Planning District Commission, Virginia Department of Rail and Public Transportation (VDRPT), Gandalf Mobile Systems, UMA Engineering, SG Associates, Federal Transit Administration (FTA) and the FHWA. The FOT started in January 1994 with a completion date scheduled for July 1996. The estimated total project cost is $3,243,593.

This Operational Test will evaluate an enhanced, ridesharing-route deviation transportation system integrated with conventional transit and ridesharing in the Northern Virginia suburbs of Washington, D.C. including Prince William and Stafford Counties. The system will provide on-demand service through an audiotext request system which uses scheduling software similar to the taxi industry. Depending on the needs and preferences of the system users. door-to-door transportation would be provided using both public and privately owned vehicles operated by paid volunteer drivers using vans, minibuses, specialized public vehicles, fixed-route buses and taxicabs. Users would be charged a standard per-mile rate regardless of the type of vehicle used. System cost not recovered by these fares would be covered by local agencies. Smart cards will be used to process transactions. It is hypothesized that this service could be provided at a much lower cost than conventional transit service. It is expected that a dispatch center will be established and 50 vehicles will be equipped. Technologies are expected to include Automatic Vehicle Location (AVL) and Global Positioning system (GPS) satellites. interactive cable TV and electronic bulletin boards.

Alternate Bus Routing FOT

The Alternate Bus Routing FOT focuses on vehicle-roadside communications. This FOT is being implemented along the Garden State Parkway in New Jersey. Partners in this FOT include the FHWA, New Jersey Department of Transportation (NJDOT), New Jersey Highway Administration, TRANSCOMM and Hughes Transportation Management Systems. The project started in October 1993. The estimated total project cost is $1,235,000.

The Alternate Bus Route Project will be a pilot evaluation of next generation Vehicle-to-Roadside Communications (VRC). The first phase will utilize a VRC transponder as both an advanced read/write traffic probe and to advise a bus driver of traffic conditions between the Raritan Toll Plaza and Interchange 129 via visual and audio massaging

Ann Arbor Smart Intermodal FOT

An FOT dealing with the Smart Bus concept is the Ann Arbor Smart Intermodal FOT located in Ann Arbor, Michigan. This FOT is a joint partnership of the Federal Transit Administration (FTA), City of Ann Arbor and the University of Michigan. The Project started in July 1991 and was completed in December 1995. The estimated total project cost is $2,442,500.

This project will support the Ann Arbor Transportation Authority's (AATA) conduct of an operational test of the Smart Bus concept. Included are an on-board bus communication and navigation system, a central control system and a "Smart Card" fare collection system. The on-board system monitors actual performance in regard to route. location. speed and status of mechanical systems. It will allow control of on-board electronics. such as the fare collection system. destination sign and enunciator. The on-board system will also enable buses to interact with traffic signal preemption devices and to communicated with the central control system. The central control system will then integrate the data from the bus fleet for coordinated supervision and will also provide real-time transit information to the public. The "Smart Card" fare system will provide a dual farecard/parking pass to encourage auto drivers to ride transit by providing them with an easy, cost-saving method for fare payment.

Baltimore Smart Vehicle FOT

An FOT focusing on automatic vehicle location (AVL) is the Baltimore Smart Vehicle FOT implemented in Baltimore. Maryland. Jointly sponsored by the FTA and the Mass Transit Administration (MTA) Baltimore. the project started in May 1988 (R&D) and ended in May 1994. The estimated total project cost was $2.5M for the R&D project phase and $8M for the deployment.

MTA is implementing an Automatic Vehicle Location (AVL) system that will provide bus status information to the public while simultaneously improving bus schedule adherence and labor productivity. A prototype system involving 50 buses was tested with LORAN-C receivers and 800-MHz radios. The buses' location is determined by the receiver and the information is transmitted to a central dispatch center. Off-schedule vises are identified so corrective action can be taken. The system will be expanded to include all 900 Baltimore transit buses and Global Positioning System (GPS) inputs are replacing LORAN-C for vehicle location. A new trunked communication system will be installed.

An initial deployment of the system (Phase 1) determined its potential in a small scale operation (50 buses, 4 supervisor automobiles and 2 consoled with map displays). The system was expanded to all transit vehicles using GPS for location, new dispatcher displays and new software. Westinghouse was the contractor. Initial installation was on 285 vehicles (215 buses and 70 light rail vehicles) and included a new communications system. The system involved route&dependent tracking. Driver feedback on schedule was used to control routes. Passengers counters were installed as part of this project.

Dallas Smart Vehicle FOT

The Dallas Smart Vehicle FOT focuses on an integrated radio system that includes automatic vehicle location. Implemented in Dallas, Texas, the FOT is a joint project of the University of Texas at Arlington, Texas Southern University and the Dallas Area Rapid Transit (DART). The project start date was 1995 with an end date of 1996. The estimated total project cost is $500K for operational tests and S60K for evaluation.

Dallas Area Rapid Transit (DART) has installed an Integrated Radio System that includes automatic vehicle location on 823 transit buses, 200 mobility impaired vans and 142 supervisory and support vehicles. The Global Positioning System (GPS). a satellite navigation system developed by the Department of Defense, is generating vehicle location information.

The Federal Transit Administration is sponsoring an evaluation of this system to determine its effectiveness in controlling bus schedules and position accuracy determinations. The evaluation is part of a national evaluation plan for all FTA sponsored demonstration activities. All projects will be evaluated on an equal basis through a common evaluation format. This approach will permit other areas to judge the effectiveness of a new technology or operational approach on a comparative basis to determine which technologies have the greatest potential for their context.

The evaluation plan was prepared by the Volpe National Transportation Systems Center and was used as the foundation for this operational test. The Integrated Radio System was installed with approximately 300 vehicles involved in system polling tests. Under the DOT ITS Operations Test Program, this system will be used to test Flexibility Routed Transit Operations, which involves routing buses off fixed routes so passengers outside the route's services area can be served.

Denver, Colorado Rapid Transit District (RTD) Passenger Information Display System FOT

Another FOT focusing on automatic vehicle locators (AVL) is the Denver, Colorado Rapid Transit District (RTD) Passenger Information Display System. This FOT is a joint partnership of the FHWA, Colorado Department of Transportation (CDOT), Denver RTD and Westinghouse Electric. The project start date was September 1993 with completion expected by September 1997. Estimated total project cost is $2M.

This project will utilize the data gathered from the Automatic Vehicle Locator (AVL) system, currently being installed on all RTD buses, to provide information to video monitors at selected locations throughout the District and at selected Ecopass companies regarding estimated bus departures for waiting bus passengers.

The memorandum of understanding between RTD-CDOT-Westinghouse-FHWA was developed. The project was approved with limited funding as compared to the original proposal. However, all activity on the project was suspended due to difficulties Westinghouse had with the Automatic Vehicle Locator (AVL) system.

Denver Smart Vehicle FOT

Still another FOT dealing with Automatic Vehicle Location (AVL) system is the Denver Smart Vehicle. Jointly sponsored by the FTA and the Denver Regional Transportation District (RTD). the project start date was September 1991 and the completion date was February 1995. The estimated total project cost is $10,520,000.

The RTD is installing an Automatic Vehicle Location (AVL) system, as part of an upgrade communications system, to provide bus location information to transit dispatchers to increase efficiency rider-ship and passenger safety. Location information is supplied by a global positioning System (GPS), which uses a series of navigation satellites. The location of each bus is determined by a GPS receiver on the buses and is transmitted to a central dispatch center. Off-schedule buses are identified so corrective action can be taken to reroute buses when needed.
A contract was issued for the upgraded Communications and Automatic Vehicle Location System for RTD's fleet of 788 buses and 28 supervisory vehicles. Map displays showing each vehicle's location wiIl permit the

dispatch to control the buses and their schedules. In the event of an on-bus emergency, the bus driver can summon help through a silent alarm that identities the bus and its location so that police can be directed to the bus. An evaluation of the system was initiated by the FTA in close cooperation with the RTD. Installation of equipment on all buses is complete with new control heads being retro-fitted to improve readability in bright light. Approximately 400 vehicles are in full AVL operation.

A future expansion will include passenger information and interactive displays has been funded under the ITS Program for implementation in 1996.

Milwaukee Smart Vehicle FOT

Another FOT evaluating automatic vehicle location (AVL) systems and bus fleet management is the Milwaukee Smart Vehicle FOT. Participants in this FOT are the Federal Transit Administration (FTA) and the VoIpe National Transportation Systems Center. The project start date was September 1993 with a completion date of September 1995. The estimated total project cost is $50K.

This project will support the efforts of Milwaukee County to conduct data collection and evaluation of its Automatic Vehicle Location (AVL) and bus fleet management system. The project will enable Milwaukee County to participate in the Volpe National Transportation Systems Center (VNTSC) Operational Test Evaluation effort. Milwaukee County will conduct data collection and evaluation in coordination with the VNTSC National Evaluation Plan. The AVL system is designed to track buses and ensure accurate schedule performance, increase overall operating efficiency and assist in fleet management activities. As new technologies are operationally tested around the country, it is critical that standard evaluations are conducted to ensure consistency and compatibility of evaluation data.

Phase I testing of all hardware and software on 15 buses has been completed. Installation of hardware is continuing and has been completed on over 50 buses. Initial implementation of route and schedule information onto the vehicle logic units is underway A draft of the project Evaluation Strategy is also complete. Schedule completion for the entire system (600 buses) was scheduled for late spring 1995. Future developments beyond the initial scope of the project are not yet anticipated.

