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Chapter 5
Technologies

Types of Technologies

This chapter discusses the various technologies that may be used for ITS applications, addressing both their merits and limitations. Following this introductory section, this chapter addresses technologies related to monitoring, communications, traveler interface, data processing and public transportation functions, as well as an evaluation of possible strategies Figure 5-1 illustrates some of the technologies commonly used in ITS applications across the country.

Monitoring technologies, which are discussed in the second section of this chapter, include vehicle detection technologies, closed circuit television (CCTV), and technologies for electronic toll collection (ETC). Vehicle detection technologies, which comprise the majority of the technologies discussed, include passive technologies and active technologies. Active technologies require that the vehicle be equipped with special devices. Discussion addresses traditional passive technologies, such as induction loops, as well as newer passive technologies, such as microwave detectors. Technologies used for active vehicle detection include technologies such as automatic vehicle location (AVL) and automatic vehicle identification (AVI), as well as transponders for ETC.

The discussion of communication technologies in the third section begins with a discussion of fiber optics, which is expected to be the primary communications medium for the Kansas City Intelligent Transportation System. Other communications technologies are also discussed. Those technologies will potentially be used for communications in areas where fiber optics have not been placed, for example on arterial streets which will be used for incident diversion, and for communications with emergency responders.

Technologies that may be used to communicate with the public are discussed in the fourth section. These technologies, which are critical because they allow the public to make informed decisions, include variable message signs (VMS), highway advisory radio (HAR), information kiosks, and dial-in information systems, such as highway advisory telephone systems.

Data processing technologies are discussed in the fifth section. This section addresses technologies used to process the data collected by detectors, as well as incident detection algorithms used to analyze this data to identify incidents.

Various strategies are discussed in the sixth section. Strategies discussed include incident detection and verification options, options to improve response time, options for site management, options to reduce clearance time, and options for traveler and motorist information. ITS applications in other cities are also presented.

Technologies that may be used for public transit applications are discussed in the last section. These technologies include transponders installed on vehicles for automatic vehicle location and identification.

Monitoring Technologies

Advanced traffic management systems (ATMS) typically provide two different sub-systems for roadway monitoring: vehicle detection and closed circuit television (CCTV). These two sub-systems provide different functions, and operate together to provide the traffic operations center (TOC) with real-time status of traffic conditions. The vehicle detection sub-system electronically monitors the flow of traffic on the roadways, and transmits this information in "real-time" to the TOC for analysis and status displays. The operators utilize the results of the analysis and the status information to make decisions regarding management of the traffic. The CCTV sub-system provides the operators with a visual means for verification of the conditions reported by the vehicle detection sub-system. The CCTV images also provide the operator with an independent evaluation of traffic conditions.

Each of these two sub-systems can be deployed and utilized jointly as well as independently. However, the complementary interaction of the two sub-systems improves the overall system operation in a manner that neither system can provide alone. The vehicle detection system, since it is automated and can function with minimal human intervention, provides continuous monitoring and up-to-the-minute data. The CCTV system allows the human observer to view and interpret an incident, or other traffic conditions, and determine an appropriate response. As more progress is made in the technologies of image processing, artificial intelligence, and expert systems, it is inevitable that computer systems will augment the capabilities of the human observer.

VEHICLE DETECTION

Vehicle detection technologies form the foundation of the monitoring sub-system used for automated incident detection and traffic management. Monitoring information provided by vehicle detection enables collection of a range of traffic data including speed, volume, density, travel time, and in some cases, vehicle position. Control strategies, incident management procedures, and motorist information displays are selected based upon the data collected by the vehicle detection system. The collected data is used in real-time for making traffic management decisions and stored to provide a historical data-base of traffic conditions. Monitoring can also be used to obtain information on vehicle classification, length, speed, acceleration characteristics, and hazardous materials.

Operational environment and maintenance requirements are two of the most critical factors in determining the types of detectors for the system. Systems that involve cutting existing road surfaces and pavement (such as induction loops) can create installation and maintenance problems or compromise the structural integrity of the roadway, especially on bridges and other structures. Technologies that do not require these modifications are termed non-intrusive installations, and minimize the traffic diversion and control problems.

The choice of detectors for an automated system depends on the data requirements. To meet the functional requirements of the recommended user services, real-time data to ascertain vehicle speed, counts, lane occupancy, classification, and changes in motion and position will be required for automated incident detection. This real-time data should be stored for historical as well as planning use.

There are two separate approaches to vehicle detection, those that are passive and involve no electronics in the vehicle, and those that utilize electronics in the vehicle and alongside the roadway. As with all areas of electronic technologies, changes occur regularly, providing new solutions to existing problems, but conversely requiring that systems be flexible enough to accommodate change on a regular basis.

Various technologies that may be applicable are discussed below. There are numerous other technologies that have been experimented with and tested by various departments of transportation (DOTs) and the Federal Highway Administration (FHWA). In particular, the "Detection Technology for ITS" project sponsored by FHWA is evaluating a wide range of equipment under laboratory and field conditions. Although many of these technologies show promise, they have not progressed to reliable field operation. In order to limit system complexity and resultant operations and maintenance costs, minimizing the number of different technologies is preferred.

Passive Vehicle Detection - Technologies that do not require any devices in the vehicle are the basis for most current vehicle detection systems. Passive approaches allow all vehicles in the vicinity of the sensor to be detected and monitored, but provide less information than will be available in the future.

Induction Loops: The most commonly used vehicle detection technology is the induction loop. This technique is extensively used for arterial signal control and freeway monitoring and has a long history of successful field deployment. The advantages of induction loops are their well-known performance characteristics, maturity, application flexibility, and multiple vendor availability. Over the years the manufacturers have enhanced and refined their equipment, providing numerous options and alternatives to meet a wide range of application needs. Pairs of loops can be used to measure speed and vehicle length for classification purposes. Some vendors have announced products that measure speed with a single loop, but field experience is limited. Some disadvantages of induction loops result from the need to embed the loops in the pavement surface, including problems associated with pavement deterioration and freeze-thaw damage. Other difficulties include damaging the loop conductors during resurfacing operations or construction, and the reduced effectiveness of loops when in close proximity to reinforcing steel.

