FINAL

Multi-Modal Traveler Information System

Alternative GCM Corridor Technologies and Strategies Working Paper #18550.01

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GARY-CHICAGO-MILWAUKEE CORRIDOR
MULTI-MODAL TRAVELER INFORMATION SYSTEM
ALTERNATIVE GCM CORRIDOR TECHNOLOGIES AND STRATEGIES

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1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this working paper is to summarize current and evolving Intelligent Transportation System (ITS) technologies and strategies related to the design, development, and deployment of regional multi-modal traveler information systems. This report provides a resource document and a framework to assist in the selection of state-of-the-art ITS technologies that may be incorporated into existing and proposed transportation management systems within the Gary-Chicago-Milwaukee (GCM) Corridor and incorporated into the GCM Corridor Architecture and Gateway Traveler Information System (TIS) design.

1.1.1 Goals of this Working Paper

The goals of this working paper are as follows:

- To summarize ITS technologies and strategies which could be incorporated into the GCM Corridor Architecture and Gateway TIS design.
- To summarize ITS technologies which are or could be implemented as integral infrastructure components of transportation management systems within the GCM Corridor and be used as data sources.

1.1.2 Intended Audience

This working paper is intended to serve as a resource and a guide to the members of the GCM Deployment Committee, Architecture/Communications/Information (ACI) Work Group, Traffic and Transit Management (TTM) Work Group, project managers, system designers, system developers, and system integrators.

1.1.3 Working Paper Organization

This working paper is organized around the following areas:

- Surveillance
- Traveler Information
- Control Strategies
- Communications
- Operations Centers

The technologies and strategies associated with each area will be described in this paper. In addition to describing the technologies and strategies, the advantages and disadvantages will be summarized within each section.

1.2 PROJECT OVERVIEW

1.2.1 MMTIS Project Overview

The Multi-Modal Traveler Information System (MMTIS) project revolves around the concept of a GCM Corridor traveler information system (TIS). It involves research in the areas of ITS systems in the corridor which are currently deployed and proposed systems identified in regional strategic plans or early deployment studies. This information will be used in recommending a corridor architecture that best suits the characteristics of the diverse resources within the corridor. Along with the corridor architecture, a corridor strategic plan will be developed. Another key component of the MMTIS project is the design of the Gateway Traveler Information System. The Gateway will be the traveler information collection and distribution hub for the GCM Corridor.

1.2.2 Definitions, Acronyms, and Abbreviations

Document #17100-1, MMTIS Project Glossary, contains all definitions, acronyms, and abbreviations associated with this project. It also contains information relating to ITS, communications, computer technologies, and other standards.

1.3 RELATED DOCUMENTS

This working paper is one in a series of documents and working papers produced to support the design of the GCM Corridor Multi-Modal Traveler Information System. Related documents and working papers include:

- Document #17100 - Project Operations Plan
- Document #17100-1 - MMTIS Project Glossary
- Document #17150 - Gateway Traveler Information System (TIS) System Definition Document
- Document #17200 - GCM Corridor Architecture Functional Requirements Document
- Document #17250 - Gateway Traveler Information System (TIS) Functional Requirements Document
- Document #17300 - GCM Corridor Architecture Interface Control Requirements Document
- Document #17350 - Gateway Traveler Information System (TIS) Interface Control Requirements Document
- Working Paper #18250 - Cellular 911 - State of the Practice
- Working Paper #18380 - Corridor User Needs and Data Exchange Elements
- Working Paper #18400 - Current and Proposed ITS Initiatives
- Working Paper #18500 - GCM MMTIS Strategic Plan
- Working Paper #18520 - Performance Criteria for Evaluating GCM Corridor Strategies and Technologies
- Working Paper #18550 - Alternative GCM Corridor Technologies and Strategies
- Working Paper #18600 - System Interfaces and Information Exchange
- Working Paper #18700 - Information Clearinghouse - Initial Administrative Network

- Working Paper #18790 - Information Clearinghouse - Final Network
- Working Paper #18830 - Weather Detection System Standard Message Sets (Proposed)
- Working Paper #19140 - Gateway Traveler Information System (TIS) Phased Implementation Plan
- Working Paper #19210 - Lessons Learned
- Working Paper #19220 - Gateway Design Options
- Working Paper #19840 - Variable Message Signs (VMS)/ Highway Advisory Radio (HAR) State of the Practice
- Working Paper #19845 - Variable Message Signs (VMS)/ Highway Advisory Radio (HAR) Suggested Guidelines

2.0 SURVEILLANCE

Until the last decade, the primary roadway surveillance technologies included roadway inductive loop detectors, pneumatic road tubes, and temporary manual counts for both real-time and historical traffic data collection. However with technological innovations, several new designs of different types have been developed and are being field tested in operational tests throughout the Country.

Detectors are either in-pavement types, such as inductive loops, magnetometers, and self-powered detectors, or overhead types. Overhead detectors such as microwave, radar, video image and ultrasonic can be attractive due to less impact on traffic during construction and maintenance. However, they do exhibit certain degrees of inaccuracy depending upon placement and other factors. Descriptions of these types of detectors follow.

2.1 IN-PAVEMENT DETECTORS

As the name implies, the detection element of these surveillance technologies is embedded in the roadway pavement sensing the presence of vehicles as they pass over the detection zone. The primary technologies currently in use are:

- **Inductive loop** – Most common type of in-pavement detector. Loops of wire are cut or embedded into the roadway, and vehicles passing over or stopping on the loop cause the inductance/magnetic characteristics to change. This change is detected by an "amplifier" located in a cabinet mounted next to the roadway.

- **Magnetometer -** Indicates the presence of a metallic object by the disruption caused in a magnetic field (induced or natural).

- **Self-Powered Vehicle Detector (SPVD) -** Similar to magnetometer, as described below.

These technologies can detect volume, occupancy, and when installed in pairs, speed.

In newer installations, loop reliability has been dramatically improved by encasing the loop wire in plastic tubing, using better sealant, and embedding pre-formed loops (consisting of loop wires in PVC conduit) into the roadbed.

The SPVD, developed with FHWA support, consists of an in-road sensor containing a transducer, an RF transmitter with antenna, a battery, and a controller housed in a cabinet along the side of the road. The in-road sensor operates on the same principle as the magnetometer sensor. An internal lithium battery with a service life of 5-7 years powers it. Data are transmitted from the in-road sensor to a roadside processor via a spread-spectrum radio link, obviating the need for lead-in or interconnecting cable. One particular version of the SPVD is available from Nu-Metrics (i.e., "Groundhog") and orders have been placed by various agencies. Along with providing volume, occupancy, speed (bins), and classification (bins), this unit also provides data regarding pavement temperature. With the Nu-Metrics device, up to 64 detectors can be connected to a single roadside processor, provided they are within approximately 650 feet of the processor.

2.2 OVERHEAD MOUNTED DETECTORS

Installation of the detection unit above or to the side of the roadway eliminates damage due to pavement deterioration and permits maintenance activities to be performed with minimal disruption to the traffic flow. Moreover, these overhead mounted detectors can generally remain operational during roadway reconstruction and rehabilitation activities that usually destroy loops and other in-pavement devices. One potential drawback with these technologies is that their optimum placement may be directly over the travel lane(s); and for such an installation to be cost-effective, an existing overhead structure (e.g., overpass, sign support) is required. The location, spacing, and placement of these existing structures can impact the effectiveness of the surveillance subsystem.

2.2.1 Microwave Detectors

One of the more common types of overhead detectors is a microwave based system. Microwave radar detectors direct low power microwave energy toward a roadway. As vehicles pass through the beam, a portion of the energy is reflected back (i.e., back scattered) toward the detector where presence and speed can be measured. Some microwave detectors measure the distance between the detector and the vehicle, and thus provide presence information when there is a change in this distance (i.e., when a vehicle is present). Other types of microwave detectors measure speed and detect vehicles using the Doppler effect. Because the measured speed depends on the angle between the direction of travel of the vehicle and the direction of propagation of the radar energy, the mounting angle is critical. These detectors can only detect vehicles moving at speeds greater than 2-3 mph. Therefore, they are not true presence detectors. Detectors are available in both wide and narrow beam widths, with different characteristics and zones of coverage.

The primary issues that define success of a microwave detector implementation are the differing areas of coverage, and the difficulty in determining the exact area of coverage of the detector. In addition, the tendency for occlusion of the far lanes by blockage of the radar beam by trucks in the near lanes has been a problem. However, there have been successful side-mount implementations of the *RTMS detector* by EIS. Another issue is the fact that these types of detectors cause auto radar detectors to falsely alert, which has caused varying degrees of public concern.

2.2.2 Ultrasonic Detectors

Ultrasonic vehicle detectors can be designed to receive range or Doppler speed data, the same information measured by the microwave radar detectors. Ultrasonic detectors transmit sound waves, at a selected frequency between 20 and 65 kHz, from forward-looking or side-viewing transducers into an area defined by the beamwidth pattern. A portion of the energy is back scattered or reflected from the road surface or a vehicle in the field of view. The preferred mounting positions for range-measuring (presence) ultrasonic detectors are forward and side viewing. The speed-measuring ultrasonic detector is mounted overhead facing approaching traffic. The transducers in both the presence and speed-measuring ultrasonic devices convert the received sonic energy into electrical energy that is fed to signal processing electronics either co-located with the transducer or located in a roadside controller.

2.2.3 Infrared Detectors

A new type of overhead device is the infrared detector. Infrared detectors consist of both active and passive models. In the active system, detection zones are illuminated with low power infrared energy supplied by light emitting diodes (LEDs) or laser diodes. The infrared energy reflected from vehicles traveling through the zone is focused by an optical system onto a detector matrix mounted on the focal plane of the optics. Real-time signal processing techniques are used to analyze the received signals and to determine the presence of a vehicle. Changes in received signal levels caused by environmental effects, such as weather, shadows, and thermal heating, can be automatically corrected by the processing.

Passive infrared detectors provide presence information. They use an energy sensitive detector element to measure, without transmitting any energy of their own, the change in energy emitted when a vehicle enters its field of view. The source of this energy is blackbody radiation produced by the non-zero temperature of emissive objects.

Several disadvantages of infrared detectors are often cited. Changes in atmospheric water content (as manifested in fog, haze, and rain) and pollutant levels can cause scatter and absorption of the infrared beam and received energy. It is hoped that these problems may be mitigated by using a detector operating at the longer wavelengths of the infrared spectrum. However, there are not any definitive resolutions to date.

2.2.4 Video Image Detectors

A technology which has rapidly gone from “experimental” to “proven” in the last several years is Video Imaging Detection (VID) image processing technology. These devices, developed from machine vision technology, extract real-time traffic flow data (e.g., volume, occupancy, speed, length) by using microprocessor-based hardware and software to analyze video images of the roadway.

Many of the current VID systems utilize a variety of signal processing algorithms to gather traffic flow data. These systems rely on user-defined detection zones within the camera’s field of vision. Each time a vehicle enters or crosses this zone, a presence signal is generated that can be processed to provide volume, speed, classification, and occupancy measurements. Multiple detection zones can be located within the image and can be configured to suit the road geometry.

Newer VID systems identify edges on an object (such as a vehicle) and track these unique edges through the camera’s field of view. The persistence of individual tracks is used to determine vehicle volume and type, and can reveal data on events such as turning movements at intersections, sudden lane changes, vehicles traveling in the wrong direction, and stationary vehicles.

The accuracy of VID is very sensitive to camera placement. The optimum situation is to have the cameras mounted as high as possible (at least 25 feet), and be centered over the roadway and aimed at a steep angle, though an oblique angle may be tolerated if the camera is mounted at least 45 feet high. Conditions that vary from this optimum placement typically result in an increase in vehicle speed measuring errors, which are proportional to the vehicle's height divided by the camera's mounting height. A major design concern with camera placement and VID is occlusion, when the image of one vehicle partially or completely masks the image of an adjacent vehicle. Positioning the camera well above the center of the roadway will resolve most occlusion problems, but this may not always be feasible. Even with this type of arrangement, densely-packed or congested traffic may still cause occlusion.