Wilmington, Delaware Smart Dart FOT

An FOT focusing on the smart card technology is the Wilmington, Delaware Smart Dart FOT. Jointly participated in by the Delaware DOT, FHWA, Federal Transit Administration (FTA) and the Electronic Payment Services. the FOT started in July 1994 with a completion date scheduled for July 1996. Estimated total project cost is $2,179,155.

This project will operationally test smart card technology in a transit application in Wilmington, Delaware. A smart card fare collection system w-ill be developed for the Wilmington bus fleet. An Employee Commute Option (ECO) program w-ill be created that allows employers to provide transit benefits through the smart card system which facilitates the administration of transit benefits. The ECO program was developed as a response to the Clean Air Act of 1992. The program will allow participating employers to quality for tax credits based on the level of employee participation in the program.

California Smart Traveler FOT

The smart card technology in Los Angeles and Orange Counties in California is the focus of the California Smart Traveler FOT. This FOT is a joint project of the Federal Transit Administration (FTA), Los Angeles Metropolitan Transportation Authority (LAMTA), Volpe National Transportation Systems Center, Aegis Transportation Information Systems. Inc., Merced County Council of Governments, University of California, and the State of California Department of Transportation (Caltrans). The FOT start date was March 1993 with a completion date of December 1994. The estimated total project cost is $3.3M.

This project is comprised of two components: (a) Los Angeles Smart Card, and (b) Orange County Smart Intermodal System. The Los Angeles Smart Card will test the use of smart cards for express transit services as well as for parking and other services at employment sites. Two different card technologies will be tested: a contact card and a radio frequency (RF) proximity card.

The Orange County Smart Intermodal system will operationally test (1) an integrated transit and traffic management system and (2) a real-time information system that will include special event information.

The first phase of the project has been completed which identified and evaluated several test sites and appropriate technologies for operating testing. A report describing the concept and an additional report providing cost estimates for implementation of smart traveler projects have been published and are available from FTX. The Los Angeles Smart Card project has distributed over 700 RF smart cards for use on three different transit systems. Card readers, computers and GPS antennas have been installed on 24 buses.

Additional operational tests are being considered as part of the Priority Corridors Program and include the integration of four state Transportation Management Centers, installation of system detectors, integration of intermodal subsystems and dissemination of information through regional clearinghouses. The smart card project, when combined with automatic vehicle location (AVL) technology could be expanded to include every aspect of bus operation rather than just a fare payment system.

Chattanooga Smart Card FOT

The use of Smart Cards for both the payment of parking fees and transit fares is the focus of the Chattanooga Smart Card FOT. The project started in January 1993 and has a completion date of August 1995. The estimated total project cost is $93,750.

This project will assist the Chattanooga Area Regional Transportation Authority (CARTA) in its ongoing "Downtown Parking and Circulator" effort. This project will support the planning and development of a smart card fare and parking system to be used to increase the appeal of transit and park-and-ride lots in the downtown area. The project will examine using smart cards for both the payment of parking fees and for transit fares on the downtown circulator. Presently, CART.4 provides a downtown shuttle system that runs from the north end of downtown to the south end. CARTA is constructing "auto intercepts" of park-and-ride lots located at key entry points into the downtown area. These intercepts will relive the congestion and act as a boarding area for public transportation. The Chattanooga Smart Card project will tie into this developing effort.

Washington D.C. Advanced Fare Media FOT

Another FOT focusing on the use of smart cards as a fare media is the Washington D.C. Advanced Fare Media FOT. This FOT has a start date of December 1994 and a completion date of February 1996. The estimated total project cost is $ 1.0M

This project tests a fare collection system that allows WMATA passengers to use the same fare media to pay for metrorail , metrobus and parking. The contractor will develop, install and demonstrate a contactless smart card based fare collection system. The system will be installed on turnstiles at 14 rail stations, on 21 buses and into 15 lanes at 5 WMATA parking lots. In addition to multimodal transit use, the fare system will be tested for increasing the throughput of passengers by decreasing fare transaction times; increasing the security of fare collection; reducing operating and maintenance costs (the system requires no mechanical card transporter); reducing fraud; increasing up-front cash deposits and resulting revenue; reducing costs of gathering ridership date; and making the system more user-friendly for passengers and WMATA employees.

Section 9 - Routing Systems

Routing is a more specific form of route selection than that provided in trip planning; it is also normally a pre-trip service. Routing allows the traveler to specify preferences such as road types, route characteristics, and intermediate destinations. The best route can then be selected based on these preferences, and current or historical route data.

9.1 Alternate Routing Systems Technologies

Dynamic data collection requirements are identical to those for trip planning, travel times, congestion, weather conditions. construction and maintenance activities, etc. Aggregation and processing of the dynamic data would also be the same at one level, but a second level (traveler preferences) is introduced in this service. Traveler preferences must be integrated into the recommendations or options communicated back to the user.

Routing services are currently provided in some urban areas, such as Ontario's Travel Guide, which integrates current travel link data with an on-board map data base. The TravTek project in Orlando also used information from the traffic management center to determine the best route. Arizona's kiosk prototype, which was installed in the Spring of 1994, gives routing information based on current conditions, including weather, construction, and travel time. San Francisco's TravInfo will give the traveler real time information on multiple modes of travel: personal vehicle, bus. and rail.

Static Route Guidance

Several PC based personal trip planning and travel guide software packages are commercially available. Personal Travel Guide, from Personal Travel Technologies, allows local trip planning in urban areas by almost any mode. The Guide has data bases for over 30 U.S. cities which provide yellow pages information. Future plans for Personal Travel Guide include a link to traffic management systems for up-to-date traffic information. Street Atlas USX. from Delorrne Mapping, is a CD ROM data base which includes street maps of almost every town in the country. Locations can be searched by address, zip coded, and area code.

Zagat-Axxis City Guides are available for a limited number of urban areas. The City Guides provide tourist information (e.g.. hotels, restaurants. attractions) and the ability to search by address, price range, and several other criteria. Once a destination is selected, City Guide plans a route to get there.

Automap is one of several programs which takes on the entire country, rather than just urban areas. Automap determines a route from origin to destination based on user-selected criteria: shortest, fastest, most scenic.
Street Wizard™, from Adept Computer Solutions, has map data bases for every county in the United States. The program can find an address or an area, and can print a map of the area. The current version of the software does limited automatic routing within a county data base, with routing across county lines. The routing is described as limited because one-way streets and illegal turns are not accounted for. Manual routing with Street Wizard™ is a simple point and click operation, and a detailed map and driving directions can be printed for the selected route.

Another nationwide package is Key Map, from Softkey Software, which selects the most efficient routes between any two locations and gives the traveler the alternatives from which to choose. When a route is selected, Key Map can print a map and instructions.

Vacation Planner is a routing program which selects either the shortest route between two user-selected towns/cities or allows the user to specify intermediate points in the trip. Directions and travel times can be printed. but the main disadvantage of this package is its lack of map graphics. Interstate Traveler, on the other had, has map graphics but no automatic routing functions. Each point along the user-selected route is highlighted. and the software calculates arrival time, cumulative and link distances, and amount of fuel remaining.

A similar program, developed for the trucking industry, is PC*Miler from ALK. This fleet management routing program has a multi-user option and could be accessed by modem.

All of these PC-based programs are simple to use and convenient to access at the trip origin. Their main disadvantage is that none currently provides real time traveler information.

Real-Time Routing Guidance

Real-time traveler guidance can assist the traveler with planning his/her trip, selecting the optimal mode or route, and dynamic decision making during the trip so as to improve the efficiency and convenience of travel. Real-time traveler routing guidance can include the areas of traffic congestion, incident location, alternate routes, construction activities, and schedule adherence for transit modes, etc..

There are different types of software packages that have been developed or are under development in various ITS-related projects. Through the traveler interface technologies such as telephone. TV, radio, variable message sign (VMS). automatic kiosks, and in-vehicle navigation system, these software packages can provide travelers with real-time routing guidance. Several relevant software packages and their implementation are discussed below.

TeleMap, by Way-finder, Inc., is a telephone based route direction service accessible from any device which emits a touch tone impulse. The system has been implemented in the Orlando. Florida area, where TeleMap provides directions between an origin and destination. both of which are located by their respective phone numbers. The route is delivered to the user via synthesized voice or by transmission to a facsimile machine.

The Oracle Communications system is capable of providing a variety of real time traffic and transportation information, using "human quality" digital speech for transmission over both multiple telephone lines and low frequency HAR radio devices. The system is also capable of being enhanced to include automated video feed for broadcast TV stations and/or roadside tourist centers. System features include the ability to transmit traffic conditions. trip planning using real time information, public information (e.g., transit fares and schedules). operational and media information (e.,., alert police, news media, system operators), and voice mail and survey capabilities.

In-vehicle navigation systems are also playing an important part in real-time routing guidance systems. The vehicle's location on the road nehvork is determined and directions are given to aid the traveler in reaching a specific destination. Location may be determined by GPS, map matching, dead reckoning, some other AVL technology described earlier, or a combination of these. Directions may be given audibly, textually, or by simplified maps.

TravTek is a driver information system developed and implemented through the cooperation of the Federal Highway Administration, Florida Department of Transportation, the City of Orlando, General Motors, and the American Automobile Association (AAA). The TravTek equipped car performs several user services: route selection, route guidance, and "yellow pages" services. It also acts as a data collection probe to provide travel time information. The in-vehicle monitor is a console mounted, 5" x 5" touch screen, and some operator controls are also located on the vehicle steering wheel.