Recent improvements have been made in inductive loop technology. Loop detectors have been primarily utilized to provide a digital output that is representative of vehicle presence above the induction loop in the pavement. In this regard, a sophisticated computer system is unable to gain access to any information contained in the magnetic or inductive signal collected by the detector amplifier. New products are available with on-board microprocessors that are able to monitor the "signature" of the detected field. Use of this data allows accurate speed measurement and provides some capability for classification. Serial data ports with RS-232 communication allow systems to access a detector amplifier internal database to perform remote sensitivity adjustments and compensate for weather conditions.

Another development is the manufacture of pre-formed loops, which are available from a number of suppliers. This type of loop is pre-assembled, with the wires encased in a filled conduit. This assembly is embedded in the pavement, typically several inches below the surface, during the construction of the roadway. This technique offers improved reliability and life expectancy.

A similar approach, that of embedding the loop in the pavement, is being utilized in some areas as part of roadway reconstruction projects. After the milling operation that is used to remove old pavement, the induction loop is saw-cut into the milled surface. After the new pavement is applied, the loop is buried several inches below the road surface, where it is less subject to damage from traffic, construction or weather.

While induction loop detectors are often maligned because of the problems noted previously, they are currently the primary source of vehicle detection in most systems around the country. Studies in Los Angeles were performed by video taping the traffic stream, time-stamping and manually counting the vehicles on the video tape. Results show that the accuracy of induction loop data with respect to vehicle counts is ±0.6 percent.

Magnetometers: Magnetometers, and the related micro-loop technology, are often suggested for deployment on bridges and other areas where loop installation in the existing pavement area could affect structural integrity. Magnetometers have had spotty operational success, and other technologies have often been considered for these particular needs. However, the use of new digital processing technology has the potential to significantly improve the performance of magnetic detectors. A re-evaluation of their role will be appropriate after sufficient field experience is gathered. Preliminary results from the ITS Detection Technology project show that magnetometers have an accuracy in the ±5 percent range.

Axle Counters: The FHWA requirement for vehicle classification on certain roadways generates the need to count axles. The most commonly used technology uses a bending beam piezoelectric strip embedded in the roadway surface. These devices, working in conjunction with inductive loops, measure the vehicle length and speed, and count the axles. The vehicle length, combined with axle count, is used to classify the vehicle.

Radar: Radar detectors operate by emitting a signal in the microwave portion of the electromagnetic spectrum, and analyzing the returned signal. These detectors are in limited use in incident detection and freeway management projects. Continuous wave (CW) radar detection operates on the Doppler effect (measuring frequency shifts between the transmitted and received beam caused by vehicle motion), and thus directly measures vehicle speed. Vehicle counts can be determined by accumulating each vehicle detected, but this approach does not directly provide lane occupancy and vehicle length information. Similarly, detection of stopped vehicles, or very slowly moving vehicles, is difficult.

Another type of CW radar detector transmits a signal that is swept over a range of frequencies. This technique allows measurement of the range from antenna to vehicle, and is thus able to function as a presence detector. The sweep frequency functions as the sample rate to quantify presence.

Pulsed radar operates by transmitting a burst of microwave energy, and interpreting the "echoes" reflected from vehicles in its "field of view". Because of the complications involved in processing multiple reflection, pulsed radar units utilized for traffic detection limit their field of view to a portion of the lane, such that a single vehicle is present in their detection zone. This technique permits the determination of the distance to the nearest reflection, and by monitoring this reflection over time, the position and resultant speed of the vehicle can be determined. This type of radar can be used to sense stopped vehicles, but has the limitation that the sample rate must be frequent enough to provide accurate presence calculations to determine other traffic parameters.

Continuous wave radar detectors of the Doppler and swept frequency types require one antenna per lane, mounted on a structure or a sign bridge over the lane The same limitation applies to pulsed radar units. The ITS Detection Technology project early results show that these radar detectors have accuracies that range from ±0.5 to ±6 percent.

Microwave Detector: When mounted at the side of the roadway, a microwave detector is able scan up to twelve lanes. Since side mounting facilities are often available or can be readily installed, the device is more cost effective than other detectors. The device can also detect vehicle presence, and is thus able to determine occupancy and the existence of stopped vehicles. However, it does not measure speed directly, relying upon "single loop" speed estimation techniques based on average vehicle length. The accuracy of this device, as stated in the early results from the Detection Technology project, is in the ±5 percent range for volumes. Test results indicate missed and duplicated counts across multiple roadway lanes upon the passage of large vehicles.

The advantages of radar and microwave devices include the ease of use, requiring no cutting of pavement and disruption of traffic flow for installation or maintenance (if mounted on a structure or sign bridge where overhead access is possible). For the Doppler units, direct speed measurement is a significant benefit. If traffic lanes are shifted, radar antennas can be easily re-aimed. The disadvantages of radar are: the overhead mounting requirement, limited field operational experience for many of the new units, a small number of vendors in the market, and difficulties of accurately sensing lane occupancy and slow moving or stopped vehicles with Doppler units.

Radar detectors can be configured with two types of interfaces: RS-232 serial data and two pulse-type contacts. The serial output provides data (volume, speed, etc.) in an ASCII text string. Modifications to this format to incorporate an error checking communications in a standardized protocol would allow a multi-lane unit to be installed without a local field microcomputer. The dual pulse-type contact closures provide for emulation of a loop-pair speed trap. The first contact closure occurs when the vehicle enters the detection zone, and the second contact closure is timed relative to the first closure by the detector to provide the correct travel time based upon a calibrated "loop spacing".