There do remain some issues which need to be addressed when the implementation of VID is considered. First, the camera needs to be mounted on a stable platform, thereby requiring specially designed poles, or other mounting hardware to be used. If care is not taken in regards to the mounting, any camera movement caused by the wind or vibration typically will introduce measurement errors. In addition, the cost of a VID processor is still expensive. Although recent improvements have allowed additional cameras to be connected to each processor, care must be given to the actual design and implementation to assure a cost-effective detection solution.

2.2.5 Laser

With the rapid development of laser technology, applications are widely gaining ground in the ITS industry. Laser sensors for traffic monitoring and control have the capability of measuring vehicle speed and volume, and also of classifying vehicles. Laser sensors can also be used to monitor other traffic parameters such as density, flow rate, and queue length. Although there is not currently a great deal of information available on in-place laser detection technologies, with the existing pace of development, laser technology should be followed to allow for future implementation.

2.3 ADVANTAGES AND DISADVANTAGES OF ROADWAY BASED DETECTORS

Selection of the appropriate surveillance technology is a complex task that includes consideration of many factors. In addition to the availability and demonstrated capability of the detectors, several other criteria must be considered, including:

- Reliability
- Cost
- Flexibility
- Installation requirements
- Operational environmental and maintenance requirements
- Data requirements
- Representative of current technology

Exhibit 1 summarizes detector technologies by providing a list of detector technologies, how they are mounted, the parameters that may be detected, advantages and disadvantages, reliability, and approximate costs as well as the current status of each technology.

Technology	Mounting	Obs	N	Detection Area	Advantages	Disadvantages	Reliability	Status	Approx. Cost
Loop	In Pavement	V,O,S,L	1	Size of Loop	Low/unit cost	-Not suitable for bridge decks/overpasses -Traffic interrupted for repair	High for loop when installed properly	Operational	$500
Laser	Overhead	V,O,S,L	2	Set to lane width	High accuracy -small vehicle, vehicle in tow, and motorcycle detection	-No maintenance record available -Traffic interrupted for maintenance	High	To be installed on Canada's Hwy. 407 and Ca SR91	$10k
Magnetometer	Under bridge decks or in pavement	V,O,S,L	1	Point	Small vehicle or obstacle detection, multi-lane coverage	-Traffic interruption for installation and repair when in pavement	Moderate	Operational	$600
Microwave (Wide)	Side or Overhead	S	1-4	Depends on Distance	Direct measurement of speed	Only provides speed data	High	Operational	$630-$995
Microwave (Narrow)	Overhead	S	1	Depends on Distance	Direct measurement of speed	Only provides speed data	High	Operational	$630-$995
Microwave (Fwd)	Overhead	V,O,S,L	1	Minimum 7-ft length	No lane closures	Side mounted may have masking of vehicles	Moderate	Operational	$3,500
Microwave (Side)	Side	V,O,S,L	1-12	Depends on Distance	No lane closures	Side mounted may have masking of vehicles	Moderate	Operational	$3,500

Obs = Observable parameter
O = Occupancy
V = Volume
S = Speed
L = Length
* = Parameter can be measured in a paired-configuration
N = Number of lanes covered by single detection unit
"Overhead" implies both forward- or back-looking, except as noted.

Exhibit 1: Detector Technologies

Technology	Mounting		Obs	No.	Detection Area	Advantages	Disadvantages	Reliability	Status	Approx. Cost
Ultrasonic	Overhead (downward)		V,O,S*,L*	1	Depends on distance and beam width	-Compact size - Installation/ maintenance may not require lane closure -Large base in Japan	-Accuracy may be affected by variations in air temp and water concentration -One per lane required	High	Used in Japan	$560 - $650
Infrared	Passive	Overhead (downward)	V,O	1	Depends on distance and beam width	-Installation/ maintenance may not require lane closure -Compact size	-Susceptibility to ran, fog, haze, and other atmospheric obscurants	Moderate	Used in Europe	$820 - $1400
	Active	Overhead	V,S,O,L	1						$3200 - $8000
SPVD	Roadway		V,O, S,L	1	Point	Fast installation – does not degrade over time as loops do.	Batteries must be replaced on some units – Solar units covered in snow or mud	High	Operational	$1450 - $2000
Video Image Detection (VID)	Overhead or side		V,O, S,L	3	User defined	-Installation /maintenance may not require lane closure -Multiple lanes observed -Detect zone user defined	-Accuracy sensitive to camera placement (occlusion) -Susceptible to adverse weather -Roadway lighting required for accurate nighttime data	Moderate	Operational testing (NJ, MN)	$17,000 - $25,000

Obs= Observable parameter
S= Speed
V= Volume
N= Number of lanes covered by single detection unit
O = Occupancy
L= Length
*= Parameter can be measured in a paired-configuration
"Overhead" implies both forward- or back-looking, except as noted.

Exhibit 1: Detector Technologies (Continued)

2.4 CCTV SURVEILLANCE

Closed circuit television is both an incident detection and verification method. CCTV cameras can be fixed position, but are normally equipped with PAN/TILT/ZOOM assemblies. Most ITS applications use color CCD, solid state cameras. These cameras are normally mounted within environmental enclosures, sealed from weather. The driving issue when installing a camera system is not the camera technology itself, but the method by which the video images will be sent to the control center. This issue is discussed in Section 4, Communications.

Design issues include:

- Type of zoom lens to use
- Desired field of view
- Stable mounting for camera

2.5 TRANSIT DETECTION

Transit operations can also be monitored to insure safety and security while traveling and to monitor schedule adherence. Some of the same technologies that are used for roadway surveillance can be applied to transit operations, such as CCTV monitoring.

In an attempt to prevent train collisions, collision avoidance measures can be implemented. Presence detection devices can be placed along the rails to detect trains and determine the speed of the train. These detectors can be spaced in a way as a means to determine the approximate spacing between trains. If the detector detects a train that is too close or moving at a speed that can cause it to collide with another train, an alarm can be sent to the operators of the trains and the system operator. Another technology used in this area is Car Side-Door Monitoring. Automatic Passenger Counters and Platform Detection Devices can be used to determine passenger loading information.

A less expensive proposition than as described above, would be to set up tag readers on the trains to verify the location of the train. The tags can also be used to schedule maintenance periods for rail cars by reading the tags of train cars as they enter the maintenance facility. This data can also be used to provide a time period since the last maintenance check for the rail car.

Issues to be considered when deploying transit surveillance are:

- Parameters to be detected
- Installation schedule and continued operations
- Maintenance considerations

2.6 ROADWAY CONDITION INFORMATION

Road Weather Information Systems (RWIS) have been proven to be effective devices in providing real-time information to those who maintain, operate and construct highways. RWIS have also aided in relaying accurate weather conditions to travelers, especially in areas prone to severe and highly variable weather conditions.

Pavement condition sensors are available from numerous manufacturers, including Vaisala, Surface Systems, Inc., and Aanderra. A road condition sensor is placed near the surface of the roadway and measures surface and subsurface temperatures. This sensor has the capability of differentiating the surface conditions based on temperature, conductivity, polarity, and/or capacitance. With these differentiating capabilities, the sensor can determine the state of the roadway surface – dry, wet, snow, ice, or frost. The sensors can also calculate the amount of de-icing chemical remaining on the surface of the road, and determine when surface moisture will start to freeze.

Surface Systems, Inc. (SSI) is the largest producer of ice detection systems in the U.S. and has the majority of market share in the aviation industry. SSI has two types of sensors:

- **Surface Sensor -** Approximately 5 inches in diameter and is placed in a 5.5 inch diameter hole flush with the pavement surface. This sensor provides pavement temperature, wet/dry status, and snow/ice alert.

- **Sub-surface Sensor** - Installed at a depth of approximately 16 inches and is located directly below the surface sensor. Highway officials have used this sensor to determine frost depth, and to regulate truck load and routing based on the frost level below the highway surface.

3.0 TRAVELER INFORMATION

3.1 BACKGROUND

Traveler information technologies provide the means by which the traveler (and soon-to-be traveler), using public or private transportation, receives real-time information regarding the roadway and transit network. Most of the information is obtained by the surveillance elements discussed earlier in this report and processed by central hardware elements in an operations center for dissemination, utilizing a variety of audio and visual techniques. The goal of a regional multi-modal travel information system is to gather the available information from the individual regional transportation management systems and process these data for distribution back to the individual systems, to independent service providers, and possibly directly to the general public. Traveler information can be categorized into pre-trip and en-route information.

3.2 PRE-TRIP INFORMATION TECHNOLOGIES

There are a wide variety of public and private traffic information services which are available or are being evaluated throughout the country.

3.2.1 Computer-Based Systems

Computer-based pre-trip traveler information systems include the Internet, Electronic Bulletin Board Services, and Interactive Television. These technologies provide access to pre-trip information from the home, workplace, or hotel.

3.2.1.1 Internet

A wide variety of organizations have developed, or are currently developing, pages on the World Wide Web which provide highway and transit related transportation services and information for major metropolitan areas around the country. These pages provide both static and real time information, and can be useful for obtaining information before a trip commences. Current Web pages include video capture from surveillance cameras, area map displays showing traffic conditions, detailed incident and construction information, route planning and directions, airline schedules, transit schedules and fares along with such traditional elements as “yellow pages” and tourist information.

Key issues include:

- Ownership of the data - cannot display copyrighted map data without permission.
- Accuracy and consistency of data presented
- Communications bandwidth to web site - to ensure adequate performance

Examples include:

- http://www.ai.eecs.uic.edu/GCM/GCM.html
- http://trafficview.seattle.sidewalk1.com/applet.asp
- http://www.smartraveler.com/cin/

- http://www.atlanta-traveler.com/traffic/rttraff.htm
- http://www.wsdot.wa.gov/regions/northwest/nwflow/

Implementation can be handled by the agency or an Independent Service Provider (ISP). The surveillance, incident and construction data are generally exported in GIF or HTML format and downloaded by the user. New technologies include JAVA appletts which download a bitmap graphic background then overlay this image with dynamic ICONS for freeway segments which are updated periodically as traffic conditions change.

Another aspect of Internet utilization is the development of Intranet, or internal network access for people with direct access to a LAN/WA. With the low cost of today's web servers, use of an intranet can provide access to travel information and system information within an organization or defined group without the necessity of developing specific client-server applications. Rather, anyone on the network (LAN/WAN) with an Internet browser, can have access to the system.

3.2.1.2 Electronic Bulletin Board Services

Electronic Bulletin Board Services (BBS) have been used for a small market of on-line information. However, they are now being replaced with World Wide Web sites available over the Internet either directly or through such service providers as America On Line, Compuserve, MSN, etc. Further development and deployment of dedicated BBS is unwarranted.

3.2.1.3 Interactive Television

Interactive television is similar to cable television in that real-time information is made available to travelers. The major difference between the two is that cable television simply presents the information on a repetitive basis while interactive television allows a traveler to directly query for specific information at any point in time.

Issues:

- Type of data to display (incidents, travel times, schedules, etc)
- Inclusion or exclusion of advertising
- Ease of use

During the four months (June 1 through September 30, 1996), of the Atlanta Traveler Information Showcase, guests in 300 rooms at the Crown Plaza Hotel, Ravinia were able to request up-to-the-minute Atlanta metropolitan area information using the television set and the remote control unit in their rooms. Ninety-eight (98) percent of the guests who had access to the interactive television in the Crown Point Plaza used it. During the four month period of the ATIS, the system was accessed 1,769 times, with 1,107 of the inquiries occurring during the two-week period of the Summer Olympics. Roughly 50% of all inquiries were for real-time traffic information, making it the most used feature of the channel.

3.2.2 Telephone-Based Systems

Telephone-based pre-trip traveler information systems such as Traveler Advisory Telephone and Automated Trip Planning Services are also in use. These technologies are generally used to access current traffic information while planning a trip. However, they can also be used while on-route via a cellular telephone. To provide access to pre-trip information, use of a touch-tone telephone allows travelers to inquire about current travel conditions, or to plan the next leg of a trip while traveling en-route to a specific destination. These systems use either text-to-voice or synthesized voice messages which can be navigated using the touch tone keypad to listen to selective areas of a city, selected highways, or construction advisories.