ZEXEL U.S.A.'s NavMate navigation and route guidance system, in the prototype stage, uses both GPS and dead reckoning for vehicle location determination. The two systems interact and provide position correction for each other. The system presents simple graphical and text directions on a console-mounted screen.

ADVANCE is the Chicago area navigation and route guidance demonstration program that uses dead reckoning for vehicle locations, calibrated by GPS input using a NavTech map data base. A color liquid crystal display (LCD) and a digitized voice will provide directions to a traveler-selected destination. The route will be updated as necessary to avoid congested areas and maintain the best route.

System Hardware

Either static or real-time routing systems must use some types of system hardware or user interface technologies to provide the information to travelers. The following techniques are discussed:

- Teletext
- Videotext
- Variable Message Signs (VMS)
- Automated Kiosks
- Local Area Broadcasting (HAR/AHAR)

It should be noted that in-vehicle routing navigation hardware is excluded from the Iist because it was covered in the last section.

Teletext

Teletext technology uses a portion of the TV channel's bandwidth - the Vertical Blanking Interval (VBI) – to transmit traveler information. The VBI is the black horizontal line located on the lower part of the TV screen, and can be seen when the TV vertical hold knob is adjusted. The information can be transmitted in conjunction with commercial TV channels or cable TV.

Teletext is a promising media for providing visual and up-to-date information on demand to the traveler at home. It provides a relatively simple means of obtaining traffic and transit information for trip planning purposes, thus improving its chances for user acceptance. To view the transmitted information, observers must have a standard television equipped with a World System Teletext (WST) chip -- the same device used to see the closed features available for the hearing impaired. At this time however, a relatively small percentage of televisions in use are equipped to receive teletext transmissions. The trend in the television manufacturing industry is to make teletext reception a standard functions; and as televisions are replaced, the potential audience for teletext will increase significantly over the next few years.

Videotext

New attempts to bring products and services into the home via the personal computer, using videotext technology, have been initiated through a joint venture between IBM and Sears. Their product is called Prodigy, Promoted for the "busy professional" yet geared for the computer illiterate, Prodigy combines text and graphics to produce and access information services such as news, weather, entertainment, financial reports, and magazine excerpts. Other interactive services such as grocery shopping, banking, E-mail, or purchasing theater tickets are available in some areas. If Prodigy (or similar services) is successful in capturing a large audience, displaying real-time traffic information and providing route planning might well prove to be beneficial since the only requirements placed on the ITS-based system will be to provide access to the database source. Provision of this type of service may be extremely inviting to Prodigy since it offers a daily use to their customers.

Variable Message Signs (VMS)

Variable message signs can provide dynamic information to travelers regarding a variety of conditions. They can be used to warn travelers of congestion that lies ahead as a result of an incident, construction, maintenance. or special event. In addition. the VMS can be used to provide safety and warning information when an unsafe condition exists. such as speed too high for conditions or low clearance conflict.

Variable message signs can also advise travelers of alternative routes that are available, or detours which must be taken. They can provide directions for obtaining additional information through other means (e.g., radio). In a congested tourist area, the signs might give information on expected delays or alternative entrances.

Several WiS technologies are available and discussed below.

<u>Flip Disk</u>. The viewing face of a flip disk sign is formed by an array of permanently magnetized, pivoted, disk-shaped indicators on a dark background surface. By electromagnetically actuating appropriate disks. they will rotate to reveal a brightly colored side and display the appropriate message.

<u>Bulb Matrix</u>. Bulb matrix signs are composed of incandescent lamps which are configured into a matrix and turned on and off to produce the desired letter array or graphics. The bulb matrix signs provide excellent visibility. both at night and in daylight.

<u>Fiber Optics</u>. A fiber optic variable message sign is comprised of bundled fiber optic cables that terminate in "dots" on the front face of the display.

<u>Light Emitting Diode (LED)</u>. The LED variable message sign is made up of clusters of super bright LEDs in a socket mounting. Each cluster forms one pixel of a character or display. LED signs provide excellent visibility under all lighting and weather conditions.

<u>Hybrid</u>. The hybridVMS is a mixture of two technologies discussed earlier – flip disk and a light emitting source (fiber or LED). The sign is made up of standard flip disks, with a small hole placed in the center of each one. Behind each hole is a fiber optic bundle, or a green or amber LED.

Automated Kiosks

An automated kiosk is a stand alone unit most commonly containing a computer terminal and some form of user interface (e.g., keyboard, touch screen). Automated kiosks are a roadside interface which the traveler must actually stop the vehicle to use, unlike any of the other roadside systems. Kiosks could be installed in rest areas, visitor information centers, and truck stops. Although a kiosk could be installed in a completely stand-alone facility, it is unlikely that a traveler would stop just to use the kiosk, for both convenience and safety reasons.

Kiosks are currently in use in Tennessee, where they are located at the State's ten Welcome Centers and at hotels and tourist attractions. Another kiosk project in Arizona is the Flagstaff Infoguide, a system by Interactive Ink Corporation supported by the City of Flagstaff.

The American Automobile Association (AAA) is promoting a new kiosk service called TravelMatch Express. This touch-screen kiosk provides users with AAA Tourbook visitor information and driving information both on-screen and in print. The service is currently being tested in the Orlando area. DriverGuide, by Navigation Technologies, also provides driving directions between user selected points.

Local Area Broadcasting (HAR/AHAR)

These systems, located at the roadside stations, provide localized traveler information broadcasts to vehicles in the vicinity of the station. The transmission range of these systems is limited to a few kilometers. Traveler information provided by these systems includes advisory information such as road closure, incidents, and special event information; safety and warning information such as severe weather (fog, ice, etc.) road hazards, and safe speed; and traveler service information near major attractions.

Highway advisory radio (HAR) provides a relatively economical means of disseminating a significant amount of information to the travelers. It is intended to provide more specific information at key locations on an immediate basis than is possible through traditional commercially broadcast traffic reports.

Automatic highway advisory radio (AHAR) provides a method to overcome the need for HAR signing and manual turning to the HAR frequency. The traveler information is the same as traditional HAR, the automatic part of the system is tuning the radio to the HAR frequency. The AHAR transmitter sends out a leading message, which is picked up by a special in-vehicle receiver when the vehicle enters the AHAR zone. Michigan's DIRECT project is currently having drivers evaluate AHAR.

9.2 Routing Systems Related Field Operational Tests (FOTs)

Following are FHWA FOTs that examine routing systems technology. The following information is from the U.S. Department of Transportation Project Book.

TravTek FOT

An FOT focusing on route guidance is the TravTek FOT implemented in Orlando, Florida. Jointly sponsored by the City of Orlando, Florida DOT, FHWA, General Motors/Hughes and the American Automobile Association, the project start date was 1990 with a completion date of 1994. The estimated total project cost is $12.OM.

TravTek (Travel Technology) provided traffic congestion information, motorist services ("yellow pages") information, tourist information and route guidance to operators of 100 test vehicles, rented through AVIS, that were equipped with in-vehicle TravTek traffic nehvork. A Traffic management Center obtained traffic congestion information from various sources and provided this integrated information, via digital radio broadcasts to the test vehicles and the data sources.

Pathfinder FOT

The use of in-vehicle navigational system to provide real-time traffic information is the focus of the Pathfinder FOT implemented in Los Angeles, CA. Participants in this FOT are the FHWA, California

Department of Transportation (Caltrans) and General Motors. The project start date was 1990 and the completion date was 1992. The estimated total project cost is $2.5M.

Pathfinder was a cooperative effort by Caltrans, FHWA and General Motors. It was the first U.S. test of the use of an in-vehicle navigation system to provide real-time traffic information to drivers. Pathfinder provided drivers of 25 specially equipped cars with up-to-date information about accidents, congestions, highway construction and alternate routes in the Los Angeles Smart corridor. A control center managed the communication, detected traffic density and vehicle speeds (via detectors and by using the Pathfinder vehicles as probes) and transmitted congestion information to equipped vehicles. The information was then presented to the driver in the form of an electronic map on a display screen or digital voice.

Section 10 - Traffic Control Systems

This functional area includes those management and control strategies which may be implemented to provide improved efficiencies on the urban roadway network and freeway, to reduce or spread out demand, and to enhance traveler safety.

Urban Traffic Control System

The Las Vegas Valley Computer Traffic System (LVACTS), which is based on the Urban Traffic Control System (UTCS) concept, is a centrally controlled system based on the "First generation” of traffic control systems. The LVACTS is currently being upgraded to a “hybrid” traffic signal system based on a distributed control architecture and will be capable of up to 1200 signalized intersections, supporting video surveillance and other ITS technologies.

10.1 Alternate Traffic Control Systems Technologies

Control technologies focus on coordinated traffic signal control, and freeway traffic control including ramp metering, and mainline control. Control strategies to improve efficiencies include the use of lane closures, reversible lanes and part-time use of highway shoulders.

10.1.1 Traffic Signal Control

There are a number of different coordinated traffic signal control systems, from simple hardwire interconnected systems with an on-street master to sophisticated computerized central systems, in use today like the LVACTS. Computerized traffic control systems can generally be classified into two categories: closed-loop systems. and central systems. The LVACTS is considered a central system.