Infrared: Infrared detectors monitor electromagnetic energy in the band above the visible spectrum. Both active and passive devices are marketed that utilize infrared detection.

Active infrared devices illuminate the detection zone with infrared energy supplied by either light emitting diodes (LEDs) or lasers. Lasers can provide a higher level of output energy. A portion of the energy reflected back from the vehicle is detected and processed. The detector consists of optical elements to focus the returned signal onto a matrix of infrared sensors. The two-way travel time of the infrared pulse from the source to the sensors is used to measure the distance to the vehicle. This strategy is similar to that used in a pulsed radar detector. Processing of the data provides vehicle counts, occupancy, presence, speed and classification information. Because infrared energy is attenuated and scattered by rain, snow, fog and mist in the air, active infrared detectors are vulnerable to these atmospheric conditions. In addition, other obscurants in the air, such as smoke and dust, can reduce the effectiveness of the detector

Passive infrared devices do not emit any energy themselves, but utilize the characteristic that all objects emit heat (infrared radiation) as a function of their surface temperature The amount of infrared energy is also a function of the emissivity of the object itself By detecting the difference between the temperature/emissivity of vehicles and the roadway surface, a passive infrared detector can determine the presence and passage of vehicles. The infrared energy is focused through an optical system onto the infrared sensors. The resultant signal is processed to provide presence, vehicle counts and occupancy. As noted above, infrared energy is obscured by atmospheric effects. Because passive infrared detectors are dependent upon the sun and other infrared sources for their input energy, diurnal changes, cloud cover, and glint from bright objects reflecting sunlight can all create confusing and unwanted signals.

By increasing the number of sensors in a passive infrared detector, an "image" of the scene of interest can be generated. This increase in detail allows additional information from the scene to be discerned and analyzed. As the number of individual sensors becomes large enough, the boundary between an infrared detector and an infrared sensitive CCTV camera becomes blurred. For practical applications, an infrared imaging system has essentially all the same characteristics of video image detection (VID) systems discussed below.

Sonic: There are several techniques that have been explored utilizing sound energy. Some devices operate as sonar devices, sending out sound waves and analyzing the returned echoes from the vehicles - much like the radar systems. The early results from the ultra-sonic unit included in the ITS Detector Technology test show an accuracy in the ±2 percent range. Other sonic detectors passively "listen" to the noise generated by the vehicles, and analyze this noise energy to detect individual vehicles and resultant location and speeds. These devices have not yet been extensively used, and thus field experience is limited. However the technology has been applied for submarine noise signature detection by the military and could become a valid tool for classification of vehicles.

Video Image Detection: Video image detection (VID) systems (sometimes referred to as machine vision systems) are comprised of fixed orientation CCTV cameras strategically located to provide views of specific areas or long sections of roadway, coupled with a computer that analyzes the video image in real-time (30 times per second). This technology has been developed for various industrial, manufacturing, military and aerospace applications. It has been applied to traffic management in recent years, with growing success. Early systems were troubled by harsh environments, adverse and changeable lighting conditions, shadows, differing vehicle shapes, and sometimes difficult operating conditions. These difficulties have, for the most part, been solved by extensive field testing, actual deployment, more powerful computers, and increasingly sophisticated software.

Two fundamentally different strategies are used to analyze the video images: fixed analysis zones that detect vehicles moving through them, and vehicle identification and subsequent tracking. A third strategy, involving reading license plates "on-the-fly" may be appropriate for toll violations and related applications, but is not directly applicable to this Early Deployment Study. The technique utilizing fixed analysis zones, analogous to a "loop" in the video image, is the most stable and best tested approach. Equipment based on this approach can provide vehicle counts, lane occupancy, speeds, and lengths. Software in the VID processor collects the standard information (volume, occupancy, and speed) and can also provide some analysis and processing of this data, including statistics accumulation, data smoothing, and level of service calculations.

A key benefit of a VID system is its ability to monitor large areas of roadway from a single equipment location. Because the CCTV camera can be oriented to monitor a section of roadway (up to one-quarter mile), and the entire image can be analyzed, significantly more roadway and a greater number of vehicles can be monitored. The most promising use of a VID system is detection of stopped or stalled vehicles (either in a travel lane or on the shoulder), providing direct detection of an incident. The monitoring of wide areas of roadway, coupled with individual vehicle detection, is expected to provide significantly more information than existing point source (such as induction loop or radar) technologies.

While the promise of VID systems is significant, it is still a young technology that will evolve and grow for many years. There are operational problems under adverse lighting and during transitions between daylight and darkness (including storm conditions) that require additional refinement. Camera placement must be carefully considered, as shadows from objects outside the detection area may affect performance. The early results from the Detector Technology project report show accuracies ranging from ±0.3 to ±2.3 percent, with accuracy decreasing under dark or adverse weather conditions.

Passive Vehicle Detector Cost Comparisons - Two different categories of passive vehicle detectors are discussed above: those that are embedded in the road surface, such as induction loops, and those that are mounted overhead, such as a radar detector or a video image detector.

As discussed, embedding detectors in the roadway requires that the road surface be cut or drilled, and subjects the detector to failure due to pavement deterioration and other environmental factors. This can create ongoing maintenance problems, and/or poor detector reliability. Newer construction techniques which embed the detector several inches below the pavement surface are being used to solve some of these problems.

Detectors that are mounted above each lane, such as most radar detectors and ultrasonic detectors, require some form of support structure. A claimed advantage of this installation location is minimal traffic disruption during installation and maintenance. Mounting on an existing overcrossing is an option, but can create aesthetic concerns and often results in limited accessibility requiring that a traffic lane be closed to service the unit. The use of signal head mast arms is another possibility, but is of limited use on a freeway, and has the drawback of motion under high wind loading and the need to block traffic for installation and servicing. Sign bridges are a third possibility, and where they already exist they are excellent choices, especially if they include a cat-walk so that the units can be installed and serviced without shutting down traffic. However, the installation of new sign bridges for the mounting of detectors is an expensive alternative.