Issues:

- Accuracy of the data - it is important that the data be current and accurate
- Number of lines, and toll access where an area may include toll exchanges
- Ease of use - directions must be simple and concise; lengthy navigation must be avoided

3.2.3 Kiosks

Kiosks are becoming an important traveler information communication device and have been adopted by many transportation agencies. Kiosks can allow travelers to access current data on road and weather conditions, directions to destinations specified, and current news regarding local events. Further benefits of kiosks lie in their availability to the traveler at rest stops, the ability of a computer system to keep the data updated, and the ability of the kiosk to record user requests and reactions to the system that allow future modifications and enhancements which are responsive to the public. The kiosks can provided travelers with access to the following types of information:

- Real-time traffic and incident data
- Point to point vehicle route planning
- Transit schedules and itinerary planning
- Rail, Bus, and Community Transit services
- Area-wide hotel reservation services
- Weather information
- Special event information
- Airport facility and airline schedule information

In some areas, traveler information kiosks have been deployed. These are typically placed in areas with high traveler volume such as rest stops, major office centers, and malls

The Georgia Department of Transportation deployed upwards of 130 kiosks for the Atlanta Olympics project. The major lesson learned during the project was that maintenance was critical to the success of the program.

Issues:

- Accuracy of the data - it is important that the data be current and accurate
- Communications link types and costs - availability may vary depending on location
- Ease of use - directions must be simple and concise
- Maintenance - lengthy distances between kiosks requires significant travel time for servicing

3.3 EN-ROUTE INFORMATION TECHNOLOGIES

En-route systems provide information and guidance to the traveler while using the transportation system. These technologies fall into these major categories:

- Roadway Based Systems
- Personal Based Systems
- Transit Systems

3.3.1 Roadway-Based Systems

Variable Message Signs (VMS) and Traveler Advisory Radio (TAR), also known as Highway Advisory Radio (HAR), systems are discussed in this section. Variable Message Signs, in many areas are considered Changeable Message Signs (CMS), and the current NTCIP protocol definitions are currently referring to Dynamic Message Signs (DMS). It is anticipated that when adopted the Traffic Management Data Dictionary (TMDD) will standardize this reference. These technologies represent the two basic technologies currently available to provide travelers with real-time and static information "from the field" while en-route. There are several derivatives of the above used in several foreign countries: variable speed limit signs and variable graphics signs, which will also be described below.

3.3.1.1 Variable Message Signs

Variable Message Signs (VMS) provide dynamic information to motorists regarding a variety of conditions, including congestion, diversion, construction information, and roadway status.

VMS can be of various types including:

- **Surface street VMS signs** - these signs are typically line or full-matrix signs and are installed over or partially over the surface street. The primary installation site is prior to a route decision point such as entrance to a freeway.

  Advantages - this type of sign provides additional space for more complete messages
  Disadvantages - can be expensive and the sign size can be an issue

- **Freeway VMS signs** - these signs are the most common form of VMS currently implemented within traffic systems. They are typically installed over the freeway traveled way either cantilevered or supported by a sign bridge. In some circumstances these signs can be installed attached to bridge structures or centered over a median barrier wall. These types of signs will be discussed in further detail in subsequent sections.

  Advantages - becoming standard in system implementation, and there is currently being developed a standard NTCIP protocol that all future signs will conform
  Disadvantages - can be expensive

- **Blank-out Signs** - usually displays a single message such as no-left-turn, ramp closed, etc. These can be fiber-optic, lamp matrix signs, fluorescent, Neon, or other technologies. Signs of this type are applicable to Traveler Advisory Radio sites where the signs are turned on in advance of a particular segment whenever radio messages are being broadcast.

  Advantages - low cost
  Disadvantages - not easily changeable

- **Rotating Drum signs** - typically limited to 1-6 messages per rotor which can be stacked to provide a limited number of overall messages. These draw little power while displaying a message, but must be illuminated at night and require heaters in northern climates due to ice build-up. This type of sign can be used when only a few fixed messages are needed at a particular site. Related, but generally not used in traffic applications are the three-sided billboard type signs.

  Advantages - low power consumption, relatively low cost (typically $15k per drum), “look like” standard signs.
  Disadvantages - cannot support flashing messages, lacks flexibility, changing is expensive.

- **Changeable Graphics Signs** - these are widely used in foreign countries and consist of a large map graphic with lighted roadway segments which show Green or Red - some may be three colors to indicate traffic conditions. These are often placed in advance of alternate route choices to allow the driver to select one of the routes.

  Advantages - can assist in providing additional information that can be currently missing.
  Disadvantages - have not been implemented in the US and can be expensive.

- **Changeable speed limit signs** - these have been used by the NJ Turnpike and are widely used in some foreign countries to slow traffic under adverse conditions (e.g. fog, incidents, etc.).

  Advantages - have successfully been implemented to affect the motorist’s speeds.
  Disadvantages - is yet to be determine if the limits shown enforceable, and the signs need to be close together

- **Trailblazer signs** - these are used on surface streets in conjunction with route diversions or special events to reassure drivers along a detour, or to direct drivers to the closest entrance to the freeway after special events. These can use a variety of sign technologies including LED, Fiber optic, Lamp matrix, Drum and Flap signs.

  Advantages - can be used to direct motorists through a route diversion rather then causing a “wandering” effect through the local street network.
  Disadvantages - can be expensive to interconnect the signs and provide the signs with power and requires close interagency cooperation (can be an advantage if the use of

trailblazers sparks the cooperation)

- **Beacon signs -** these signs consist of either a static message board or a blank out message and flashing beacons that can be remotely activated. They are commonly used to highlight specific circumstances such as notifying drivers to turn on their radios to a particular station.

  Advantages - low cost and static message boards are standard signs
  Disadvantages - with static message boards, care must be given to ensure that motorists that follow the message directive are not discouraged by the possible lack of any message.

3.3.1.1.1 VMS Configurations

VMS can be configured differently depending upon the type of messages planned. Consideration should be given to internal maintenance (i.e. walk-in signs) where the signs are used over an expressway. This allows maintenance without expensive maintenance of traffic. In virtually all locations without walk-in signs, failures that do occur (and all signs experience pixel failures) tend to remain that way for much longer times as the cost to simply replace a pixel or lamp can run into the thousands of dollars. Internal maintenance allows a single person with a bucket truck to access the sign from the shoulder lane without expensive and scheduled traffic diversion. Signs thus are better maintained and the public perception is of a better system.

The letter size determines the sight distance, 18 inch being typical for expressway configurations and 12 inch for surface streets.

Character matrix - these use individual pixel modules of 5x7 panels separated by blank space for each character. This configuration only allows for a single fixed font, but is the most economical configuration for the maximum number of characters.

Line matrix - these provide a continuous matrix of pixel columns - typically 7 high which allow variable width characters including double stroke characters and special graphics such as arrows on a single line. These lines are usually composed of the standard 5x7 panels closely spaced to form a continuous matrix. Typical line width supports 16-20 characters (80-120 pixel columns).

Full matrix - This type of sign is a continuous matrix - both vertically and horizontally of pixels which can then be used to form any message with a variety of graphic characters. This type of sign supports variable fonts including “very large” messages which have a high target value. This type sign is the most expensive configuration for the text to be displayed.

3.3.1.1.2 VMS Technologies

LED - Light Emitting Diode (LED) sign technology has been around for several years such that the technology is well understood and offered by a variety of experienced VMS vendors. There are issues of brightness in full sun, degradation caused by heat and the gradual loss of brightness. Earlier signs used green and red LED to create an amber display, but these are now being replaced with high intensity amber LED which boast a 10 year life. LED signs tend to be expensive, but are far lower cost to operate than lamp matrix signs. They can be intensity controlled for night operation, and support animation, flashing, and the rapid display of messages.

Lamp Matrix - Lamp matrix signs provide the best visibility, and are the lowest cost, but require higher maintenance and operating cost than any other technology. CALTRANS established a standard (sign type-550) for lamp matrix signs using a Type 170 controller which has reduced the maintenance costs and established a level of interchangeability between vendors not previously seen in the VMS industry. Lamp life is typically less then 10,000 hours.

Fiber Optic - Fiber optic signs are available in several different configurations. Some installations utilize a purely shuttered fiber configuration. These signs typically use 2 Halogen lamps to illuminate all the fibers for up to four 5x7 modules. To compose a letter, the sign will allow the light to pass through individual pixels of a 5x7 module to form the letter, the remaining pixels are individually shuttered or covered to block the light. Several providers now manufacture the shuttering device that can be used in this type of sign. The second type of fiber optic sign is the flip-fiber using a reflective disk to cover the fiber optic light pixel. The reflective disk improves visibility during high ambient lighting conditions. The fiber optic elements are much slower than LED or lamp matrix which makes display times longer, and true animation is far slower. It is important to specify writing speeds and message display times since these depend upon the exact electrical configuration of the element drive electronics.

Other hybrid - As indicated above, flip disks have been used with fiber optic elements to enhance the readability of the messages. Recently flip-LED signs have also been used to provide night visibility of otherwise reflective signs.

3.3.1.1.3 VMS Summary

Samples of all of the above can be seen throughput the US and Canada. The configuration depends upon the intended use; the technology depends upon the available budget. The shuttered fiber types seem to have the best overall legibility, but cost more than LED or lamp technology.

3.3.2 Highway Advisory Radio

Highway Advisory Radio (HAR) systems, usually located at roadside stations, communicate locally relevant traveler information to all vehicles in the vicinity of the station. They are commonly "broadcast only" (infrastructure to vehicle) systems using the conventional AM broadcast band radio in the vehicle. HAR can provide travelers with information regarding construction activities, special events, road closures or hazards, traffic congestion, incidents, alternate route guidance, and traveler information concerning local attractions. The transmission range of traditional HAR systems is limited to a few miles.

3.3.2.1 HAR Configurations

HAR systems consist of an audio controller, recorder, transmitter controller, transmitter, antenna, and ground plane. The HAR can use either live messages, pre-selected taped messages, or synthesized messages based on information from an ITS traveler information database.

Types of systems:

- **10-Watt Transmission (FCC Licensed)** - Broadcast radius of approximately 3-5 miles depending on topography, atmospheric conditions, and the time of day. Frequencies used are generally located at the extreme ends of the AM band using specific frequencies based upon the availability of "holes" in the spectrum left by government and commercial stations. New FCC rules permit HAR to be broadcast on any frequency between 530 kHz and 1710 kHz provided an FCC license is obtained. License can be potentially lost due to new commercial broadcast operations.

- **Low-Power Transmission (No FCC License Required)** - Broadcast radius (per transmitter) is generally limited to 500 feet to 1500 feet. Approximately 100 transmitters can be coordinated into larger and well-defined saturation zones. Zones may be established whereby unique site-specific messages may be transmitted to provide condition updates in advance of decision points. However, this concept is relatively new and has never been successfully fully implemented

The basis for judging the validity of a low-power HAR application rests primarily upon a field test evaluation study that was performed for the Los Angeles Smart Corridor (August 1993) using Triangle Digicom transmitters. The results of this evaluation confirmed -- albeit on a small scale (i.e., 10 synchronized transmitters in a zone within an urban surface-street environment broadcasting at 1520 kHz) -- the feasibility of the low-power HAR.

A recent installation of low-power HAR in San Jose, California has proven to be unsuccessful. Maintaining the original zonal configurations has proved to be exceedingly difficult and as a result, only a small amount of the intended traveler information is actually disseminated to the public.

3.3.2.2 Message Distribution

A number of decisions pertaining to the message distribution must be made. One alternative is centralized recording, storage, and playback of messages where transmission lines for audio connectivity and time synchronization with selected transmitters need to be considered.

Types of systems and issues:

- **Centralized Recording -** Messages are created and stored at a central operations center. Audio is typically retrieved from a digital recorder system and is transmitted via a distribution network to the appropriate HAR controller for radio broadcast. Analog audio is sent over a network, with the potential for low quality. This architecture is subject to single point failures at the central operations center.

- **Distributed Recording -** All system functionality is remote to the field HAR station. Data circuits are used to select the message to be transmitted, control the transmitter, and provide the timing synchronization, if required. Messages are downloaded into message storage at the HAR. Message selection for broadcast, and control of the transmitter controller and digital recorder/player are performed via remote commands from the central site. Messages can be sent as analog or digital; digital allows for higher end transmission quality.

Note that "beacon" signs are typically used to notify the driver that an important traffic condition is being broadcast on the HAR.