Optional functions such as emergency or transit vehicle preemption. closed circuit television surveillance, environmental monitoring. and incident management are features that are becoming more prevalent in systems today. In addition. real-time traffic adaptive control is now becoming a consideration in traffic signal control systems. An overview description of the system types are provided below.

Closed-Loop Systems

The closed-loop system is primarily used for arterial applications and makes extensive use of distributed processing. Closed-loop systems distribute the computer processing load over three levels. The operator interface and database management functions are performed at the highest level by a microcomputer which is typically installed in either the Traffic Engineer’s office or the Signal Shop.

This top level is connected to an on-street master unit by dialup telephone or other similar communications channel. The master, in turn , communicates to each of the local controllers. The maximum number of controllers that can be linked to a single master ranges from 16 to 32 depending on the system design.

The on-street master performs two primary functions: plan selection and equipment monitoring. The plan selection may be made either on a time-of-day basis or on a traffic responsive basis using inputs from system detectors. Commands are issued by the on-street master to implement timing plans stored at the local controller.

The equipment monitoring function identifies, reports, and logs failure conditions such as an invalid response from a particular controller or a continuous pulse from a system detector.

One of the primary advantages of a closed-loop system over a central system is its lower initial cost for installation of the communications cable plant.

Central System

Central systems generally operate on a minicomputer or PC-based hardware platform and either use a distributed architecture which monitors the local intersections, or a centrally controlled architecture which sends commands to each local intersection on a second-by-second basis.

A centrally monitored-distributed system operates on a minicomputer or PC-based hardware platform. This system maintains continuous communications from a central location, collecting and monitoring the data, but the execution of the data is surrendered to the field controllers. This reduces the communications infrastructure while maintaining a fully functional system. With a PC-based architecture, satellite locations are set up with workstations that access the main system. Users at each workstation have the full range of features at their disposal simultaneously. Most centrally monitored systems offer the following features: window-based user interface, graphics capability, traffic-responsive and fixed-time control, modular system architecture, traffic data collection, traffic incident and demand management capabilities, and video surveillance capabilities. Communications can be multi-drop or point-to-point, with multi-drop support up to 30 intersections/link depending on the system. The City currently has multi-drop communication with up to 8 intersections/link. These links can be retained with a centrally monitored system. This system operates with any NEMA standard or Model 170 controller. Controller databases can be uploaded and downloaded and can be compared to the central system database.

The disadvantages of a centrally monitored - distributed system are that the communication system may be proprietary. Volume and occupancy data is measured and averaged in minutes instead of seconds, however some systems have addressed this and raw traffic data is available. Complexity of the field equipment is high, however this does not appear to be a problem with the technology that is available, and communication channels must be continuous from the central facility to each field unit.

Centrally controlled systems are generally known as a "first generation system", a term used in conjunction with the Federal Highway Administration's (FHWA) Urban Traffic Control System (UTCS). The software used is similar to FHWA's Extended or Enhanced UTCS and is integrated with a general purpose minicomputer or PC-based system. This type of system transmits control data from the central facility to the local field controller. This data is also monitored from the central facility. The difference behveen a centrally controlled system and a centrally monitored system is that the centrally controlled system provides once-per-second communication and the commands are transmitted to the traffic signal controller each second; whereas for a centrally monitored system, the intersection functions locally through the traffic signal controller which maintains the timing plan data and only changes timing plans when commanded from the central system.

Similar to a centrally monitored system, a centrally controlled system uses PC-based workstations to access the central computer from remote locations or serve as operator terminals at central. Users at each workstation have the full range of features at their disposal simultaneously.

A disadvantage to a centrally controlled system is the higher cost to provide the second-by second communication capability.

Real-Time Traffic Adaptive Control

Real-time traffic adaptive (RTTA) control provides for the real-time adjustment of cycle length, phase split times, and relative offsets at each signalized intersection in the system. Two approaches are being taken to provide real-time traffic adaptive traffic signal control. One is the Split Cycle Offset Optimization

Technique (SCOOT) system, developed in the United Kingdom, uses the central control system architecture. The other is the Real-Time Traffic Adaptive Control (RT-TRAC) system currently under development in the United States which distributes the real-time timing adjustments to the local intersection.

Real-time traffic adaptive systems require system detectors at each intersection to provide the necessary data to the system. Detector locating and validation of the system control parameters is labor intensive but is a one-time effort. Timing plan development and maintenance is virtually eliminated.

10.1.2 Freeway Traffic Control Systems

Ramp Metering

Ramp meters are traffic signals placed at the freeway on-ramps. They control the rate at which vehicles enter the mainline (i.e., a form of demand management) such that the downstream capacity is not exceeded, thereby allowing the freeway to carry the maximum volume at a uniform speed. Although it may seem paradoxical, by controlling traffic at the ramps such that the freeway's throughput is maximized, more vehicles can enter from the ramps than if the mainline flow was permitted to breakdown.

In most systems, ramp metering rates are determined off-line using historical volume data. For each ramp meter controller, the rates are selected on a time-of-day basis.

Although most systems operate on a time-of-day basis, the state-of-the-art is calculating the appropriate metering rate on-line in real-time. The ramp metering component of the Seattle freeway surveillance and control system is an excellent example of this capability. This system employs an algorithm that optimizes the metering rates at all ramps in the system to meet both strategic and local objectives.

The traffic responsive ramp metering algorithm has three components which calculate or adjust meter rates on the basis of local conditions. system capacity constraints, local queues and volume, and'or merge conditions.

When the first two components of the algorithm suggest different optimum metering rates. the system resolves the conflict by selecting the most restrictive of the suggested rates. The last component, local override adjustments, has the highest priority and can overrule the other calculated rates.

The first rate computed uses occupancy data from loop detectors that are located in the freeway upstream from the ramp. A relationship at the upstream detector station between occupancy and volume is determined based on historical data collected at that station. Using this calibrated volume-occupancy relationship. metering rates are calculated in real-time to allow ramp volume to make up the difference between estimated freeway capacity and estimated freeway volume. In general, meter rates are selected from pre-determined. finite set of discrete metering rates.

The system capacity constraint is the strategic component of the metering algorithms. With this level of control, the tic demand entering a freeway bottleneck section is controlled by adjusting the ramp meter rates at the series of ramps upstream from the bottleneck.

The algorithm begins by examining each station beginning at the upstream section and moving downstream in turn. When the downstream detector station detects occupancies above an operator-defined threshold, the section is considered to be near capacity. When the section is operating near capacity, and the number of vehicles entering the section exceeds the number of vehicles exiting the section, then the section is said to be storing vehicles.

When the above conditions are met, the system calculates the upstream ramp volume reduction as the number of vehicles currently being stored. The ramp metering rates at upstream ramps are adjusted to reduce the number of vehicles entering the system to be equal to the number of vehicles being stored.

The final step in the process is to take care of any ramp-surface street operational problems. Final adjustments to the metering rate are made in this third step, and therefore have the highest priority. Typical override criteria include: queue adjustment, ramp volume adjustment, and maximum queue adjustment.

10.1.3 Lane Control

Lane control is concerned with the regulation, warning and guidance of traffic on the main freeway or arterial lanes in order to improve the uniformity and stability of traffic flow, and to forestall congestion.

Lane control strategy is typically implemented through one or more of the following means:

- Lane closure
- Reversible lane control
- Part-time use of shoulders

Lane Closure

Lane closure prohibits entry to one or more of the main lanes on the highway. It is used to increase the efficiency and safety of freeway operations during periods of reduced capacity. Use of closure as a means of mainline control is usually confined to the following applications:

- Advance warning of lane blockage
- Improvement of entrance ramp merging operations
- Tunnel control

In Detroit lane-control sips were used to indicate the existence of temporary lane blockages downstream caused by maintenance operations. The effectiveness of this system seemed to depend on the freeway demand. The usefulness of the system thus, seemed to be limited to off-peak periods. The effectiveness of this system with respect to a reduction in accidents, because drivers had been alerted to blocked lanes downstream. was not evaluated.

In Austin, Texas. lane control signals and changeable message signs are used on a freeway where express elevated main lanes are introduced parallel to and above existing main lanes.

In the Netherlands, lane-control signals are used in conjunction with the variable-speed control messages to warn drivers of lane blockages ahead. Fiber-optic type matrix signals are located above each lane at intervals of about 500 meters. Each signal has the ability to display a range of numerical speed messages, a red X, a right or left change lane arrow, and an end of temporary limits message.

In Houston, lane closure has been used to reduce congestion caused by merging operations during heavy traffic flow conditions at a freeway-to-freeway interchange. Lane control signals were installed upstream of the merge area and loop detectors were installed on the entrance ramp. When a queue is detected on the ramp. the lane-control sign displays a red X over the right lane. indicating the lane is closed.

Lane closure is often used in tunnel control on the mainline. In a system in Naples, Italy, if an incident or very slow traffic is detected in a tunnel by speed and occupancy checks, entrance to the tunnel is denied by conventional, red metering installations on the freeway.

Reversible Lane Control

Reversible lanes are used to change the directional capacity of a freeway in order to accommodate peak directional traffic demands. Therefore, if reversible lanes are to be warranted. peak-period traffic volumes must exhibit a significant directional imbalance (e.g., 70 percent, 30 percent) which would be predicted to continue to exist for a number of years in the future. If warranted, reversible lanes would enable a more economical and efficient use of road space and right-of-way.

The concept of reversible lanes also has been incorporated into the design of some freeways (e.g., Kennedy Expressway in Chicago, Interstate 5 in Seattle, Washington, and Interstate 95 in Northern Virginia.