In general terms, many of the overhead detectors cost between $750 and $1,000 per unit that monitors a single lane. Poles and mast arms cost about $200 per foot (with foundation and installation), resulting in a cost of roughly $2,400 for a 12 foot lane. This is about 2.5 times the cost of the detector. Sign bridges roughly cost $500 per foot (with foundation and installation), or $6,000 for a 12 foot lane. This is about 6 times the cost of the detector. This needs to be compared to the installed cost of induction loops of about $1,000

Thus, overhead mounted detectors that must be positioned over each lane can be significantly more expensive than induction loops, when the cost of a mast arm and pole or sign bridge must be included. Under those situations where an existing structure or sign bridge is available, they can be cost effective - but may still require traffic disruptions for installation and servicing.

Another category of overhead devices, side fired radar and VID, can be mounted off the side of the road or on a pole in the median. This reduces the cost of mounting to roughly $5,000, and does not require stopping traffic for access to the unit. These devices also have the advantage of being able to monitor several lanes from a single unit, thus spreading the cost of the unit and the mounting pole across several lanes. A disadvantage of side mounting or an oblique camera view is the fact that trucks may obscure smaller cars. This results in missed counts. With VID, the ability to discriminate between two closely spaced vehicles is a function of mounting height and angle of view. Increased height improves the discrimination ability, but results in a more costly pole and foundation. Another problem noted with VID is motion of the mounting pole under wind loading, or twisting of the pole due to differential solar heating. These conditions result in the camera field of view changing and "moving" the fixed analysis zones to another portion of the image.

For comparison purposes. costs for different technologies have been estimated for an eight lane cross section of freeway, as shown in Table 5-1. Five different equipment configurations are shown:

- Induction loops, with lead in wires saw-cut into pavement surface and processor cabinet on one shoulder.
- Side fired radar, with unit mounted on a pole located on one shoulder adjacent to the processor cabinet.
- Video image detector (VID), with two cameras mounted on a pole in the median and the processor cabinet on one shoulder.
- Overhead mounted sensors on mast arm with the pole in the median and the processor cabinet on one shoulder.
- Overhead mounted sensors on sign bridge with processor cabinet on one shoulder.

Table 5-1. Estimated Costs for Passive Vehicle Detection

Configuration	Cost Per Lane	Eight Lanes
Induction Loops	$3,400	$20,300
Side Fired Radar	$3,725	$22,350
Video Image Detector (VID)	$10,100	$60,600
Overhead Mounted Sensors on Mast Arm	$6,250	$37,500
Overhead Mounted on Sign Bridge	$13,250	$79,500

For all configurations, it is assumed that power and communications conduits are available at the location of the processor cabinet. With the exception of the VID, a Model 170 processor and cabinet is included. Conduit, cable, installation and testing costs are included for all cases. For the two configurations with median located poles (VID and overhead sensors on mast arm), costs for jacking conduit under four lanes are included

Maintenance costs must also be considered Maintenance costs are usually calculated on an annual basis as 10 percent of the original equipment cost. Maintenance costs associated with induction loops may be higher, as indicated by local experience

Active Vehicle Detection - Technologies that include electronics in the vehicle that interact with the roadside infrastructure and other vehicles in the immediate vicinity appear to be the next step toward automated guidance and highway systems. Although it is expected to be at least two decades before these technologies become widespread, devices in this category are currently being used for specific applications around the country

Automatic Vehicle Identification: The recent conversion of many toll facilities to electronic toll tags for electronic toll collection (ETC), also referred to as automatic vehicle identification (AVI), creates a potential for vehicle detection and monitoring in some areas. By monitoring the movement of individual vehicles past various AVI antennas, the vehicles become active probes and link travel times can be determined. This technology is successful in areas where AVI tags are being used for toll roads, but is of limited applicability elsewhere. The installation of AVI on the Kansas Turnpike may eventually result in an adequate population of AVI equipped vehicles in the Kansas City area, however, other technologies are probably more appropriate in the near future.

Another use of AVI technology is its use on transit vehicles to determine their location The use of induction loops as the reading antenna has been successfully deployed in some areas. This use of AVI has found a receptive audience as a method for more accurate tracking of bus fleets for control and dispatch.

Global Positioning Systems (GPS): GPS equipment is being used by various emergency (police and emergency medical) and fleet (trucking) organizations to permit continuous tracking of vehicle locations. In fact, a number of emergency response agencies in the Kansas City area have plans to acquire these systems in the near future. The costs per vehicle are still too high for widespread use by the general public, but the technique is very beneficial in those cases where it can be justified. Accuracies range from a few hundred feet to a few feet, depending upon the capabilities of the GPS receiver. The more accurate units are proportionally more expensive. GPS receivers as accessories for PCs are now available at prices of less than $1,000. As sales volumes increase, prices will continue to come down and additional hardware and software features will be added.

GPS receivers are an important component of vehicle navigation systems currently being tested. It is included as a component of the in-vehicle navigation systems and vehicle emergency notification systems (such as MAYDAY system discussed later in this chapter) being considered as part of the National ITS Architecture. Vehicle location using this technology coupled with a data channel linking a public service vehicle (such as police, fire, or transit) to the TOC is being evaluated as a component of incident response systems elsewhere in the United States. The ability to locate emergency response vehicles in real-time on a status map is a very useful tool in managing and coordinating incident response over a wide area. After some initial operational experience is gained from systems currently in development, the effectiveness and costs can be evaluated for possible use

Automatic Vehicle Location (AVL) · A variation on the GPS strategy is the use of fixed location beacons that can be monitored by a vehicle, such as a bus. Through the use of an on-board computer, monitoring of the vehicle's movement with an electronic odometer, and known information about a route to be followed, the location of the vehicle can be estimated The location beacon allows the strategy to be refined by providing "check-points" that permit the on-board computer to update and correct its estimates of location. This is basically the system used by the Kansas City Area Transportation Authority (KCATA) and MAST, the emergency medical responder in Kansas City, Missouri. Although the KCATA's system is not currently operational, the KCATA does have a grant to replace the equipment which will make the system operational.