3.3.3 Personal-Based Systems

Personal Communication Devices (PCDs), or Personal Digital Assistants (PDAs) as referred to by some, utilize two-way wireless communication to small devices which relay information to the user. PCDs operate on limited bandwidth and are not designed for high-speed transfer of large data blocks. Examples of a PCD include alphanumerical pagers and cellular telephones, and portable computers which are equipped with alphanumeric paging cards.

Issues:

- Pagers are one-way, have limited display capability
- Cellphones and PCD devices use potentially expensive airtime
- Two-way devices are not widely deployed or tested.

3.3.4 Transit Systems

In-transit vehicle based technologies include technical innovations which support the transit user en route. Travelers are aided by in-vehicle message board and automated annunciation systems which provide information on routes, schedules, and connecting services. Transit agencies are including these devices in their vehicles for two key reasons:

- To facilitate the transit trip and make necessary information more user friendly
- To comply with the requirements of the ADA

The ADA requires that all fixed-route transit vehicles provide both visual and audible information at transfer points with other fixed routes, other major intersections, and destination points, and intervals along a route sufficient to permit individuals with visual impairments or other disabilities to be oriented to their location. Further, any stop must be announced/displayed on request of an individual with disabilities. Automated annunciation devices also remove the responsibility for announcing stops from the drivers, leaving them free to concentrate on driving which should result in greater safety for passengers.

Rail systems typically have provided audio announcements for stops because they operate on exclusive rights-of-way. Bus systems are in the process of providing this type of information through automated annunciator technology. This technology, based on GPS location or on odometer readings, automatically announces/displays stops, major intersections, and major transfer points. As transit agencies implement AVL systems, more accurate and real-time information will become available. Both rail and bus are beginning to implement in-vehicle information systems that provide not only transit-related information, but also news, weather, and advertising information.

The following technology requirements have been identified for in-vehicle transit passenger information systems:

- Information must be timely and accurate. The transit operator must prioritize the sequencing of messages so riders are not overloaded with information. Next-stop, key-destination information, connecting routes and any other information should be provided based on accurate schedules or real-time information if possible.

- There should be high quality output. Messages should be visible from all seats and readable in all lighting with comfortable speed and scrolling. The display graphics, colors and text should be interesting to passengers. Audio messages should be clearly audible, using automatic volume control to overcome varying ambient noise levels.

- Message triggering technology must be capable of operating a variety of environments traveled by vehicles, including tunnels, bridges, between tall buildings and behind hills.

- Integration, installation, maintenance and repair should be accomplished efficiently. All on-vehicle electronics and support technologies should be integrated. Components should be modular and compatible so the system can be easily modified or expanded, ensured by adhering to hardware, software and communications standards.

- Passenger information should be capable of relating visual and audio communication to each other. Since vehicles are used on multiple routes, there must be adequate message and route memory to accommodate all routes served between memory updates, regardless of the update method used. An automatic information system should be capable of being readily modified and upgraded. Equipment should be reliable. Maintenance features should include the capability to readily isolate problems with easy-to-use diagnostic tools or basic test equipment.

- Operation should run smoothly. The process of programming messages should be simple, and messages should be easy to update. If messages require frequent updating, there should be a remote means of updating messages.

3.3.4.1 Message Boards

Several readable matrix message display systems are in use at the present time on transit vehicles, including flip data displays, liquid crystal displays (LCDs) and light emitting diode (LED) displays. LED is the most commonly used technology for providing passenger on-vehicle visual information. LCD devices and flip dot displays were used less frequently. These products have the capability of providing nearly any type of information, including next-stop announcements, service revisions, routine transit announcements, emergency messages, entertainment and advertising.

3.3.4.1.1 Advertising Potential

Message boards can be appealing to advertising for a wide variety of reasons, including:

- Electronic signs are a new and innovative medium
- Messages can be targeted to any or all bus areas based on the demographic characteristics of the riders
- Transit riders are a captive audience and viewers receive a high frequency of exposure that increases recall and product awareness
- The medium is more affordable than television, radio or print advertisements, with low production costs, quick turnaround to place advertisements on the air and flexibility to change copy daily if desired. In Dallas, up to three different copy rotations are broadcast every day.
- The advertising reaches diverse audiences and all ethnic groups. With this medium, there is the ability to present bilingual messages as well as promotions of special events and ties to other media, such as radio stations, for promotional events.

Cost is not the primary factor that determines media choice. Other factors are also important, including the advertising concept, the message, the media habits of the target audience, and the characteristics of the product. It's been estimated that exposure of 80 times a month to a message board will guarantee 100 percent recall. This provides advertisers with high value and good return on their advertising investment.

3.3.4.2 Automated Annunciation Systems

The Washington Metropolitan Area Transit Authority's system combines advanced navigation equipment produced by the Andrew Corporation, with the Talking Bus automated voice announcement system which is produced by Digital Recorders, Inc. The Andrew Corporation has developed a navigation system which uses a combination of dead reckoning and Differential Global Positioning System (DGPS) navigation. The system determines distance using a vehicle speed sensor that keeps track of vehicular wheel speed, and a fiber optic gyroscope to determine the vehicle's compass direction. Location updates, which are accurate to the nearest meter, are made using DGPS technology. The combination of dead reckoning and DGPS provides a more reliable approach to determining a vehicles location in urban and downtown areas which contain a large number of taller buildings. As such, the improved navigation technology allows for more accurate and timely dissemination of information.

Digital Recorder's Talking Bus system announces stops, transfer points, and major interchanges as required by the ADA regulations to passengers located inside and outside the vehicle. The Talking Bus system utilizes open systems architecture, and is capable of:

- Interfacing with various advanced vehicle location (AVL) systems
- Providing transit operator control of on-board electronic signs via a single keyboard
- Supporting of future integration needs, as it is fully reprogrammable
- Providing simultaneous internal and external announcements
- Accommodating on-site message updates. New messages can be remotely recorded and programmed onto a memory card, and subsequently transferred to the field for use.

The New York City Metropolitan Transportation Authority is implementing several pilot programs to test in-vehicle message systems. There are two “new technology” subway cars which are being tested which include real-time in-vehicle announcements. An RFP has just been released for the bus program AVL, which will include in-vehicle announcements. As part of this RFP, there will be a one-year pilot program based on the 126th Street Bus Depot and Bus Command Center locations. As part of the goal for service improvements, it is anticipated that accurate customer information will be transmitted in-vehicle and at kiosks at remote bus stops to provide real-time schedule information.

New Jersey Transit is testing two Automated Voice Annunciator Systems (AVAS) to enhance bus service and comply with the ADA. One of the systems, called Automatic Passenger Information System, is developed and marketed by Clever Devices Ltd. and Siemens Transportation Systems, Inc. The other, called the Talking Bus System, was developed and marketing by Digital Recorders Inc. Both systems are being evaluated on a trial basis along diverse and heavily patronized bus routes in northern New Jersey.

The AVAS device was installed on a New Jersey Transit bus which operates on a route between Dunellen and New York. The route was chosen because of its unique qualities, providing both long-distance runs and frequent stops along different legs of its intercity and interstate service. This device uses the bus odometer to automatically read a pre-programmed announcement to customers on the bus at major stops being approached by the bus. Beside this audio announcement, the locations are displayed inside the bus just above the operator, for passengers with hearing disabilities. After the operator has stopped the bus and opened the door, visually impaired passengers outside the bus hear another automated announcement that identifies the bus route number and its destination. Hearing impaired customers can identify the bus route by the destination sign on the front of the bus.

3.4 IN-TRANSIT STATION-BASED SYSTEMS

In-transit station-based systems provide schedule updates and transfer information for passengers already en route. This information includes arrival and departure times, information on transfers and connections, information on other regional transportation services and information on related services, such as park-and-ride lot availability. This information can be provided via message boards, display monitors, public announcement systems, or kiosks. Information, available through the use of technologies such as AVL, will help transit agencies now, and in the future, provide information in real time. The key benefit for the traveler will be a more accurate sense of departure and arrival times for a trip.

Traditionally, in-terminal and wayside information has been disseminated manually in the form of paper schedules or static signs. Further, real-time information, such as actual bus arrival or departure time, has not been traditionally available to give to the customer. With the advent of advanced public transportation system such as AVL, real-time, en-route transit information can be made available to the customer in a variety of forms. However, automated in-terminal and wayside information systems are in their infancy in North America, primarily because APTS technologies needed to support these systems are just beginning to be fully implemented. Currently, there are only a few of these systems in operation, although many are being planned. A few transit agencies are providing smart kiosks which convey schedule information, trip planning information, and static files such as location of popular restaurants. Visually and hearing disabled travelers are enjoying the benefits of kiosks that convey transit information in a form that they can acquire with a minimum of effort. Display Monitors, Message Boards, Public Announcement Systems, and Kiosks are discussed below in further detail.

3.4.1 Display Monitors

Display monitors are used to provide the traveler with current schedule, destination, and performance information. Within major transit stations, they are typically used in platform areas to keep travelers abreast of current conditions.

3.4.2 Message Boards

Message boards are also used in transit stations as well as in the in-vehicle environment. Within the station, message boards are used to provide the traveler with current schedule, origin, destination, track assignment, and performance information. They are typically mounted within full view of any traveler who would be passing through the lobby area of a transit station.

3.4.3 Public Announcement System

Public announcement systems are used to keep travelers informed of significant changes to the schedule, destination, track assignment, and performance information. The systems routinely broadcast information to travelers within the main lobby of transit stations.

3.4.4 Interactive Kiosks

The advent of the personal computer has supplied the technology that allows information systems to directly interact with all types of users, in multiple locations, and for a low cost. A device that is increasingly being used to allow interaction between information systems and users is the computer-based kiosk. The computer-based kiosk originally imitated the functions of a newsstand on the corner of a city block. The newsstand was a source of information and, likewise, the kiosk (named after the hut or structure that housed the newsstand) is a supplier of information. However, being computer-based, the kiosk allows the public access to a computer terminal and thereby access to databases and software within larger computer systems. Within its own evolutionary development, the kiosk evolved from an information-only device (such as those used in trade shows) to one that supplied and sold services (the most prevalent of which is the automated teller machine used to supply banking services to the public).

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.

A kiosk consists of four primary components: interactive presentation software; a personal computer; user interfaces such as the display, keyboard, touch screen and telephone; and the physical enclosure. Because the public has physical access to the kiosk and is able to interact with a remote system, topics not always associated with information systems must be addressed. Some of these topics are physical security, data security, identification of the user, and use by physically-challenged individuals and untrained operators.

These last two topics present opportunities for state-of-the-art technology to aid the user community. Hearing-impaired persons can use standard touch screens. For the visually-impaired, a telephone can be provided that uses audio prompts to activate kiosk commands via a Braille-like telephone keypad. Additional Braille-like menus can be mounted on the kiosk surface to aid in the communication. All users, whether physically impaired or not, desire a positive feedback to know that they have successfully engaged an interactive button or other input device. Therefore, the kiosk must react with positive visual and audio responses to all input by the user. Moreover, effective use of graphics and sound provides an engaging presentation which makes the kiosk experience not only informative but entertaining.

4.0 CONTROL STRATEGIES

Several of the emerging ITS technologies relate to control strategies that may be implemented to provide improved efficiencies on the roadway network, reduce or spread out demand, enhance traveler safety, and improve commercial vehicle operations. Specific roadway and transit oriented strategies are addressed in this section.

4.1 RAMP METERING

Ramp metering is the primary tool that is used in addressing recurring congestion, and has been used as a tool for minimizing traffic at incident locations. Ramp meters are traffic signals placed at the freeway on-ramps. They control the rate at which vehicles enter the mainline such that the downstream capacity is not exceeded, thereby allowing the freeway to carry the maximum volume at a uniform speed. Though 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 were allowed to break down.

Another benefit of ramp metering is its ability to break up platoons of vehicles released from a nearby intersection. While the mainline, even when operating near capacity, can accommodate merging vehicles one or two at a time, queues of vehicles attempting to force their way into freeway traffic create turbulence and shockwaves that cause the mainline flow to break down. Reducing the turbulence in merge zones can also lead to a reduction in the sideswipe and rear-end type accidents associated with stop-and-go, erratic traffic flow.