The Kennedy Expressway in Chicago has a 7-mile, 2-lane reversible roadway built in the media strip. The reversible lanes are express lanes and have only one access point between their terminals for outbound-only flow. The outer roadways have 3 to 4 lanes and operate in only one direction.

Median reversible lanes have been constructed on Interstates 395 and 95 in Northern Virginia in order to relieve the congestion of peak hours. In A.M. peak, lanes are open to the in-bound traffic; in P.M. peak, they are open to outbound traffic.

Part-time Use of High way Shoulders

The use of paved shoulders on urban freeways for travel is an effective and inexpensive method of increasing capacity in critical bottleneck sections. Studies on U.S. 50 freeway in Houston show that average speeds have increased and total travel times have decreased on the freeways that have implemented shoulder lanes. However, the placement of a strong pavement in the shoulder prior to its conversion for travel, either continuously or by specified time periods is advisable.

The studies conducted on 7.7 miles of Interstate 95 in Virginia show that the combination use of HOV and shoulders increases capacity more than 30% under constant roadway density, but in one direction the traffic fatality rate is 29% higher than the Virginia Department Of Transportation general interstate highway accident rate.

10.2 Traffic Control Systems Related Operational Tests (FOTs)

The following information from the U.S. Department of Transportation Project Book examines FHWA FOTs that focus on traffic control technologies.

Borman Expressway Advanced Traffic Management Systems (ATMS) FOT

The Borman Expressway Advanced Traffic Management Systems (ATMS) FOT focused on installing and evaluating a functioning prototype advanced traffic management system on the Borman Expressway (I-80/94) in northwest Indiana. This FOT is a joint project between the FHWA and the Indiana Department of

Transportation (INDOT). The project start date was July 1994 and the completion date was April 1995. The estimated total project cost was $1.75M.

INDOT. in conjunction with Hughes Transportation Systems/JHK/Avilla, is developing and installing a functioning prototype Advanced Traffic Management Systems (ATMS) deploying several of the more promising electronic sensors and integratin g them into the prototype using spread spectrum radio communications. The equipment will be independently evaluated for dependability and cost effectiveness by Purdue University before being incorporated into the permanent ATMS that will be constructed in a later phase. The Borman ATMS will become an essential component of the Gary-Chicago-Milwaukee, Midwest Priority ITS Corridor.

Fast- Trac FOT

The Fast-Trac FOT focuses on a combined Advanced Traffic Management Systems (ATMS) and Advanced Traveler Information Systems (ATIS) technologies implemented in Oakland County, Michigan. Partners in this FOT are FHWA, Michigan DOT, Siemens Automotive, GM, Ford, Chrysler, Road Commission for Oakland County (RCOC), County of Oakland, AWA Traffic System - America and the University of Michigan. Project start date was April 1992 with a completion date of January 1996. The estimated total protect cost is $70.0M.

FAST-T&AC (Faster and Safer Travel through Traffic Routing and Advanced Controls) will combine Advanced Traffic Management Systems and Advanced Traveler information Systems technologies in Oakland County, Michigan. The Australian SCATS traffic adaptive control system will be installed throughout Oakland County, Michigan. Traffic detection for real time traffic control will be provided using Autoscope video image processing technology. For the Advanced Traveler Information Systems part of the test, vehicles will be equipped with the Siemens Ali-Scout route guidance and driver information system. Infrared beacons will be installed at critical locations in the nehvork to provide for a continuous exchange of real time traffic and route guidance information. A Traffic Operations Center has been established, not only as the heart of FAST-TRAC operations, but also as the focus for systems integration.

Integrated Ramp Metering/Adaptive Signal Control FOT

An FOT evaluating the operational effects of balancing traffic flows between freeways and parallel arterial streets is the Integrated Ramp Metering/Adaptive Signals Control FOT in Irvine, California. Partners in this FOT are the California Department of Transportation (Caltrans), City of Irvine, Farradyne Systems, University of California - Irvine and the FHWA. The project start date was September 1993 with a completion date of December 1996. The estimated total project cost is $3,337,000.

This project will evaluate the operational effects of balancing traffic flow between I-5/I-405 and the parallel arterials streets. The project will also demonstrate the effectiveness of collaborative action on the part of transportation management agencies to optimize their strategies to improve traffic flow. The project will integrate an existing centrally-controlled freeway ramp meter system with an arterial signal system consisting of existing signal controllers, a new Advanced Traffic Controller and a candidate adaptive control measure (OPAC).

Agreements and contracts among the project participants are nearing finalization.

Minnesota Guidestar Program FOT

The Minnesota Guidestar Program FOT, which focuses on providing overall direction to the ITS program, is implemented statewide through Minnesota. Joint partners in this FOT are the Federal, State and local agencies and private companies interested in the evaluation and deployment of ITS user services and technologies. Started back in 1991, the project is still ongoing. The estimated total project cost is $2,413,790.

The Minnesota Guidestar provides overall direction to the ITS program by providing a focus for strategies planning, project identification, project initiation, project management and evaluation. Minnesota Guidestar also provides coordination with other State and local agencies in Minnesota. such as the University of minnesota which have an interest and role in ITS.

In addition to the national ITS operational field tests, the Minnesota Guidestar program manages a number of locally important operations field tests and a large ITS Research program jointly with the University of Minnesota, Center for Transportation Studies, Intelligent Transportation Systems Institute. Some of these tests are described below:

<u>Integrated Corridor Traffic Management (ICTM)</u>: This project is evaluating the ability of multiple agencies to manage freeways and arterials in a heavily traveled corridor as a "seamless" system using real-time adaptive control systems covering street signal systems and the freeway ramp metering system. Phase I covering the ramp intersection signals is underway as of January 1. 1995. Full operation of the test is expected in 1997.

<u>St. Paul Incident Management (SPIM)</u>: This project will provide for real-time adaptive management of traffic signals in downtown St. Paul when there is an incident on the freeway system. As of January 1, 1995, the operational test is underway with data collection continuing through 1995.

<u>Portable Traffic Management Systems (PTMS)</u>: This project used a portable electronic traffic management system including changeable message signs, CCTV. portable signal systems, cellular and spread-spectrum radio communications and a lap-top computer monitor and control system to manage traffic associated with several sporting events and the Minnesota State Fair. The PTMS has resulted in a package of devices which can be deployed in fairly short notice to manage traffic where no surveillance and control systems exists.

<u>Adaptive Urban Signal Control and Integration (AUSCI)</u>: I-394 is a radial freeway entering the Minnesota CBD from the west. It is fully managed with metering and CCTV. It connects to the city street system with four entrances and exits and two parking garages located over the freeway with additional exits. The city street signals are managed by a central computer system. During peak periods. incidents and events. there is need to better coordinate the city and freeway management. This project is in the preliminary design phase.

North Seattle Advanced Traffic Management System (ATMS) FOT

An FOT focusing on sharing date across boundaries and between adjacent traffic signal systems is the North Seattle Advanced Traffic Management System (ATMS) FOT located in North Seattle, Washington. Spearheading this FOT is Farradyne, Inc. The project start date was March 1994 and the completion date is March 1996. The estimated total project cost is $4.4M.

This project will explore methods for adjacent traffic signal systems to share loop detector and operational data to improve operations across boundaries and between adjacent systems. Jurisdictional issues which often prevent coordinating adjacent systems will be addressed during this project. Data will be obtained from several systems in the I-5 corridor north of Seattle by a single microcomputer connected with street or central master controllers belonging to the various jurisdictions within the corridor. The microcomputer will compile the volume, occupancy and operations data and transmit it back to the participating control systems. Each system will then use the data to improve its traffic management capabilities.

SCOOT Adaptive Traffic Control System FOT

The SCOOT Adaptive Traffic Control System FOT implemented in Anaheim, CA focuses on evaluating SCOOT as an adaptive signal timing control package. Participants in this FOT include the City of Anaheim, California Department of Transportation (Caltrans) and Odetics. The project start date was September 1993 and the completion date was December 1995. The estimated total project cost is $2,271,147.

This operational test will implement SCOOT in an area of the City of Anaheim's traffic control system so that it can be evaluated for its effectiveness as an adaptive signal timing control package. SCOOT automates data collection process and then automatically optimize traffic signal timing based on real-time traffic conditions. The test will also include the installation and evaluation of Video Traffic Detection System (VDTS) cameras in conjunction with the SCOOT system. The VTDS cameras will potentially provide a way to adjust the traffic count locations so that optimal data collection sites for the SCOOT system can be identified.

Integrated Traffic Management System FOT

The Integrated Traffic Management System FOT features an integrated, interjurisdictional approach to managing traffic associated with special events. Implemented in Anaheim, CA, the project participants include the City of Anaheim, Orange County Transportation Authority (OCTA), California Department of Transportation (Caltrans). FHWA, Federal Transit Authority (FTA) and the U.S. Department of Energy. The ongoing project started in September 1987. The estimated total project cost is $13,134,609.

The Anaheim Integrated Traffic Management System features an integrated, interjurisdictional approach to managing traffic associated primarily with special events in the City of Anaheim and surrounding parts of Orange County. The surface street system features computerized traffic signal control, highway advisory radio, closed circuit television and changeable message signs. The system is linked electronically with the California Department of Transportation's Traffic Management Center, which manages freeway traffic in Orange County. Several new traveler information elements have been recently implemented, such as traffic advisory telephone and cable television distribution of traffic information.