The periodic transmission of vehicle location to a central computer allows a central dispatcher to track the vehicle. This tracking can be matched to a bus schedule, for example, and alert the driver and the dispatcher if the bus is ahead of or behind schedule. This automated vehicle monitoring can be input to the traffic management system, providing active probes in the vehicle stream, similar to the AVI system discussed above. When transit vehicles are used as probes, the start/stop nature of transit vehicles must be taken into account when estimating the flow of traffic. The integration of this tracking with voice communications to the bus driver is a very useful tool in locating incidents, and determining their nature and severity. Although monitoring transit vehicles through an AVL system would be possible in Kansas City, it would be of limited benefit for freeway monitoring due to the lack of transit vehicles regularly using the freeway.

Detector Comparison Matrix - Table 5-2 illustrates the major features of the most common types of vehicle detectors. This table includes the primary parameter that is most directly measured by the detector and the preferred mounting.

CLOSED CIRCUIT TELEVISION

Closed circuit television (CCTV) provides the eyes for the operator at the TOC, and has proven to be one of the most valuable elements of an advanced traffic management system. Operational experience shows that constant monitoring of CCTV images by operators is not effective, as the operator soon becomes "numbed" by the constant repetition of vehicles moving across the screen. The primary role of CCTV is to verify a reported incident or other traffic condition, to evaluate its severity, and determine the appropriate response vehicles and personnel to dispatch to the incident scene.

In addition to its primary role in incident verification and response coordination, CCTV can also be used for other purposes, including:

- Monitoring the operation of critical signalized intersections that are in the vicinity of the CCTV camera. This allows evaluation of signal timing and the related functions of the controller. Overland Park and Lenexa, Kansas, are considering the use of CCTV for monitoring selected intersections.

Table 5-2. Major Features of Common Vehicle Detectors

Detector Type	Primary Data	Mounting Location	Comments
Loop	Presence	Roadway per lane	Roadway cut installation life is approximately 3 years.
Piezoelectric	Axle count, Weight	Roadway per lane	Installation involves roadway cut.
Radar (CW)	Speed	Overhead per lane	Poor results at low speeds.
Radar (multi-zone)	Presence	Overhead, Side, Multi-lane	Some tests show difficult calibration.
Passive IR (non-image)	Presence	Overhead per lane	Few installations
Passive IR (image)	Presence	Overhead, Side, Multi-lane	Few installations
Active IR (non-image)	Presence	Overhead per lane	Few installations.
Acoustic (passive)	Presence	Overhead per lane	Some tests show reliable operation. Few installations.
Ultrasonic (pulsed)	Presence	Overhead per lane	Poor sample rate for high speed flow statistics.
Ultrasonic (CW)	Presence	Overhead per lane	Poor results at low speeds.
Magnetometer or Microloop	Presence	Roadway per lane	Manufacturer claims good results on bridge decks.
Video Image	Tracking	Overhead, Side	40 ft mounting height suggested.
AVI	Travel time, Location	Overhead, Side, Limited Range	As electronic toll use increases, population of users should grow.

- Utilizing the CCTV camera to monitor freeway diversion routes to determine current operating conditions. This allows verification that the arterial streets have adequate capacity.

CCTV cameras, lenses and typical mounting heights (40 feet above the roadway surface) allow monitoring of roughly one-half to one mile each direction from a camera location. This is, of course, restricted by topography, roadway geometry and vegetation. Some installations have mounted CCTV cameras on high-mast poles or towers more than 100 feet above the road. This added height provides a larger area of coverage, if topography and vegetation are favorable.

Specific selection of camera locations is controlled by the desire to monitor high-incident locations and other areas of interest. Ability to view parallel surface streets and ramps should also be considered in site determination. The constraints imposed by access, available locations for cabinets and pole foundations, and communications often limit the optimum selections. Each prospective site must be investigated to establish the camera range and field-of-view for the mounting height and lens combination selected.

The biggest issue with respect to CCTV is the transmission of the image from the camera location to the control center. Direct video requires a communications channel that is equivalent to more than 1,500 voice grade audio channels. Thus, most efforts in optimizing CCTV systems are directed toward reducing the bandwidth of the CCTV communications channel. These efforts range from not updating the image in real-time (real-time requires 30 updates per second), to digitally compressing the image, through analyzing the image and transmitting only the moving elements of the image

The standard for CCTV pictures is a "broadcast" quality, full-motion, real-time image At present, this is usually implemented by use of a fiber optic communications system, with a separate full bandwidth fiber allocated for each CCTV camera. With the tremendous bandwidth available on a fiber optic system, this direct approach is often the least costly and provides the best performance. When this direct approach is not cost effective, alternative solutions must be utilized.

Camera Type - Color images provide the greatest amount of visual information and are the preferred choice of most TOCs. However, color CCTV cameras rapidly lose their sensitivity under night, or other dim lighting conditions. Black-and-white cameras, on the other hand, are available that will produce usable images even when it is too dark for a person to see. A black-and-white camera is able to produce a usable image with 10 percent or less of the light level required for a color camera. Some vendors have solved this dilemma by packaging both a color camera and a black-and-white camera in the same housing. This increases the price of the assembly, but the added cost may be acceptable in some locations. Actual field testing should be performed, or the performance of cameras at existing TOCs should be verified before committing to a specific equipment selection. The typical cost of a color camera, with field controller and cabinet, pan/tilt unit, housing and mount, and installation and testing is roughly $20,000.