4.1.1 Ramp Meter Configuration

A schematic of a typical ramp meter installation is shown in Exhibit 2. Most locations use single-entry metering -- that is, only one vehicle per lane is released during each red-green cycle. The demand detector indicates (to the ramp controller) that a car has arrived at the stop bar and that the metering cycle should commence. Without demand at the stop bar, the ramp signal indication remains red. The passage detector senses that the vehicle has passed the stop bar, indicating that the ramp signal should go back to red for the next vehicle. The passage detector can also be used to monitor meter violations (i.e., drivers who ignore the red light), and provide historical data on the violation rate at each ramp. The queue detector is used at locations where ramp backups may impact surface street operations. The mainline detectors provide volume and occupancy data for traffic responsive operation of the ramp metering.

4.1.2 Ramp Metering Issues

- Metering Rates – What are appropriate values for each location?
- Control Mode – Pre-timed, traffic responsive, or central system control?
- Ramp Geometry – Are the characteristics suitable for metering, such as available storage behind the meter?
- Impact on Surface Streets – Will the problem be transferred onto the local network?
- Enforcement – Are there resources and laws in place to ensure compliance?
- Public Acceptance – Public relations program may be needed.

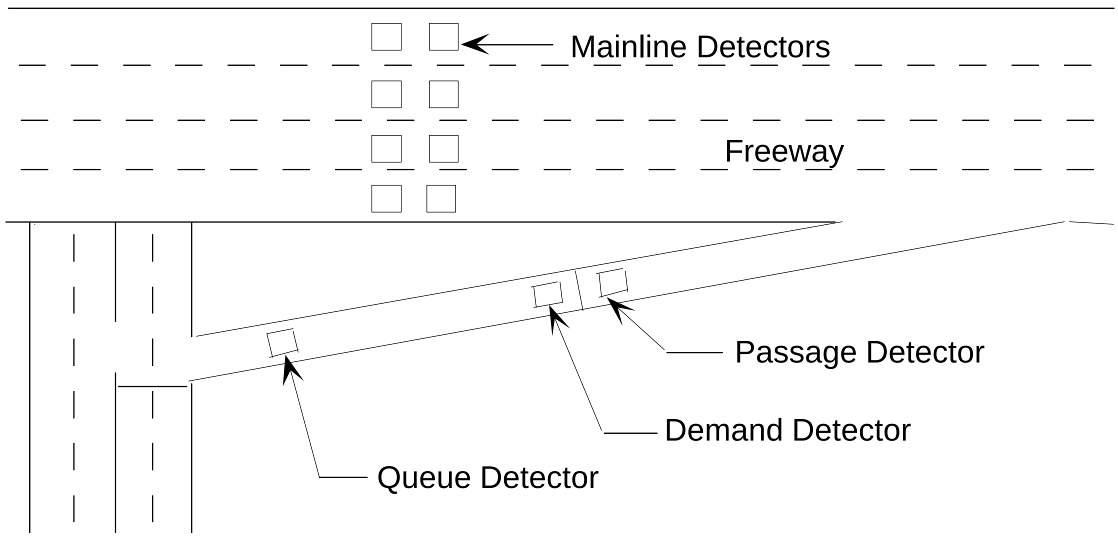


Exhibit 2: Typical Ramp Meter Installation Layout

4.2 TRAFFIC SIGNAL CONTROL SYSTEMS

Traffic flows change and vary constantly from hour-to-hour, day-to-day, and week-to-week. Therefore, traffic signal controllers should be able to detect these conditions and respond appropriately. Traffic engineers and researchers have developed a variety of different timing schemes to improve signal response to changing traffic conditions, including:

- Time of day scheduling
- Local Actuated Control
- Critical Intersection Control (CIC)
- 1.5 Generation Control
- 2nd Generation Control
- 3rd Generation Control
- SCOOT
- SCATS
- Adaptive Control (OPAC)
- RT-TRACS

Every signal system, regardless of the size, is based on one or more of these signal control strategies. There is a wealth of information available on both the software and hardware aspects of signal system control. The key point is to match signal system capabilities as closely as possible to on-street traffic demands.

Common issues to be considered when choosing a strategy are:

- Are there particularly critical intersections within the network?
- Is the overall desired architecture to be centralized or distributed?
- What are the communications capabilities of the system?
- Are there existing conditions which dictate one particular type of system?
- If an adaptive strategy is selected, is the budget adequate to maintain the integrity of the data collection system and field devices to support the system?

4.3 LANE-USE CONTROL SIGNALS

Lane-use Control Signals (LCS) have been in existence for over 30 years. The purpose of these signals is to symbolically portray the current status of each roadway lane. Historically, the most prevalent use of LCS has been for the operation of reversible lanes. However, the Manual of Uniform Traffic Control Devices (MUTCD) does allow LCS on freeways when it is desirable to keep traffic out of certain lanes at certain hours, to indicate that a lane ends at the terminus of a freeway or to indicate that a lane is temporarily blocked by an accident, stalled vehicle, etc. IDOT's reversible lanes in Chicago are currently the only LCS in use within a system in the Corridor, but preliminary engineering has begun to include LCS near the new Miller Park Stadium within the MONITOR system in Milwaukee.

Commonly used LCS include:

- **A downward green arrow -** to indicate that the lane is open and that a driver is permitted to drive in the lane over which the arrow is located

- **A steady yellow X** - to indicate to a driver that he or she should prepare to vacate the lane because a signal change is being made to a red X (similar to the use of yellow indications at intersection traffic signals)

- **A flashing yellow X -** to indicate that a driver is permitted to use the lane over which the signal is located for a left turn (applicable to arterial streets only)

- **A red X -** to indicate that the lane over which it is displayed is closed to that direction of traffic, and that a driver shall not drive in that lane.

Issues:

- Public Acceptance - In a new installation, the public may not be aware of the meaning of these signals, and a public relations campaign may be necessary

- Enforcement - Sufficient enforcement must be in place to ensure compliance.

- Litigation history when accidents occur - Several agencies have discontinued use of LCS after setbacks in court cases.

4.4 ELECTRONIC TOLL COLLECTION

Electronic toll collection (ETC) enables the collection of fees from drivers without requiring the vehicle to stop at toll plazas. Elements of an ETC system typically include Automatic Vehicle Identification (AVI) tags on vehicles and AVI readers at the toll plazas, and a video monitoring system/license plate reader to identify violators.

ISHTA is currently in the process of implementing ETC within their network. In addition, plans exist to supplement the existing toll plaza readers with readers at key locations throughout the network and at transition points onto the freeway system. The additional readers within the tollroad network will be used to supplement the toll plaza data with additional travel time data. These additional leaders will increase the number of detectors within the system and reduce the actual length of the links, both of which increase the accuracy of the travel data. The addition of the readers at the transition points between the toll road network and IDOT's freeways is intended to provide a cost effective method of collecting traffic data along transition sections that would not be covered by the current IDOT and planned tollway AVI system.

Toll plaza operations with and without ETC differ significantly. Toll plaza lanes may be categorized as follows:

- Attended
- Automatic (coin machines)
- Mixed AVI (electronic toll collection is mixed with either manual or automatic in the same lane)
- Dedicated AVI (lane contained within conventional toll plaza, but permits only AVI patrons)
- Express AVI (lanes are physically separated from other types of toll lanes permitting free-flow speeds)

Issues to be considered when implementing ETC include:

- Number and configuration of lanes required (which is a function of the level of AVI participation by patrons)
- Position of ETC-lanes within the plaza (which must consider adequate and safe weaving lengths)
- Safety of toll collectors when arriving or departing from their toll booths.
- Enforcement.

4.5 TRANSIT FARE PAYMENT

Transit systems across the country are exploring and adopting advanced fare payment system concepts that promise greater flexibility in fare structures, less expense in money handling, greater convenience for riders, and more efficient cooperation between fellow transit providers.

Most of these advanced fare payment systems concepts rely on the use of electronic fare media. This can be accomplished with various technologies, such as:

- Magnetic stripe cards
- Contact and Contactless Smart Cards
- Wireless Proximity Cards

Issues include:

- Strategic Planning and Fare Policy – How will the system be used and manage?
- Technology – Which of the technologies will function best under a given set of circumstances?
- Payment Process – Is the current value of the card stored within the media, or a central computer? How will disbursements to the participating agencies take place? How will a user "recharge" his card?

5.0 COMMUNICATION NETWORK

5.1 NETWORK ARCHITECTURE

The overall architecture has a major effect on the design of the communications network. Although a variety of architectures exist, the main generic concepts used are Centralized, Distributed and Hybrid.

5.1.1 Centralized Communications

In this architecture, all processing is done at the control center. A centralized system configuration keeps communications technologies consistent throughout the system. The data transmission and reception rates remain constant. One common protocol exists for the entire system. Communications are handled directly over trunk lines interconnected directly by local distribution circuits to each surveillance and control element in the field.

Advantages:

- Greatest control over the system
- Allows all communications troubleshooting and maintenance to be handled at one physical location

Disadvantages:

- Direct connections between the control center and all field equipment requires an extensive and expensive communications network
- System more susceptible to disruptions due to communications link failures.

5.1.2 Distributed Communications

This architecture uses a similar concept to that of the central system in that most information and control are processed at a single point (i.e., operations center). The major difference is that the communications are distributed among several key locations (i.e., "hubs") throughout the network rather than to each field site. The field elements are connected to hubs for the transmission of low-speed data channels. At the hub, these channels are multiplexed together into high-speed channels and transmitted to the operations center (or other hubs) via a large-bandwidth trunking network. Data from the operations center are transmitted to the hubs, where the high-speed circuits are demultiplexed into low-speed channels for distribution to the field devices. In addition to multiplexing hardware, the hub may also contain CODECs to digitize analog video signals from CCTV cameras. In a distributed network, the data rate varies between pieces of equipment and the hub.

Advantages:

- System can be built so that single point failures are less disruptive
- Costs can be lower than a fully centralized system

Disadvantages:

- Single point failures can still occur
- More equipment to maintain

5.1.3 Hybrid

The Hybrid is a combination of centralized and distributed communications architectures. In a hybrid architecture, hubs operate independently but are connected to a central control center that monitors the operations of the hubs. The central center fuses data received from the hubs for regional control at an area-wide level. These systems combine the best advantages of the above, while minimizing the disadvantages.

5.1.4 Redundancy

Each of these architectures can be a configured in a redundant network. The system utilizes additional machines and transmission media within the system in the event of a machine or medium failing. The additional plant is backup in the event of the main communications link failing or power loss. The backup equipment maintains all information required to operate the system, so that if a failure occurs within the main system, no information is lost and the system can continue to operate using backup service until the problem is resolved.

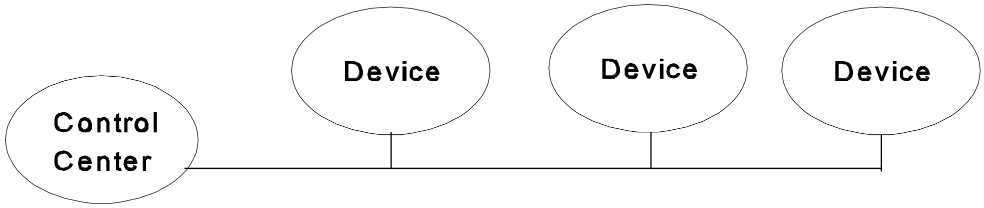
Although most networks can be configured and developed for redundancy, there is always a cost that is associated with each increased level of redundancy that is implemented. Because the cost of complete redundancy can at times be very large, a needs analysis should be conducted to determine the appropriate redundance level. Depending upon the type of data and the level of control there will be differences in how critical the loss of any data will be to the overall system operation and data credibility.