The project is fully operational and is continually being, expanded and enhanced. Three reports have been completed, one covering the system implementation process, one covering the multi-jurisdictional coordination of traffic signals along Katella Avenue and one covering the role of ITS in transit operations in Orange County. A fourth report covering the evaluation of the overall effectiveness of the system has been submitted.

SMART Corridor FOT

The SMART Corridor FOT focuses on the use of advanced technologies to advise travelers of current conditions and alternate routes. Implemented in Los Angeles, CA the participants in this FOT include Los Angeles County Transportation Commission (LACTC), the City of Los Angeles and FHWA. The project start date was July 1991 and the completion date was October 1995. The estimated total project cost is $47.0M.

The SMART Corridor is a joint operational project located along 12.3 miles of the Santa Monica freeway corridor in Los Angeles, The objective of the Smart corridor are to provide congestion relief, reduce accidents, reduce fuel consumption and improve air quality. This will be accomplished using advanced technologies to advise travelers of current conditions and alternate routes (using communication systems such as Highway Advisory Radio (HAR), Changeable Message Signs (CMS), kiosks and teletext), improving emergency response and providing coordinated inter-agency traffic management. The freeway systems will be operated by the State and the arterial streets by the City with coordination provided via voice communications and electronic data sharing.

Section 11 - Traffic Prediction Data Processing

This functional area deals with the prediction of future traffic situations. The principal predictive tools that are under development concern the prediction of real-time traffic volumes and the assignment of these traffic volumes to roadway nehvorks. These volume and assignment algorithms are necessary for several of the Advanced Traffic Management System (ATMS) strategies proposed by the ITS National Architecture program.

11.1 Alternate Traffic Prediction Data Processing Technologies

Predictive modeling approaches can be grouped into four categories: historical, data-based algorithms; time-series models; simulations; and neural networks. Research on the application of these four approaches to the demands of a real-time environment is underway on many different projects. Each project has developed their own set of conclusions as to which approach is the best.

Research performed at the University of California claims that improvements in computer storage have made a gradient projection approach using path enumeration superior to the Frank-Wolf algorithm. (1) A study by Smith and Demetsky compares the alternative approaches and concludes that the neural network appears to offer an attractive alternative because neural networks can model undefined, complex situations (2). The results of providing information to drivers with different levels of adherence to alternate routing instructions was discussed in one recently conducted project (3). and two of the authors have gone on to develop an assignment technique for determining an optimal path assignment scheme for users entering the nehvork for a short term future period.(l) These are only a few of the many projects that have recently been reported.

The work that is being disclosed in these reports is largely theoretical. However, several of the algorithms that are under development are on the verge of being tested in a real world environment. The one that is probably closest to an actual test is being conducted in Europe.

The DYNA Project

The “DYNA” project is part of the Drive II program, being sponsored by the European Community. The system under development as part of the DYNA project will model and predict traffic conditions in real time on a highway nehvork in the area around Rotterdam. These predictions will be used to provide information on congestion to a traffic operator and to drivers. The system receives traffic data such as traffic flow, average speed and average detector occupancy in real time, as well as having access to a database of historic traffic information.

The Real-Time Traffic Prediction System contains several submodels: a statistical model for filtering “noisy” traffic data, and for very short term predictions (prediction horizon: 5-15 min.), a dynamic traffic assignment model for short term predictions (prediction horizon: 15-60 min.), and a real time Origin Destination matrix estimation model to provide the necessary O-D information.

The present and predicted traffic conditions will be displayed for evaluation by the traffic operator, who can take appropriate action if required.

Incident Related Models

Although algorithms which identify incidents have been in existence for a generation, several of the newer algorithms include the ability to monitor the impact of the incident, and predict the impacts of these incidents on a dynamic basis.

One of these is the model developed by Chen and Chang for the FHWA which has a self-learning capability (5). This system is designed to detect incidents and to assess their severity in real-time. Another algorithm developed by Huang uses a combination of simulation and artificial neural network techniques to provide delay estimates to motorists several miles upstream of the incident (6).

11.2 Data Requirements and Processing

There are two major classes of data required for the real-time traffic diversion and assignment: static data and dynamic data. The static data components include network data- land use zoning information, structural information on the links, signal timing plans, etc. Geometric data includes number of lanes, lane widths, shoulder presence and widths, roadway configuration, and speed limits. Besides these, this data set also contains link by link historic traffic volumes, flow speeds and past incident occurrence data. Dispatch locations for all participating incident management agencies is also included in the incident management models. as well as operational data on route restrictions to specific traffic types, jurisdictional information, transit station locations, positions of water mains and access to major facilities like airports.

The dynamic data consists of the road and traffic information that changes periodically. This includes real-time traffic data, and for incidents, information on incident type, time of occurrence, location of occurrence, lane closures, vehicles involved, injuries or fatalities, etc.

11.3 System Hardware

In addition to the algorithm development previously cited it should also be mentioned that at least one study-is investigating the use of special purpose computers to speed the execution of the algorithms. (7)

The hardware requirements for the real-time prediction of traffic volumes and assignments are exemplified in the system developed by the Virginia Tech Center for Transportation Research for use in the real-time support for incident management (S). This system supports a data processing procedure which contains a GIS user interface and expert system response module. Once an incident has been detected and verified, the incident details are input into the model through the GIS user interface. This information includes incident type, location, time of occurrence. vehicles involved, injuries involved, fatalities involved, Hazrnat involvement, lane blockage, and other incident specific details. The geometric and land use information at the site are available from the data set.

Once the system receives the input information, the first action of the system is to provide an incident response plan from the response module of the expert system. The module selects the agency dispatch locations to respond and also picks a set of routes to the incident site for the emergency response vehicles. The final response plan is prepared following the execution of the duration prediction module, the delay estimation module, the network generator and the signal retiming model.

The system hardware developed by Virginia Tech Center for Transportation Research constitutes a SparcServer 1000 from MicroSystems, and eight Pentium (P90) machines. The SparcServer 1000 provides for a centralized computational facility: and the Pentium PCs allows a large degree of distribution of computing resources as well The most demanding pieces of software being run for this project are GIS ArcInfo and the expert system shell. The SparcServer 1000 houses four SuperSparc CPUs, capable of outperforming a single PC by as much as 10-15 times in raw computing power. This speeds and facilitates the execution of the ArcInfo and Smart Elements packages chosen for the process. Not only can more than one person use the systems at once. but the SparcServer can keep up with the constant load of running this CPU intensive software, allowing for a level of productivity that could not be achieved under a smaller server.

All eight of the Pentium machines are capable of network connection, and remote use of the SparcServer. The Network connecting the PCs and the SparcServer 1000 consists mainly of a central network hub capable of 10 megabits per second throughput, and a great deal of 10baseT cable. A system hardware setup diagram is shown on the Figure 6.1.

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11.4 Traffic Prediction Data Processing Related FOTs

Following are FHWA FOTs that focus on traffic prediction data processing technology. The information provided is from the US. Department of Transportation Project Book.

San Antonio TransGuide FOT

An FOT dealing with the installation of an advanced traffic management system is the San Antonio TransGuide FOT. implemented in San Antonio, Texas. Participants in this FOT include the Texas Department of Transportation (TxDOT), Allied Signal Technical Services Corporation, Southwest Research Institute (SwRI), Texas Transportation Institute (ITI) and the FHWA. The project start date was November 1993 with a completion date of December 1995. The estimated total project cost is $1,298,466.

The TxDOT is installing the first phase of an advanced traffic management system (TransGuide) in San Antonio at an estimated cost of $33 million. Upon completion of this first project, the three story control center and twenty-five (25) miles of the one hundred ninety 9190) mile proposed AIMS will be operational. TransGuide will provide:

- Complete Digital Communication network (voice, data and video);
- Communication standard "SONET";
- Fully redundant fiber optic network;
- Fault tolerant computer system;
- Software developed to "POSIX" standards;
- Fully developed Central Control facility with a test-bed development computer;
- Field equipment consisting of changeable message signs, lane control signals, loop detectors and surveillance cameras;
- Incident detection goal of 2 minutes; and,
- System response goal of under 1 minute after detection.

This Operational Test will document the San Antonio TransGuide system design rationale and goals, evaluate the system's success in meeting the design goals, and evaluate the digital communication network for cost effectiveness and benefits versus "traditional" transportation date communication systems. An additional element of this Operational Test is the on-line evaluation and comparison of several incident detection algorithms.

Section 12 - Signalized Traffic Control Algorithms

12.1 Signalized Traffic Control Algorithms Technologies

New and improved technologies in traffic signal controller units have expanded the role of traditional traffic control systems from time-of-day control with basic timing plans to systems capable of responding to fluctuations in vehicle demand or adapting new plans based on real-time traffic data. These algorithms include:

- Split Cycle Offset Optimization Technique (SCOOT)
- Sydney Coordinated Adaptive Traffic System (SCATS)
- Optimized Policy for Arterial Control (OPAC)
- Real-Time Traffic Adaptive Control (RT-TRAC)

Split Cycle Offset Optimization Technique (SCOOT)

The Split Cycle Offset Optimization Technique (SCOOT) is known as a third generation system that uses a real-time traffic model to control intersections. The SCOOT algorithm was developed by the British Government's Transport and Road Research Laboratory. The model continually optimizes the cycle length for each region, and the splits and offsets at each intersection, based on current traffic flow. This eliminates the need for timing plans. The prime objective of the SCOOT model is to minimize stops and delays. The software and hardware are compatible with both NEMA and Model 170 controller units. The SCOOT model is currently operating in two locations in North America: Oxnard, California; and Toronto, Canada.