Pan/Tilt/Zoom/Focus Control - The CCTV camera in the field must be moveable (left and right, and up and down) in order to permit it to monitor the greatest possible area. Similarly, a zoom lens to allow viewing of vehicles at varying distances and associated focus control is required. These functions must be capable of being controlled by all operators who have access to the CCTV images. This functionality is implemented by placing a microcomputer at each CCTV location that receives commands from the traffic operator. This microcomputer turns on and off the appropriate motor in the pan/tilt unit or the motorized lens.

Each CCTV system vendor has its own proprietary system for this type of control. As systems grow and expand over time, control compatibility must be maintained so that the operator is not faced with several different camera control systems. The needs of the control system, both initial and long-term, must be addressed during the system design, considering the growth requirements and future needs.

Digital vs. Analog Transmission - The technology used to date for most long haul, "broadcast quality" CCTV systems has been analog transmission. Within the past five years, significant progress has been made in the development of cost-effective digital transmission equipment. Once video is converted to the appropriate digital format, it can be transmitted long distances over a fiber optic link using a digital protocol such as a Synchronous Optical Network (SONET) communications system with no further conversion and without degradation of image quality. Additionally, digital video switches are smaller and less expensive than analog switches

Another benefit of digital video is the ability to compress the video image, and thus utilize lower bandwidth on a less expensive data communications channel, which may be used to transport the video to another facility. Typical compression ratios are 40:1. The cost of compression/decompression (codec) equipment is currently about $5,000 per unit.

Fiber vs. Coaxial Transmission - The use of fiber optics for transmission of video has almost completely replaced the use of coaxial cable, except for very short runs of less than 500 feet. Disadvantages of coaxial cable include requirements for amplification of the transmitted signal every few thousand feet (to compensate for signal attenuation), the susceptibility of the cable to induced noise, and damage to the electronics from lightning strikes. Fiber optic transceivers are now available with ranges up to five miles for multi-mode fiber, and over 20 miles for single-mode fiber. These transceivers range from less than $300 for short range units to over $2,000 for long range devices.

Geographically Distributed Control - An effective and needed strategy in modern incident/traffic management systems is distributing video images to the multiple locations and agencies that can utilize them. This provides for joint, coordinated response to an incident In addition to the video images, camera selection and pan/tilt/zoom control may also need to be distributed. Geographic distribution of these control functions should be considered in the basic design of the CCTV system, since adding these capabilities to a simpler system is often difficult and costly.

Video Switch - A key component of the CCTV system is the video switch that allows any CCTV camera to be viewed on any monitor, at any location that has access to the CCTV system. A variety of switch architectures are available, from fully centralized to fully distributed. Each has its own advantages and disadvantages, and associated costs. Most CCTV systems have more cameras than monitors, with typical ratios ranging from 3:1 to 10:1.

The cost of analog video switches is a function of the number of switching points, which is the product of the number of camera inputs and monitor outputs. Thus, prices can increase exponentially as the size of the switch grows. For a relatively small switch (30 camera inputs and 10 monitor outputs), the installed cost is about $20,000. Doubling the size of the switch to 60 camera inputs and 20 monitor outputs results in the cost increasing to about $75,000.

Newer digital techniques, similar in concept to a local area network (LAN), are being utilized to transmit and switch video images. With these techniques, the video image is digitized and divided into small segments. These segments (or packets) are then distributed on a very high speed transmission system, and those users who need to view a particular image copy the packets for that image and reassemble the image for viewing. This strategy is commonly used in the telephone industry for switching voice conversations Since switches of this nature do not increase exponentially in size, they have the potential for being less expensive than analog switches. However, because of the high bandwidth and transmission speeds required, these devices are still more expensive than moderate sized analog switches. With the typical decline in costs for all digital based systems, digital switching of video images is expected to become a cost effective alternative.

In all cases, the cost of video monitors, interconnection to the video transmission system and monitors, operator controls and system integration must be added to the cost of the basic switch.

Large Screen Video - A large video screen (Often 3x4 feet, or larger) is frequently included in TOCs. The ability to project either an enlarged video image, or an enlarged computer generated graphic can be useful for decision support during incident response or for public relations during tours or demonstrations. Operators in TOCs with large screens report that they seldom use these enlarged images during normal operations

Two fundamental technologies are available, video projection, and video wall Video projection utilizes either a cathode ray tube (CRT) or an liquid crystal display (LCD) system to optically enlarge the image and display it on a screen (using either front or rear projection). Care must be exercised with respect to room lighting since the projected image is easily washed out by typically available light. A video wall provides a large display area that overcomes this problem. The video wall combines a number of moderate sized (21 inch typical) video monitors into an array. This array is often four monitors high and four monitors across Electronic circuitry divides the original image into smaller parts (for example, sixteen images for a 4x4 array) and displays each sub-image on a separate CRT. Current cost for large screen projectors is in the $35,000 range, while video walls are often more than $50,000.

ELECTRONIC TOLL AND TRAFFIC MANAGEMENT

Electronic toll and traffic management (ETTM) systems encompass automatic vehicle identification (AVI) and electronic toll collection (ETC) with communication between vehicle and roadside. Transponders carried by vehicles participating in the program can be used to track travel times of vehicles on the roadway. The information obtained in this manner can be used to improve detection of incidents that create significant impacts on the level of service provided by the roadway system.

The use of ETC has recently been implemented on the Kansas Turnpike (the electronic tag is called a "K-tag"). Electronic tags, slightly larger than credit cards, are placed on the inside of the vehicle windshield. The tags communicate on high frequency radio links with equipment at a toll plaza as the vehicle passes through the toll lanes. These tags may eventually be used for vehicle identification for commercial vehicle applications, including enforcement activities. Furthermore, vehicles with K-tags may eventually be used as traffic probes, as discussed next.