5.2 NETWORK CONFIGURATION

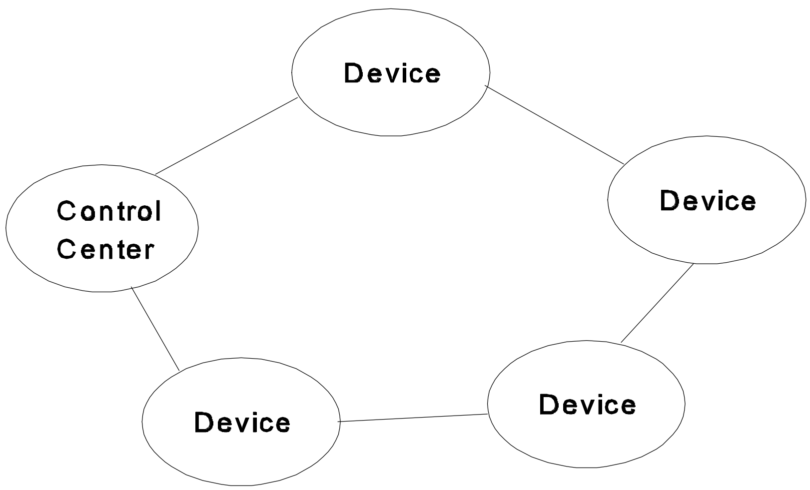
5.2.1 Topology

Topology refers to the physical and logical layout of the network. There are three basic topologies, and often the network will be a hybrid using a combination of them. Note that these topologies are not limited to any one part of the network, such as device to hub, or control center to control center. Rather, they can be used throughout the system, and can even be mixed and matched as necessary to a degree. The three basic topologies are described below and shown in Exhibit 3.

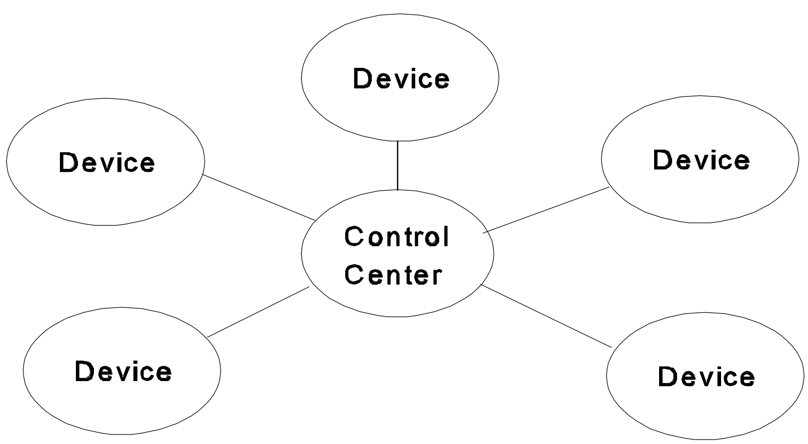
- **Bus** - In a bus topology, the devices are connected into a common "bus", or common communications path. Bus topology offers flexibility in that additional stations can be added without reconfiguration of the network. For LANs using bus topology, a cable failure will only affect part of the network while a station failure will affect no other station.



"Bus" Topology



"Ring" Topology



"Star" Topology

Exhibit 3: Examples of Network Topologies

- **Ring -** In a ring topology, the devices are connected in a closed ring. This topology is configured for a fixed number of nodes. A failure in a station or a cut in the cable will not affect other stations if the ring can counter-rotate, providing redundancy.

- **Star -** In a star topology, the devices are each connected to a central hub. In this topology, a station failure will affect no other stations, however, a central hub failure will affect the whole network.

6.0 COMMUNICATIONS

The communications function provides for the transmission of all information, data, video, and voice, between the various elements within the ITS infrastructure, and between vehicles and the system infrastructure. Communications to and from vehicles have been addressed in previous sections (e.g., AVL, AVI, navigation/guidance). This section focuses on technologies that may be utilized to connect field components (e.g., detectors, CCTV, AVI readers, VMS, signals, ramp meters) with the system control center, and to provide interconnection between control centers.

6.1 DATA AND VOICE REQUIREMENTS

Data and voice transmission technology is now virtually all digital, with the capacity of the communications channel being expressed in bits per second (bps). Typical data network communications, such as sharing information between computers and peripherals, are examples of data which use a variable bit rate (VBR). The data tend to be "bursty", requiring a high bit rate for a short period of time with long idle periods between bursts. Conversely, Constant Bit Rate (CBR) is typically used for digitized voice and video applications where the data are transmitted at a constant rate, and delays for each portion of the transmission are not tolerable.

Serial data transmission has become the preferred method of data transfer between computers and is the most effective method for data acquisition and control in traffic control systems. If a receiver and transmitter are connected via a serial connection, data may be transferred using synchronous or asynchronous serial data techniques. The synchronous transmission data technique has the transmitter and receiver synchronized and transmits data characters at a fixed rate. Buffers within the terminals for the data transmission and reception are necessary as there are no gaps between bits.

Another consideration for data transmission is multiplexing, which allows more transmitted signals to be combined onto a single communications channel

Many standards are in widespread use, with most being driven by the telecommunications and computer industries. Some examples of these are:

- **T1** – A 1.544 Megabits per second (Mbps) data channel
- **ISDN** – two 64 kbps channels, usually combined into one 128 kbps channel (plus a 16 kbps "signal" channel, not usually available for the user.)
- **SONET** – Synchronous Optical NETwork, A high speed fiber standard, used for data, voice and video trunking. Data rates from 50 Mbps to over 600 Mbps.
- **X.25** – Telephone company protocol for multipoint or point-to-point networks. Usually limited to low speed data. Being replaced by Frame Relay
- **Frame Relay** – User data is placed in "Frames" which are sent through the phone company network. Data rates from 56 kbps to 1.544 Mbps.
- **ATM** – Asynchronous Transfer Mode, a High speed trunking network gaining greater acceptance. It can be used to transport data, voice, and video.
- **Etherne**t – Used in local area networks at a data rate of 10 Mbps (also Fast Ethernet, at 100

Mbps)

A comparison of digital standards can be found in Exhibit 4, showing the data speed and composition of various types of T-Carrier and SONET system standards.

TYPE	DATA SPEED	COMPOSITION
Fundamental Unit (DS-0)	64 Kbps	1 “voice-grade” channel
T-1 Channel (DS-1)	1.544 Mbps	24 DS-0 Channels
T-2 Channel (DS-2)	6.312 Mbps	4 DS-1 Channels
T-3 Channel (DS-3)	44.736 Mbps	28 DS-1 Channels

T-Carrier System

TYPE	DATA SPEED	COMPOSITION
OC-1	51.84 Mbps	1 DS-3 Channel (Equivalent)
OC-3	155.52 Mbps	3 OC-1 Channels
OC-12	622.08 Mbps	12 OC-1 Channels
OC-24	1.244 Gbps	24 OC-1 Channels
OC-48	2.488 Gbps	48 OC-1 Channels

SONET System

Exhibit 4: Digital Standards

6.2 VIDEO REQUIREMENTS

Video requires a much higher bandwidth than data and voice for transmitting the image. Thus, when designing the communications network, video images usually become the dominant factor. The transmission of video images, whether from CCTV cameras to an operations center, or between centers, places the heaviest data load on the ITS communications network. Another consideration is that NTSC video is an analog source, while data communications and their transmission standards are digital. Accordingly, video transmission has typically been the most problematic element of network and architecture design.

To transmit a video signal digitally and minimize the communications load, video compression techniques are used. Data redundancy and human visual limitations are the factors that allow video compression techniques, thereby reducing the amount of bandwidth needed for video transmission.

An analog video network provides the best video quality (i.e., often referred to as "broadcast quality"). The major drawback is the need for a high-bandwidth communications medium such as coaxial or fiber optic cable. Telephone companies make extensive use of fiber optic cable. However, most do not lease the physical fiber optic cable, rather they lease digital data circuits that are multiplexed onto the fiber optic cable. The communications industry has responded to these challenges with innovative solutions. Developments have included fiber optic video multiplexers that allow the transmission of up to 80 analog video signals over a single fiber, and fiber optic transceivers that allow analog video and digital control signals (required for the control of each camera’s pan, tilt, and zoom) to be transmitted over the same fiber. These devices, however, tend to be proprietary.

Significant developments have occurred in the area of video compression. A COder-DECoder (CODEC) digitizes the analog video image and compresses the bandwidth such that the real-time picture may be transmitted over a digital communications medium. The digitized signal is received by another CODEC unit where the digitized information is converted back to an analog format for viewing on a television monitor.

CODEC devices are available in five general groups:

- **High Speed** – 45 to 90 Mbps, performs little compression, excellent quality, low cost
- **Medium Speed** – 384kbps to 1.544 Mbps, high compression, medium to good quality, high cost
- **Low Speed** – 56 to 128 kbps, very high compression, fair quality, low cost
- **Network** – 20kbps to 10 Mbps, high to medium compression, low cost, one signal at a time
- **Slow Scan** – 28.8 kbps, very high compression, low quality, low cost

The choice of a CODEC device is usually a tradeoff between quality and cost. In addition, the availability of communications resources plays a major role in the selection. Another factor to consider is standards; many of these devices support the H.261 video conferencing standard, which allows for a certain degree of interoperability. Some higher quality devices, however, use a proprietary algorithm. The Network CODEC is implemented in software running on a personal computer. While currently limited to one video “stream” at a time, the technology bears watching, as it could become very cost effective.

6.3 MEDIA

The communications medium is usually the driving factor in the cost of most LANs. Media used for LANs include twisted pair, baseband coax, broadband coax, and fiber optics. Twisted pair, which may be shielded or unshielded, is used in the ring, star and bus topologies. It is easy to install and is low in cost. The drawbacks include low immunity to noise, and limitations on transmission distance and data rate.

Baseband coax, used in the ring and bus topologies, has high noise immunity and is easy to install. It is not, however, physically rugged and is more costly than twisted pair. Broadband coax, used in the bus topology, can handle very high data rates, supports video, is rugged, and has high noise immunity. It is, however, more difficult to install and more expensive than twisted pair and baseband coax.

Fiber optic cable, used in the ring and star topologies, offers a very wide bandwidth, very high electrical noise immunity, support of video, and high security. Fiber optic communications has been generally more expensive than the other media due to the cost of end equipment and fiber splice equipment.

Media technologies can be categorized into one of two types -- land line technology and wireless technology. Both are discussed in this section.

6.3.1 Land Line Technologies

Fiber optics, leased telephone, twisted pair cable, and coaxial cable are currently the primary and most prevalently used communication technologies that are based on physical hardwired cabling, or otherwise known as Land Line Technologies. These primary technologies are discussed in this section.

6.3.1.1 Fiber Optics

Fiberoptic cables are strands of glass which transfer light. Data, voice and video can be modulated onto the light, and sent for long distances. Fiber optics has become the defacto standard for ITS communications. Many agencies are now in the process of designing or installing their own fiber optic networks . Some advantages fiber has over other types of media are:

- Large bandwidth – Limited only by end electronics
- Immunity to electromagnetic and RF interference, such as lightning and AC power
- Small, flexible, lightweight cable

The electronic equipment required (e.g., multiplexers, video transceivers) is commonly available in a robust market with a good future. The SONET standards, which define transmission capacity, optical interconnects, and internal formatted signals, are well established with multiple vendors offering compatible multiplexers and related hardware. Moreover, when installed in a "SONET ring" topology (e.g., fiber trunks installed to create a loop on both sides of the freeway), redundant opposite-direction (or counter-rotating) paths are provided that allow each node to communicate with every other node even when a cable is cut or otherwise disrupted.

For a distributed communications network, fiber would be utilized for connections between cameras and their associated hubs, and between hubs and the operations center (i.e., "fiber backbone"). Fiber may also be used for the low-speed communications between hubs and field hardware (e.g., VMS, detector processors, AVI readers). This approach is used in Toronto, the logic being that maintenance personnel have only one type of communications medium to deal with. The use of fiber optics typically requires a dedicated, agency-owned communications network. This requires right-of-way and conduit throughout the network. Right-of-way is usually the limiting factor for private companies, but not for state agencies. The initial cost of installing conduit where none exists, however, is significant.

6.3.1.2 Leased Telephone

Leased telephone circuits are mostly wire to the end user and often possess the flexibility, speed, and bandwidth required for an ITS communications network. A wide variety of circuits are available from the region’s telephone companies including voice grade circuits, and low and high speed data circuits that use either twisted pairs or fiber optic cables. Refer to *Working Paper # 18600 - System Interface and Data Exchange* for a more detailed discussion of leased communication options being considered for the MMTIS.

Advantages of leased lines:

- Reliable communications solution in that some grid redundancy is incorporated into the carrier’s network.
- Low up-front costs
- Maintenance handled by phone company

Disadvantages:

- Susceptible to noise and lightning
- High long-term costs
- Maintenance out of agency’s control

6.3.1.3 Twisted Pair Cable

Agency-owned twisted pair cable has been widely used for the low-speed transmission (e.g., 1200-9600 bps) of data, especially in traffic signal control systems and between hubs and field elements. This type of technology may also be found in leased telephone lines. Twisted-pair cable can support low-speed transmission distances of 6-10 miles before repeaters become necessary. DS-0 signals (64kbps “voice grade” channels) can be transmitted over twisted-pair for distances up to 2 miles.