SCOOT represents an important development that recognizes the errors of the earlier real-time control developments. It was implemented and tested in numerous locations and can be considered proven technology.

SCOOT was developed based on the following concepts:

- Minimize transients. SCOOT uses frequent small incremental alterations to split, cycle and offset. These alterations minimize transients but can add up to create substantially different patterns of coordination.

- Short term prediction. Most SCOOT decisions are based on the current situation and longer term predictions are seldom necessary.

- Fast response. In SCOOT every red/green transition is optimized. This enables SCOOT to respond to cyclic variations in traffic flow.

- Faulty detectors. Detectors are monitored continuously for faults. Suspect detectors are automatically ignored and cause the local controller to revert to fixed timing that have a minimal effect on the normal operation of SCOOT.

- The on-line traffic model. SCOOT uses data from the detectors to predict the queues at signal stop lines. This traffic model provides information from which the signal optimizes make their decisions.

- No background plans. SCOOT needs no initial fixed timing plans and can start from any traffic signal setting.

However, SCOOT also has some drawbacks including:

- Since the program was developed during the late 1970's, its highly centralized architecture reflects the computer and communications technology of that era. Consequently, the designers of this method were not able to take advantage of the microprocessor capabilities that exist today for the implementation of distributed control.

- Evidence shows that SCOOT does not consistently out-perform conventional off-line optimization methods.

The SCOOT model contains a large amount of useful traffic data, derived from the detectors. This includes traffic flows, delays, and various occupancy-related data. One type of information not generally present is turning data, unless there are detectors in turning lanes. A database called ASTRID has been developed for storing, processing and displaying SCOOT data.

Sydney Coordinated Adaptive Traffic System (SCATS)

The Sydney Coordinated Adaptive Traffic System (SCATS) is a computer-based area wide traffic control system developed in Sydney, Australia. SCATS is a complete system that includes hardware and software and operates in a real-time mode, adjusting signal timings based on current traffic flow and system capacity. A range of cycle lengths, split timings and offsets are predetermined for each subsystem. The system measures congestion and chooses the appropriate values to implement the new timing plans every cycle to minimize stops. delays and fuel consumption. The SCATS system uses a specific controller (Delta 3 SCATS) that is compatible with current NEMA connector configurations and other controller cabinet components: however the system is not directly compatible with either the NEMA or Type 170 controller units. A SCXTS system is currently operating in one location in North America, namely, Oakland County, Michigan.

SCATS utilizes a distributed intelligence, three-level, hierarchical system using microprocessors and minicomputers. The system architecture consists of a central monitoring minicomputer at the central center, remote regional minicomputers and local traffic signal controllers. For large scale networks, a management computer may be added to provide improved management support.

The local controller processes strategic data collected from traffic detectors, makes tactical decisions on signal operation. and assesses detector malfunctions. Each regional computer autonomously controls the intersections in its area. They implement the real-time operation of the signals by analysis of the detector information pre-processed by the local microprocessors. A minicomputer allows access to the regional computers for traffic data collection, data input, and monitoring. It performs the following functions without influencing traffic operation:

- Outputs traffic and equipment status for fault rectification

- Stores specified traffic data for short-term or permanent record

- Maintains a core image of each regional computer and reloads the regional computer if required

- Allows central control to monitor system, subsystem, or intersection, alter control parameters, manually override dynamic functions, or plot time-distance diagrams.

SCATS has some relevant program drawbacks which are:

- SCATS needs background plans.
- No studies have been made to determine the network benefits of SCATS timing plans compared to time-of-day plans.

Traffic flows are available from detectors and some turning flows are available where there are detectors in turning lanes; however for the purposes of producing new plans, manual counts are commonly carried out.

Optimized Policies for Adaptive Control (OPAC)

Optimized Policies for Adaptive Control (OPAC) was developed as an on-line signal timing optimization software and hardware control system for a single intersection control. The software and hardware developed is compatible with both NEMA and Model 170 controller units. An Advanced Transportation Controller (ATC) processes data from upstream vehicle detectors and develops real-time timing plans including cycle lengths, offsets and splits to be implemented by the local controller unit. The OPAC is currently under testing on the New Jersey State Route 18 to examine its application in a closed-loop system environment.

Real-Time Traffic Adaptive Control (RT-TRAC)

This project was contracted to Farradyne Systems by the FHWA in mid-1992 to develop and field evaluate a real-time. traffic adaptive signal control system that is similar to the SCATS and SCOOT systems, suitable for use in ITS environment by 1997. Currently four independent contracts have been awarded by FHWA to develop a real-time traffic adaptive algorithm for use in an ATC controller unit.

RT-TRAC will provide four levels of control: system, district, section, and intersection. Each level should be able to seek optimization within the constraints imposed by higher levels. These levels are defined as follows:

- The system level is the highest level and consists of all intersections connected in the network. This level will provide the means to execute global functions.

- The district level will be the next level of control. The system will be divisible into geographic districts of several square miles in size. Every intersection within the system will be required to be in only one district. RT-TRACS will support 16 districts, each with the ability to support functions that address a large area of a city.

- A section will be a logical cluster of intersections. Intersections may be assigned to one or more sections. There will be a maximum of 256 sections, but there will not be any limit to the number of sections to which an intersection can be assigned.

- The intersection is the lowest level in the hierarchy. RT-TRACS will be designed to control a maximum of 5,000 intersections, in order to accommodate universal control in large urban areas.

RT-TRAC will provide for short term and long term strategies. The short term strategies respond to the current traffic as measured by detectors. while the long term strategies manage congestion control for fall-back to off-line optimization feature. In both cases, a combination of strategic and tactical control decisions will be used to identify the system control level to be used in each section and to set signal timings accordingly.

RT-TRAC will support a minimum of four types of vehicle detector inputs: count, speed, occupancy, and vehicle probe data. Count detection will provide the number of vehicles counted; speed detector will provide the speed of each vehicle; occupancy detection will supply information regarding the percent of time the loop is occupied; and the vehicle probe data will provide count, travel time and vehicle classification.

The data should be available to RT-TRAC within one second of the event. The processing of the vehicle detector data will be essentially the same for a given measure regardless of the technology. RT-TRAC will employ logic to determine if the observation is reasonable, and will flag illogical data.

RT-TRAC will consist of a variety of signal control strategies, one of which will be dynamically selected for operation at a particular set of intersections at any given time. This selection of signal control strategies will be changed according to the time-of-day, the prevailing traffic conditions, and other appropriate circumstances (e.g., holiday, special event, weather). An option for RT-TRAC will be that it could be operated with only a subset of the signal control strategies available, for use in those street networks and local jurisdictions that have no perceived need for the more sophisticated range of control strategies.

12.2 Signalized Traffic Control Algorithms Related Operational Tests (FOTs)

Following are FHWA FOTs that examine the signal traffic control algorithm technology. Information is provided from the U.S. Department of Transportation Project Book.

Fast-Trac FOT

The Fast-Trac FOT focuses on a combined Advanced Traffic Managment Systems (ATMS) and Advanced Traveler Information Systems (ATE) technologies implemented in Oakland County, Michigan. Partners in this FOT are FHWA, Michigan DOT, Siemens Automotive, GM, Ford, Chrysler, Road Commission for Oakland County (RCOC), County of Oakland, AWA Traffic System - America and the University of Michigan. Project start date was April 1992 with a completion date of January 1996. The estimated total protect cost is S70.0M.

FAST-TRAC (Faster and Safer Travel through Traffic Routing and Advanced Controls) will combine Advanced Traffic Management Systems and Advanced Traveler Information Systems technologies in Oakland County, Michigan. The Australian SCATS traffic adaptive control system will be installed throughout Oakland County, Michigan. Traffic detection for real time traffic control will be provided using Autoscope video image processing technology. For the Advanced Traveler Information Systems part of the test, vehicles will be equipped with the Siemens Ali-Scout route guidance and driver information system. Infrared beacons will be installed at critical locations in the network to provide for a continuous exchange of real time traffic and route guidance information. A Traffic Operations Center has been established, not only as the heart of FAST-TRAC operations, but also as the focus for systems integration.

Integrated Ramp Metering/Adaptive Signal Control FOT

An FOT evaluating the operational effects of balancing traffic flows between freeways and parallel arterial streets is the Integrated Ramp Metering/Adaptive Signals Control FOT in Irvine, California. Partners in this FOT are the California Department of Transportation (Caltrans), City of Irvine, Farradyne Systems, University of California - Irvine and the FHWA. The project start date was September 1993 with a completion date of December 1996. The estimated total project cost is $3,337,000.

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Section 13 Database Processing

13.1 Alternate Database Processing Technologies

The database processing components of ITS will serve critical functions of gathering and distributing data throughout the system.

A database management system (DBMS) provides the necessary access control and support. Data aggregation and processing algorithms of a DBMS will be responsible for placing the collected data into the database where it may be accessed by the application programs within the system and thus, be made available to the traveler.

Data will be received from a variety of sources. Many types of data collection hardware may be in use in the field, and many sources may enter manually collected data. Therefore, it will be necessary to convert the received data to a common format for each data type prior to insertion of the data into the database. Processing may also be needed in order to correctly associate data within the database. Some mathematical or statistical processing may be necessary to convert the raw data into a form that is suitable for use in the database and by other processes.