Vehicle Probes - ETC provides the opportunity for vehicle tracking that was formerly not possible. Each K-tag has a uniquely identified electronic serial number and can be read at highway speeds. The use of equipment to read the tags at opposite ends of a highway link allows the system to track the passage of individual vehicles and thus provide a direct measurement of link travel time. Each equipped vehicle provides the system with an origin location and time and a destination location and time for each equipped link and hence becomes a probe vehicle without disturbing the traffic flow.

Installation of the antenna to communicate with the in-vehicle transponder must usually be done so that the communications range can be kept below a distance of about 30 feet. An overhead antenna may be able to cover three or four lanes simultaneously. The question of interference from multiple tags responding simultaneously has been considered by the various manufacturers, although this would probably not be an issue in the Kansas City area due to the fact that only one entity currently uses ETC and the population of users is relatively small For the purpose of collecting travel time data, a lower cost "compact reader" interfaced to only one antenna could be used to scan multiple lanes. Some vehicles will be missed when in the shadow of another vehicle or when simultaneous responses cause the return data to be garbled. Vehicles will also be missed if they are beyond the range of the equipment. If the population of ETC users increases significantly, data collected from a few stations should provide enough matches of transponder reads to calculate an estimate of travel time.

Alternative Probe Technologies - Investigations are being performed that utilize cellular telephone serial number tracking with direction finding capability at some cell towers to determine average vehicle speeds. Legislation concerned with privacy may affect the use of this type of device, but products that do not monitor conversations and do not use actual telephone number identification are still in development.

Communications Technologies

Two primary alternatives are available for system communications, commercial circuits and agency owned circuits. Typical systems use a mix of these alternatives, driven by costs and requirements. Communications technologies are rapidly changing, providing faster and higher capacity circuits at lower costs. New wireless options are emerging, spurred by growth in portable computers and personal communications. To take advantage of these changes, the system communications architecture must be flexible and designed around common and commercially supported standards.

The following summary reviews selected communications options. Since the primary communications for the Kansas City ITS system will be based on fiber optics, this technology is discussed first. Other alternatives are also discussed, because there may be some applications for their use on arterials where fiber optics have not been installed, to connect field equipment to the fiber optic network, for communications with emergency responders and other secondary functions.

FIBER OPTIC CABLE

Fiber optic cable is being installed in all new communications systems used for incident/traffic management, and is the proposed communications medium for the ITS system in Kansas City. Fiber optic cables provide very high data rates (2.5 gigabits per second, Gbps) over long distances (over 25 miles) without amplification. Other advantages are the small cable diameters (a 0.5 inch cable can contain 72 fibers), immunity from electrical interference, and avoidance of ground loop and lightning strike problems encountered with metallic conductors.

Fiber optic cable is commonly manufactured with two internal structures: those fibers that support single-mode transmission and those that support multi-mode transmission. Single-mode fibers are used for long haul circuits that are longer than a few miles, but require more expensive transmission and receiving equipment to take advantage of its higher performance characteristics. Multi-mode fibers are typically used to transmit video images a short distance from the CCTV camera to a communications hub that is at most a few miles away, where the images are combined, or multiplexed, onto a long haul single-mode fiber for transmission to the control center. Multi-mode fiber utilizes lower cost transmission and receiving equipment, but has a limited transmission range

Because fiber optic communications is the primary technology being installed, and because it is expected to be the backbone for the communications system in Kansas City, additional details are provided in the following two sections, *System Architecture* and *Network Configurations*.

Fiber Optic System Architecture - Fiber optic communications systems were initially developed in the 1960s by the telephone companies for long haul transmission of voice and data. The technology has undergone successive refinement over the past quarter-century, and is today the technology of choice for essentially all new communications systems. Early deployments of fiber optic systems replicated the existing systems that were based on twisted pair, coaxial cable and microwave channels, implementing digital carrier systems at DS-1 (1.544 megabits per second, Mbps) and DS-3 (43.232 Mbps) transmission rates.

Within the past 10 years, a new standard termed Synchronous Optical Network (SONET) has been developed. The SONET standard is based on multiples of 51.84 Mbps, which is known as an Optical Carrier 1 (OC-1) channel. An OC-1 channel carries a DS-3 data stream, plus additional control and status information. SONET systems typically are installed with OC-3 (155.52 Mbps), or OC-12 (622.08 Mbps) capacity, with some systems implementing OC-48 (2488.32 Mbps). Faster data streams are being planned.

A key design concept of SONET is redundancy. This redundancy is achieved by the use of dual counter-rotating ring circuits. These rings provide for automatic rerouting of traffic onto the secondary ring, in the event of a failure in the primary ring. Since the secondary ring transmits data in the opposite direction from the primary ring, a cable break at one location does not result in a system failure. This re-routing capability is referred to as a self-healing ring. The switch-over from the primary to secondary ring occurs rapidly enough that most data communications can recover without data loss, however, real-time traffic such as voice or video may incur a momentary loss of communications. Restoration of full system functionality requires field repair of the broken cable. Equipment failures are also contained by the inclusion of redundant components at all key locations. This redundancy is included in the basic design of the SONET system.

While alternative configurations may be considered, SONET is the preferred choice of all new communications systems. The use of SONET by the telephone companies and long distance carriers has resulted in a wide range of manufacturers and vendors of equipment. The resulting competition has generated a wide range of features and capabilities, and very attractive benefit cost ratios. Other alternatives do not have the range of options and features, and typically are more expensive when compared to SONET on a functionality basis.

The advantage of SONET is also its greatest drawback, namely the very wide bandwidth that is supported. This communications capacity results in higher costs when compared to the lower bandwidth solutions, but extending the lower end solutions to SONET capabilities ultimately requires a higher system cost. The other limitation of the higher bandwidth is the impact of a system failure, in that it impacts more field devices and communications channels. However, the self-healing capability and designed-in redundancy of SONET typically results in a more reliable overall system.