Advantages of Twisted Pairs:

- Easy to maintain
- Relatively low up-front costs
- Maintenance handled by agency

Disadvantages:

- Susceptible to noise and lightning
- Quality tends to degrade over time
- Relatively low bandwidth

Twisted pair cable is a reliable and proven technology of relatively low capacity. A properly designed and installed twisted-pair communications system features reasonably low maintenance requirements in terms of average time between failures, the average time to repair, and the necessary levels of skill and equipment. Like fiber optics, it does require right-of-way and conduit, the latter often resulting in significant costs.

6.3.1.4 Coaxial Cable

Coaxial cable is a radio frequency wave-guide designed to carry or channel RF signals for transport between distant sites. The signals are restricted to the wave-guide and are thus prevented from radiating through space and causing interference with other RF transmissions. Radiating coaxial cable, on the other hand, operates as an antenna which radiates low power RF to the immediate surroundings where it is placed, much the same as a perforated, “leaky” garden hose does when spread out on a lawn. This “leaky coax” is able to distribute RF to select locations where localized transmissions are required. Radiating coaxial cable will also serve as a receiver antenna for 2-way radio communications.

Two areas for use of radiating coaxial cable in ITS are for maintaining radio communications where normal transmission is impaired, such as in tunnels, and for localized low power operation along right-of -way.

“Leaky coax” is being evaluated as a medium for wireless telephone systems. It is presently installed in some highway tunnels to provide uninterrupted radio reception for travelers.

Advantages of coax cable:

- Relatively high bandwidth
- Not susceptible to noise if installed and maintained correctly
- Maintenance handled by agency

Disadvantages:

- Difficultly with installation and maintenance of connections
- Quality tends to degrade over time
- Older technology

6.3.2 Wireless Technologies

Spread spectrum radio, microwave, cellular radio, cellular digital packet data, mobile data, trunking radio technologies are discussed in this section. The chief advantage of wireless communications is that no physical connection is required between the transmitter and receiver.

6.3.2.1 Spread Spectrum Radio

Spread-spectrum radio was originally developed for the military to prevent the enemy from jamming or intercepting transmissions. This is accomplished by spreading out the data signal over a wide frequency band, and then reversing the process to recover the data at the receiving end. Spreading the signal out across a wide frequency band reduces the potential for the signal to interfere with other transmissions since the spreading process reduces the power density of the signal at any frequency within the transmission band. Moreover, any noise interfering with a spread-spectrum signal will tend to obscure only a very small fraction of the entire band. Since the signal is divided and spread over the entire spectrum, the transmitted signal can still be reliably reconstructed at the receiver.

Advantages:

- No conduit required
- Relatively low cost

Disadvantages:

- Line of sight required
- Susceptible to some interference
- Requires specialized installation and maintenance techniques

6.3.2.2 Microwave

Microwave frequencies are those frequencies in the range above 1 GHz (gigahertz). The frequencies currently allocated by the FCC for private and common carrier use are in the 4, 6, 10, 11, 12, 13 18, 23, and 28 GHz bands, with the lower GHz channels (2-12) being used for long-haul transmissions.

Microwave signals radiated from an antenna propagate through space along a line-of-sight path. The frequencies used must be unique to that area to prevent interference from other microwave transmissions. Because of this constraint, the FCC licenses microwave frequencies. Therefore, it can be very difficult to obtain a microwave frequency allocation in crowded urban areas. When frequencies are available, they are usually in the higher frequency bands (18 and 23 GHz) which have reduced transmission distances. Additionally, if two-way transmission links are required, two different transmit/receive frequencies are required.

Microwave communication provides an alternative to leased line and fiber optic point-to-point backbones, offering high data transmission capacity and the capability to transmit video. In areas where conduit is expensive or impossible to install and a connection to a leased line is not practical, microwave should be considered. To obtain a microwave license, a "path search" is required. The search will determine if line-of-sight is available, what antenna heights are required, and what frequencies can be used. This search is an additional up front expense to be considered when choosing microwave radio.

Advantages:

- Low interference potential
- High quality and high speed transmission
- Low long-term costs

Disadvantages:

- Line of sight required
- Potential for some interference from precipitation
- FCC license required for all but the shortest links
- High up-front costs
- Frequency may not be available in urban areas

6.3.2.3 Cellular Radio, Cellular Digital Packet Data (CDPD), and Trunking Radio

Cellular radio is a technique for frequency reuse in a large radio communications system. It is primarily used for mobile telephone networks. It gets its name from an area being divided into cells that are 2 to 20 miles in diameter. In the center of each cell is a control radio that bundles the network management functions, including the assignment of frequency sub-channels. A radio requests a frequency over a control channel and one is assigned by the cellular control system. The cellular layout allows frequencies to be reused in non-adjacent cells.

The newest of the cellular technologies is Cellular Digital Packet Data (CDPD). This technology is a digital data connection provided over existing cellular telephone networks. The most important feature of this technology is its relative low cost for basic connectivity. By using the voice infrastructure for digital pathways in such a way as to interfere very little with the voice functionality, this technology allows almost universal coverage with little investment in new infrastructure. The cost effectiveness is high for communication solutions which require random intermittent connectivity and short message length.

Trunking radio operates in a manner very similar to cellular, but over dedicated public service frequencies. This allows dedicated channels to be used for data transmissions.

6.4 INTER-AGENCY COMMUNICATIONS

6.4.1 Electronic Mail (E-Mail)

E-mail can allow member agencies to communicate through on-line services, electronic postal delivery and facsimile. E-mail management is relatively simple and the user can easily send, reply or forward any message or files to a single user or to a select group of users. The system can notify users of incoming messages. The indication can take the form of an audible tone, a flashing window or a display of unread messages at boot-up. Communication with agencies should be semi-automatic and not require manually dialing each agency, and the system should get the proper information to the proper parties through an optimized rule structure.

6.4.2 Voice

Communications between agencies can also be via a mutual voice/data communications system. Voice processing systems, also referred to as "voice mail" or "voice messaging" systems, provide an efficient system for handling incoming messages and getting them to the intended party on a timely basis.

6.4.3 Facsimile

A fax machine has become a standard piece of equipment for modern business communications. Facsimile transmission is defined as a process involving the transmission and reproduction of photographs, maps, drawings, other graphic matter, and text at a distance. Quality of transmitted images is the major utilization issue.

6.4.4 Modem

A modem facilitates on-line communication, i.e., the transferring of data between computers and other data processing devices through the use of telephone lines. It works by translating the digital language of the personal computer (PC) into analog tones. This is typically accomplished by MODulating the digital signal over an analog channel and then DEModulating the analog signal back to digital at the receiving end. These tones are then transmitted over telephone lines and are reconverted back to digital form by another modem. A communications software package must be available on the computer for on-line communication. The software package contains the instructions that are needed by the computer to activate the modem.

Modems are extensively used in data communications to facilitate the transmission of information between computers or between remote terminals and a central computer system over a voice-grade telephone circuit. Modems can be invaluable tools in transferring information in an efficient manner between agencies that are separated from each other.

6.4.5 NTCIP Center-to-Center Communications

The NTCIP center-to-center communications protocol working group is currently in the process of discussions concerning the approach that the center-to-center protocol should take. There have been several working group meetings that have discussed and are proposing differing approaches for the development of the protocol. As discussed below in this section, there has not been a single method or approach for the protocol agreed to by the working group members. However, current plans are to develop prototype protocols for testing purposes. These prototypes are expected to be developed and start testing by the end of 1997.

Center-to-center communication protocol is intended to enable a continuous and automated exchange of information between transportation management centers, or more specifically, between computer systems involved in real-time transportation management. Transportation management centers likely to use the protocol include those managing freeways, surface streets, public transit, parking facilities, emergency services, and travelers information services.

The protocol will make use of message sets being developed by various related standards activities including ITE's Message Set for External TMC Communications involving road traffic management messages, SAE-ITSA ATIS Committee work on center-to-center traveler information messages, ITE's Transit Communications Interface Protocol messages related to transit operations, and IEEE's Message Sets for Incident Management. The center-to-center protocol work is also being coordinated with various data dictionary and message template activities, with Commercial Vehicle Information Systems and Networks (CVISN), and with international standards activities.

The protocol will be built on Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) at the transport layer, and Internet Protocol (IP) at the network layer. Lower OSIRM layers are not defined and will be implementation specific. The goal is to use off-the-shelf solutions for interfacing between the data link and physical layers.

The primary emphasis of the protocol development to date has been at the application layer, where various services need to be standardized in order to ensure interoperability. The following services are currently identified as important for center-to-center communications.

- Start-up notification/discovery
- Security
- Naming convention and registry
- Subscriptions
- Synchronous request/reply
- Message delivery atdifferent levels of service
- Time/date

The NTCIP center-to-center working group has determined that it is necessary to specify two different approaches to providing these application layer services. One approach involves system developers using middleware adhering to the Common Object Request Broker Architecture (CORBA) standard. While the other approach involves system developers programming procedurally and directly to the TCP/UDP sockets. The two approaches are referred to as the CORBA and Sockets approaches.

The CORBA approach will reduce the amount of programming required to implement the standard, especially when developing new systems already using an object oriented approach. The Sockets approach will achieve the real-time message delivery needed in some applications, and will avoid the requirement to implement CORBA on existing non-object oriented system. These two approaches are not interoperable, although they can operate concurrently on the same system, and conversion or translation between the two should be possible.

Current guidelines indicate that a compressive implementation of the protocol would require both approaches to ensure all services including real-time messaging delivery are provided, and to ensure direct interoperability with all other systems.

7.0 OPERATIONS CENTERS

7.1 BACKGROUND

The Transportation Operations Center (TOC) is the focal point of an ITS-based system. It is from this facility that all system functions are monitored and controlled, and decision makers interact.

7.2 ISSUES

Proper design of the TOC is essential to efficient operation of a system. General issues including location, space and layout, security, human factors, environment, equipment room, console, and computer networks necessary to the successful operation of a center are briefly discussed below. In addition to affecting the individual control centers, these issues also directly affect the inter-connectivity and data sharing abilities between centers.

7.2.1 Computer Networks

A computer network allows users to share information and computer resources including mass storage devices, backup facilities, applications software, data files, printers, plotters, and processors. A Local Area Network (LAN) is such a network confined to a limited geographic area with moderate to high data rates (100 Kbps to 1 Gbps). The area served may be a single building, a cluster of buildings, or a campus-type arrangement. A wide area network (WAN) provides the same data sharing, but over a large geographic area. Several factors need to be considered when configuring a network including topology, potential access methods, the media, the availability of technology, and the use of bridges, routers, and gateways needed to provide interconnection in a LAN or WAN.

7.2.2 Central Hardware

Central hardware issues, including hardware architecture, central processing requirements, workstations, projection systems, and video monitoring are discussed herein.

7.2.2.1 Hardware Architecture

An ITS can be characterized as a data collection, processing, and distribution system. Early transportation management systems (e.g., the UTCS-based signal systems of the 1970s) incorporated a centralized architecture in which a single large computer was utilized for all data storage and processing with minimum distributed computing. The boom in information processing and the capability to link systems via local area networks (LANs) during the 1980s changed this approach. The architecture for recent data processing applications, including ITS, may be classified as distributed.

A distributed architecture can be defined as a collection of data bases distributed across many computers running a number of different applications over a communications network. A (LAN) provides data access to applications within a site, while a (WAN) provides data access to a number of geographically dispersed sites. Not only are the data and their processing distributed, but access to the data is also dispersed, consisting of a wide variety of workstations, terminals, and other computer systems. The use of a client-server model in a roadway-oriented operations center represents the state-of-the-art in a distributed architecture environment.

7.2.2.2 Client-Server Model

The client-server model is based on the concept of distributed processing, with the front end (or the user application) being the client, and the back end (the database access and manipulation), the server. The respective functions performed by the server and client are summarized in Exhibit 5.