In this section. the types of data that an ITS system would likely be required to support will be discussed. The data collected from the devices in the field and data that is collected manually will be presented. and the processing that is typically required to make this data useful is discussed in the following sections.

Data Types

Many types of data are required to represent the road network and the associated components in ITS especially in the ATIS and ATMS areas.

Network Data

The road network may be represented by a link-node model. Dynamic or historical link information might also be applicable in trip planning and routing in order to compute travel times and predict potential areas of congestion. Real time link data might be used by the traveler advisory system to make recommendations enroute. The static attributes of the links can provide a geographically encoded description of the road network and surrounding facilities which might be useful for route guidance, automatic vehicle location, and dispatching of services.

Many of the other items that are a part of the road system will be classified as devices. These devices include detectors. controllers, variable message signs, highway advisory radio, etc. Each device will also be represented in the database.

Static vs. Dynamic Data

The static part of the data does not change, or it is changed only when attributes of the road network are changed. The static data generally describes configuration and identification parameters. In contrast, dynamic data changes often, either on a periodic or an event driven basis. Dynamic data might include measurement data or status data. For a detector, static data might include the detector identifier, the location of the detector, the agency that owns it, the type of the detector, etc. The dynamic data for a detector might include speed, volume, and vehicle type, depending on the type of the detector. In addition, status information reflecting the operational state of the detector might also be provided as a part of the dynamic data. For variable message signs and highway advisory radio, the static data might include location information and the dynamic data might include the numbers of current messages or the actual text along with the status.

Incident Event Data

The incident information may have an impact on routing decisions and estimated travel time, and it may require that advisories or warnings be transmitted to the traveler.

Much of this information will be manually collected by traffic engineers in contact with emergency services, maintenance crews, etc. This information, once collected, will be manually entered into the database. Incident information is dynamic in nature, coming into existence when an incident has been placed into the system. It is modified as the incident is managed, and it is eventually cleared. The impact on travel and the appropriate advisories may change several times during the incident. As such changes take place, user services that are interested in incidents will have to be notified. The data will need to be filtered and packaged in a format that is appropriate for the public. This will differ considerably from that information which is appropriate for incident management purposes. The most likely approach will be to advise the traveler of delays resulting from the incident and not provide details about the incident. Incident information may be useful for the trip planning routing, and traveler advisory services.

Traveler Services Data

Another category of manually collected and input data that could be provided by the ATIS is information about services and attractions that are available along or near the road. This data will be basically static, because the available services and attractions change rather slowly. A variety of data sources and types may be reasonable for this category, including text descriptions of services and attractions including operating hours. audio descriptions. and video. Depending on the user interface, multi-media presentations of this information may be possible. The storage and processing requirements for multi-media data are high, so analysis will be required to determine appropriate levels of hardware and software support. Services and amactions may be indexed geographically and/or by the nearest link or node on the road network. This information may be used by the trip planning, and traveler and routing services.

Public Transportation Data

Similar to event construction, and traveler services data, the bulk of data regarding public transportation may be manually entered into the database. This data, which could include locations of transit stops together with schedule, connection, and transfer information, will be mostly static in nature. The information will need to be updated only after regular schedule reviews/updates. Exceptions to this may be temporary changes in transit schedules due to special events (e.g., Main Street is closed to traffic forcing alternate routing). The transit agency would be primarily responsible for the input and maintenance of this data. Data entry could be achieved either through an in-house interface or by coordinating schedule updates with the central processing facility.

AVL Data

The rural ATIS may aIso process AVL data. The specific technologies that are employed will dictate the amount of processing that is required at a centralized facility to compute location data. Independent of that processing. the location and vehicle ID must be processed by the system along with any other command or request information that might accompany it. Additionally, AVL data may be used to report real time transit schedules. providing travelers with information such as how many minutes until the next bus/train arrival. Real time knowledge of transit's schedule adherence will also allow operations to coordinate intermodal connections and ensure travelers that their connections will be made. This is another application in which attributes may be associated with links in the network. The AVL data may be used by the route guidance, traveler advisory, and the emergency services components.

Database Processing

Data Processing

There are several forms of data processing in urban trafftc management systems. The baseline functionality would generally involve translating the data received from the devices in the field into a form that is suitable for storage in the database. This often involves unpacking blocks of data that are received from devices in the field to separate out the data that belongs to each individual device that is interfaced to the controller. Then, for each device, the data must be translated and reformatted into the structures that are used to represent the data in the database. Finally, the data base must be updated with the new values.

For some devices, this procedure will likely be performed on a cyclic basis, driven by the communications hardware. Typically, for directly connected detector processing stations, data would be received every 30 to 60 seconds. Other devices may only transmit data when a change occurs.

Raw detector data is rarely used within a traffic system. More commonly, the data is aggregated over a specified time period. A very common aggregation period is five minutes. The aggregation period is intended to ensure that measurements are collected for a meaningful period. Without aggregation, the system may be affected by statistically insignificant deviations in measurements. An aggregation period may not necessarily coincide with a data collection cycle. so normalization is often performed to alleviate this effect. The normalization will adjust the measured data to reflect complete data collection cycles. It is important to note that aggregation time does not necessarily restrict the frequency of data updates.

Link status data can be derived from the aggregated and normalized detector data. The link configuration information in the database can indicate which detectors contribute to the measurement values for each link.

Database Design

The amount of data, the complex relationships between the data, and the multi-user access requirements will likely necessitate the use of a database management system. Traditionally, a relational database would be used for this type of application. However, the use of a relational database has several drawbacks for a geographically dispersed system. The relational model is very flat, requiring that data elements be placed into rows with columns that are very simple data types. The relationships between data elements are represented through the use of primary and secondary keys and the use of complex queries known as "joins".

Network support has improved significantly over the years, as has the ability to use multiple data bases. However, the distribution of a single database over several hosts, and specifically splitting a table between machines, remains a problem for relational databases.

A different approach to the database problem is found in the newer object oriented databases (OODB). The OODB allows the representation and storage of complex data elements. Data elements are stored as objects which generally correspond to the real world objects such as roadway links and intersection nodes. Objects may also contain other objects and pointers to additional objects. The pointers allow complex relationships between ITS elements to be utilized without the use of the expensive database join operation. As a result, OODBs tend to give faster performance for complex distributed systems which have many data interrelationships.

A feature of many of the OODBs is that they were designed from inception to support widely distributed databases. The bookkeeping required to find and maintain the data objects is hidden in the OODB internals. For a system like the ATIS which is very complex and very distributed. the OODB model is a good fit. It allows integration of data and processing that is distributed among geographically dispersed data collection and processing stations.

Real-Time Data Distribution

The distribution of data in ATIS has several characteristics that differ significantly from an urban traffic management center and system. The most significant difference is that the ATIS may only be connected to the data providers for intermittent short time periods. In addition, communications bandwidth may be limited by the media that are available between the data providers and the users at remote sites or in vehicles.

The dynamic data will arrive at various times, some periodically and some event driven. Distributing this data upon arrival may not be appropriate, because it would imply continuous connections with each user that requires the data. Furthermore, it may not be desirable to constantly interrupt the users with updates. Therefore, aggregation of the dynamic data may be in order. This aggregation would serve to collect all of the updates that occur over a specified time period and present them to interested users in a single burst, or on request. If a specific data item has been updated several times during the aggregation period, the users would probably be interested in only the most recent value, eliminating the need to transmit the intermediate data. The transmission periods may be either periodic or even driven. Periodic updates might be appropriate for remote computer sites and automated kiosks. Event driven updates might be appropriate for in vehicle systems. since they might only be accessible when they are within range of a data delivery system.

Some ITS projects have a regional Traffic Operation Center that will require a combination of dynamic data (e.g., link volumes/travel times, transit schedule adherence, VMS conditions. incident reports, equipment status) and static data (VMS libraries, timing plans, GIS, etc.). The regional TOC may also require timely information for the entire roadway network from the local TOCs including weather conditions, special events, construction activities, and emergency situations.

The local TOCs will be collecting and processing this data within their own databases. When data arrives that is required by the regional TOC system, each local system may convert that data to the form required by the regional database and transmit the data to the regional TOC. When the data arrives at the regional database. it becomes available to the entire system immediately. It is important to note that the regional database design does not necessarily dictate the design of the local databases. Differences between the local and regional database definitions may be accommodated during the conversion phase of data forwarding.

13.2 Database Processing Related FieId Operationai Tests (FOTs)

Following are FHWA FOTs that focus on database processing technology. The following information is from the U.S. Department of Transportation Project Book.

Advanced Rural Transportation Information and Coordination FOT

An FOT dealing with coordinating the communications systems of several public agencies is the Advanced Rural Transportation Information and Coordination FOT located in Itasca and St. Louis Counties in Minnesota. Participants in this FOT include Minnesota DOT, Minnesota State Patrol, Arrowhead Transit. City of Virginia Transit, Arrowhead Regional Development Commission and the U.S. West. The project start date was October 1994 and the completion date is April 1996. The estimated total project cost is $1,542,000.

The Advanced Rural Transportation information and Coordination (ARCTIC) project is part of the Minnesota statewide ITS program, Guidestar. ARCTIC will coordinate the communication systems of several public agencies (highway, state patrol and transit) by establishin, a centralized communication site. Improvements are expected in response time to accident and road condition emergencies, and real-time vehicle status and schedule information will be provided through ARCTIC. The primary objective of ARCTIC is to evaluate the improvement in the transportation system and traveler safety by establishing a centralized communication site.