Client	Server
Customized user interface	Centralized data management
Front-end processing of data	Data integrity and database consistency
Initiation of the server remote procedure calls	Database security
Access to a database server across a LAN	Concurrent operations (for multi-user access)
	Centralized processing

Exhibit 5: Client-Server Functions

The client-server architecture allows running an application on one computer while running the database on another. In this architecture, the client is responsible for handling user-specific database access tasks. The client gathers data required for queries to the server, processes this information and constructs queries or commands in a predefined protocol for presentation to the server, presents the query to the server, and collects the results. The client will then often process the data returned from the server for presentation to the user.

The client-server architecture offers a flexible, expandable, and cost-effective solution to complex shared database applications. The server is customized for interactive display-intensive tasks. System expandability is achieved easily as long as the servers have spare capacity to handle a large number of clients. The clients, in typical configurations, can be different from that of the server. A mix of configurations can be used with the same server, thereby giving the user the opportunity to select the client architecture most appropriate for the application. The client architecture can be based on a variety of user interfaces, including graphical user interfaces.

The client-server model is a modular architecture in that the system functions are carried out by groups of computers (i.e., clients and servers) linked together through a local area network (LAN). This configuration makes accessible shared resources such as printers, large storage devices, and special purpose processors. The local area network may also be connected to outlying devices and other transportation management and process systems via a wide area network (WAN) consisting of bridging, routing, and other standard networking devices.

7.2.2.3 Servers

A server provides a service to client machines, or workstations. The nature of a service may include data retrieval, management of shared data, data distribution, data processing and analysis, hardware interface, and control. A server responds to client queries and does not initiate communications with a client. Typical servers that meet these criteria include data base servers, VMS interface servers, data interface servers, expert system servers, network printer servers, and network communications servers.

With a modular architecture, much of the processing is distributed among operator workstations, PC-based servers for VMS control and expert systems, and field controllers/processors. Nevertheless, a more centralized approach is often required for managing the large real-time data base, as well as for data storage and to support the advanced user interface and decision support mechanisms. The centralized data approach can also provide fast response to the multiple users who will often access the system simultaneously. The use of GIS technology may also necessitate the establishment of a centralized database manager.

The database server and the data interface server may function as the central processing units -- processing and storing data, distributing this information to the various workstations as required, and coordinating the overall activities of the various system components. The database information is distributed between servers with the static and slowly varying portions on the database server, and the dynamic portions on the data interface server. The static portions of the database typically are much larger than the dynamic portions, and queries against static items are more complex and often require the transmission of more data. The dynamic parts of the database are updated frequently. Splitting the central processors into static and dynamic servers optimizes system performance by preventing the complex static queries from affecting the time-critical dynamic data updates. This configuration may provide spare capacity on the database server to support the processing necessary for incident detection and automated ramp meter rate selection, or these functions may be ported onto separate servers.

Additional servers may be included in the system to provide specific functions, such as communications, VMS, and CCTV control and display. An example of a centralized Local Area Network (LAN) can be found in Exhibit 6.

7.2.2.4 Integrated Workstations

Within typical traffic and transportation management systems the “client” of the client-server system architecture is the integrated workstation. A typical integrated workstation consists of a desktop computer operating a multi-tasking operating system which is capable of running several applications

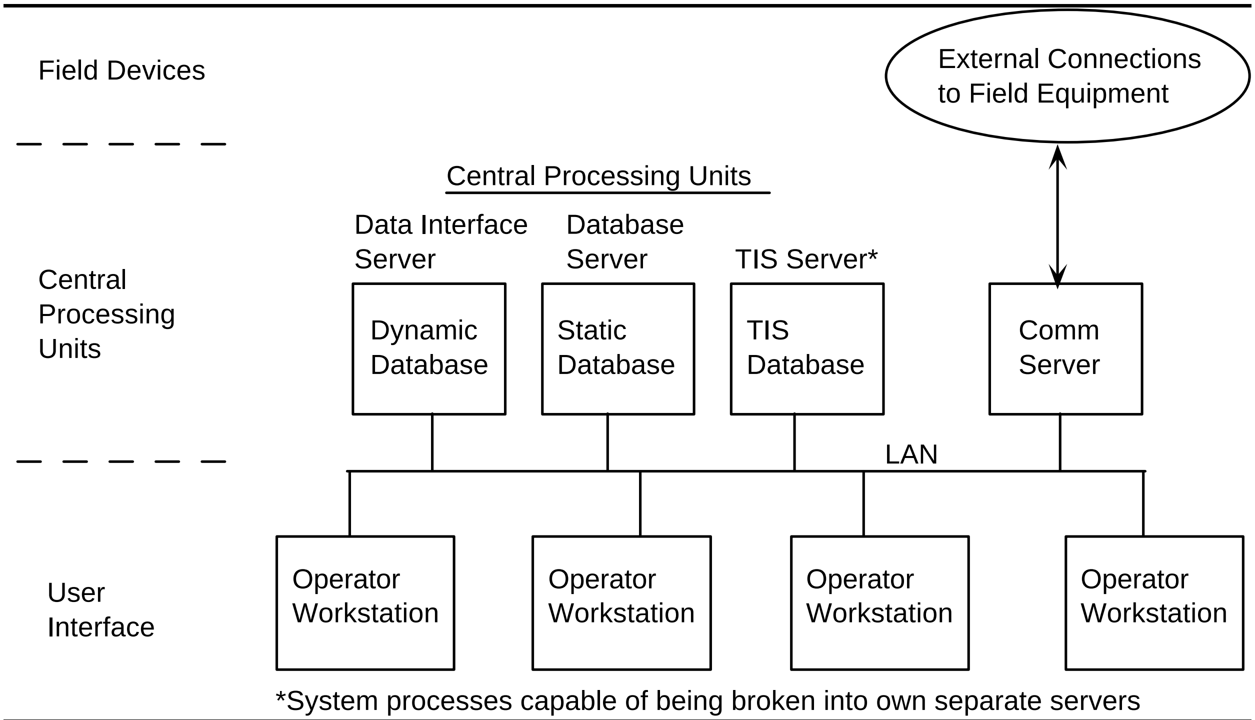


Exhibit 6: Example of a Centralized Network Architecture

simultaneously. All system user access is typically via workstations. In addition to the numerous workstations located in the TOC (e.g., console room, staff offices), several remote workstations may also be included in an ITS-based system. The primary objectives of the operator interface are to provide an effective means for personnel to collect and categorize traffic information, to simplify the interpretation of system information, and to provide the ability to quickly formulate solutions to problems that arise. The "integrated workstation" concept allows common information to be shared across multiple systems and provides a common interface to the network. The integrated workstation should also allow all system functions, manipulations, or operations to be performed at either a single workstation, or at two workstations. An operator should not need multiple workstations to perform or complete daily functions. An integrated workstation not only benefits the users of the system, but can promote economies-of-scale in the installation, operation, and maintenance of the system.

7.2.2.5 Display Equipment

Large screen projection systems allow the projection of data, graphics, or video directly onto a large screen. Computer terminals, PCS, VCRs, or other video signals are connected to the projection system via straight cable or through an electronic interface. The electronic interface is required to convert the input signals to the projection equipment's format when their scan rates or interface standards (e.g., NTSC, RGB, PGA, VGA, Super VGA) differ.

7.2.2.6 Video Monitoring

When analyzing the potential for full CCTV coverage of all roadways and related facilities in an ITS network, obviously not all images can be viewed simultaneously, due to the amount of bandwidth necessary to carry all the images, and from a human factors standpoint. A wall filled with TV monitors showing pictures of traffic may be impressive to the casual observer, but is not terribly useful to the operator. Based on previous TOC experience, it is estimated that one operator can monitor up to four CCTV images concurrently during a typical 8 hour shift.

For verification and monitoring of a single incident and resultant traffic congestion, a minimum of two cameras is typically used. These can focus on the incident site plus upstream segments, diversion points, or alternative routes. Given the above human factors limitations, the use of three operators means that up to 12 CCTV images can be monitored simultaneously. This allows concurrent monitoring of four to six major incidents. Additional incidents can be monitored through appropriate camera switching functions, including cycling between images at selected intervals.

7.2.3 Central Software

Many basic control strategies and functions that can be included in ITS have been described in previous chapters. These and other system functions are coded into software/firmware, and ported onto the central, field, and vehicle processing hardware as appropriate.

7.2.3.1 Automated Operation of Field Devices

VMS and HAR systems can be automatically activated to broadcast or to display pre-recorded and programmed messages based upon detected traffic conditions. Likewise, CCTV cameras can be programmed to verify detected traffic conditions, thus expediting the detection of an incident. Algorithms can be developed to compare current and historical data collected by the detection system for use in setting parameters to automatically activate message selection, the activation or de-activation of selected field devices, or for instructing CCTV cameras to zoom in on specific areas of detected traffic anomalies. Known activities which impact traffic flow, such as construction and lane closures, could also be factored into the database since both occurrences can result in congestion.

In the case of VMS, the system can select the appropriate message or sequence of messages from a list of pre-programmed messages for the particular traffic situation. The system should also be able to display the selected message on pre-designated signs. Different messages could also be sequenced if necessary. As an example, an advisory of heavy congestion between exits could be displayed followed by a suggestion to take an alternate route.

The VMS message selection algorithm could also be used for the selection and sequencing of pre-recorded HAR messages. Based upon the detected traffic condition, the algorithms could also be developed to script a real-time message, thus substantially minimizing the time required to disseminate real-time traffic condition advisories using HAR.

7.2.3.2 Workstation Requirements

All system user access to a system is typically provided via workstations. In addition to the workstations located in the TOC, remote workstations may be necessary when all operations of the agency are decentralized.

Workstations might also be provided to outside agencies or authorities for informational purposes. For example, if the transit operations center gathers and processes AVL information from their vehicles, information such as average travel speeds can be disseminated to the municipality’s traffic department through the workstation. The workstation at the traffic department's offices or traffic management center would then be used for incident detection or congestion management.

For an "integrated workstation", as discussed in Section 7.2.2.3, different systems or software may exist in the operations center, all of which should run on a single workstation.

7.2.3.3 Data Sharing

With the existence of local area and wide area networks, it is very common for agencies to want to share data within its own departments and possibly with other agencies. Some of the advantages of sharing data is that all users have access to the same information, though each user may have different uses for that data. For example, using AVL technology, software is available to automatically, or periodically, log into a database with a time stamp and determine exact location of each transit vehicle at any point in time. If the vehicle is taken out of service because of a breakdown, a log entry would also be entered into the database. Accessing the same database, the scheduling department would have a workstation to analyze the schedule adherence information for planning purposes, while the maintenance department would have a workstation for printing mean miles between breakdown reports. By sharing data, all users across the network have a common point of reference from which coordination between the users can take place.

A key to data sharing lies in using common data identifiers. Various software packages often use different means to identify the same object. For example, an on-vehicle annunciation system might use one label (name of the station) for a train station, while an automatic fare card system might use another label (station 251), and the facilities design department may address the station with another label (latitude and longitude). By identifying the common elements across multiple subsystems and using common names and functions, personnel can more readily coordinate their efforts across the various departments.

8.0 TECHNOLOGY SUMMARY

The technologies presented in this paper are representative of the state-of-the-art for the ITS arena. For the most part, they have been deployed and are tested and functional in areas around the world. Decisions about which technologies to deploy must be made on a case-by-case basis, with a detailed examination of all the risk factors, and potential advantages each has to offer.

In recent years, the ITS community has attempted to standardize the architecture from a national standpoint. The National Architecture creates the opportunity for interoperability across diverse ITS deployments while preserving flexibility and choice for the many transportation providers involved in the deployment process. At the regional level, the National Architecture provides a general framework that should be adapted and elaborated for use in supporting an interoperable regional transportation system design. It is focused around three central guiding principles:

- Adaptation or development of common standards for products based upon the requirements set forth in the National Architecture.
- Development of regional architectures which interpret the National Architecture and tailor it to support regional needs.
- Incremental deployment of compatible systems.

The architecture must support all user services, be scalable to suit the needs of all transportation providers, and be sufficiently flexible to accommodate current and future technologies. This flexibility enables each implementor to maximize use of existing assets and provides a variety of evolutionary paths for maturing ITS capabilities based on individual priorities.

The technologies discussed in this paper can be implemented consistent with the National Architecture, and it is in everyone's best interest to ensure that this compatibility is maintained.