The design of a SONET system utilizes four single-mode fibers on each link, preferably with two separate routings, using 1310 nanometers (nm) or 1550 nm for transmission Interconnection of field devices to the SONET backbone requires the use of a "communications hub". A hub serves to interconnect low speed (1200 to 9600 bits per second, bps) data streams from field equipment, such as individual 170 controllers and VMSs, to the much higher data rates of the SONET backbone. This interconnection is performed by devices knows as multiplexors/demultiplexors. Data originating at several field devices is combined together in a "time-slice" format for transmission to the central facility. This combination makes best use of the capacity of the SONET system. In the reverse direction, the data coming from the central facility is extracted from, or demultiplexed, from the combined data stream and routed to individual field devices. An equivalent set of multiplexors/demultiplexors exists at the central facility to perform the same functions of combining and separating data.

Since voice can be represented in a digital format, the SONET system can also be used for voice communications. Digital transmission of voice is extensively used by all the telephone companies and long distance carriers, and has been the driving force behind the development of digital carrier and SONET technologies. Highly cost-effective and very reliable systems are thus available from the telephone company equipment suppliers. Agencies often utilize this voice capability of a SONET system to implement PBX-to-PBX links between various locations, and to bypass the telephone companies to reduce their long distance charges.

FIBER OPTIC NETWORK CONFIGURATIONS

There are three basic network configurations, or topologies, that are used to design fiber optic systems: star, bus, and ring.

Star Configuration: In a star configuration, separate fiber optic trunks are used to connect the communications hubs to the central facility. At each hub, connections are made to the field devices through a local distribution network which can consist of several different types of media, such as fiber optic cables, twisted pair, or radio based communications. The data to and from the central facility is multiplexed and demultiplexed at the communications hub.

This type of configuration has a disadvantage in that separate "home runs" are required from each hub to the central facility, and that it is typically not configured with redundant, automatic switch-over, fibers or equipment. However, this is a proven system and has been successfully used in many traffic management systems.

Bus Configuration: In a bus configuration each communications unit, which may be a device located at a node or communications hub, or a field device such as a 170 controller, is connected to a fiber optic link or series of fibers carrying data in two directions, i.e., full duplex. Every device connected on the bus is assigned a channel and an address Each device is accessed by polling it on its assigned channel, using the specified address, to retrieve data in the device and to send it control information. This bus configuration is commonly used in local area networks (LANs) used to link together personal computers.

The advantage of this configuration is the use of a single communications facility reaching from the central location to each field device. However, low cost fiber optic modems that are directly compatible with 170 controllers, VMSs, and related equipment are not readily available This technology has not been utilized in operational traffic management systems, and thus there is very limited experience.

Ring Configuration: Ring configurations can be implemented as either a single ring, or as a dual (redundant) ring. Most ring configurations being installed today utilize a dual ring to take advantage of automatic reconfiguration, or self-healing capability of the system This fault-tolerant approach significantly increases system reliability.

The operational advantages of self-healing rings are clear. Because this configuration is being widely implemented and utilized, a full range of equipment at competitive prices is readily available. The disadvantages are the requirement for additional fibers, and redundant equipment at the communications nodes. However, the incremental costs of additional fibers within the same cable is very small (approximately $150 per fiber per kilometer). Similarly, the incremental costs of redundant equipment when compared to the life-cycle cost of system failures is quite small.

Star-Ring Configuration: A combination of the star and ring configurations is recommended in the Kansas City area due to the geometric configuration of the roadways, and the redundancy provided by such a configuration.

COMMERCIAL COMMUNICATIONS CIRCUITS

The local telephone company, cellular carriers, and other communications service suppliers provide a variety of circuits operating at a wide range of speeds. Initial installation costs and short term monthly costs for low speed data circuits are low, and are thus advantageous for vehicle detection and variable message sign circuits. Maintenance and repair is provided by the commercial service provider, removing the requirement for special training or equipment within an agency. The drawback of this arrangement is the "finger pointing" that often occurs when multiple parties are involved. The primary disadvantages are the long term costs (recurring monthly billings), and the expense of high speed circuits. Since the monthly costs are considered operational expenses, they must be budgeted from annual operations budgets and are thus often more difficult to obtain than initial capital funds.

Commercial communications circuits are available as either switched (dial-up) or dedicated (private line) facilities. Each of these basic types can be configured as point-to-point (two parties) or multi-point (three or more parties) circuits. For dial-up service, a multi-point circuit is usually referred to as a "conference call". For dedicated circuits, the term multi-drop circuit is often used interchangeably with multi-point. A further distinction is the transmission technique used, analog or digital. The original telephone network was designed as an analog system for the transmission of voice. The availability of low-cost, high-performance computer circuits has allowed the telephone system to convert much of its transmission and switching equipment to digital technologies, resulting in better quality and performance at reduced cost.

Pricing of commercial circuits typically involves a one-time installation charge, and a recurring monthly charge. Circuits can be obtained on a month-by-month basis, or on various contractual terms ranging from 1 year to 10 years. Month-by-month service provides the most flexibility since service can be terminated when required, but it is the most expensive option. Multi-year contracts provide lower monthly costs, but include penalties for cancellation prior to the end of the contract period.

Dial-up Analog Service - This is the basic voice-grade telephone service provided for residences and businesses. These channels are provided to support voice communications and are universally available. Currently available modems (modulator/demodulator) provide data transmission speeds in excess of 14.4 kilobits per second (Kbps) on dial-up phone lines These units are inexpensive (about $250), and are widely available with numerous features and options. They are extensively used on personal computers for data and fax transmission, and well supported by commercially available PC software.

Dial-up telephone service is a useful alternative for occasional, relatively short-term data transmission. The dialing and connect time (15-30 seconds) does not realistically permit data collection or control of devices more frequently than every five minutes. The dial-up telephone network is designed and configured for human calling patterns and call holding periods, allowing the expensive central office equipment to be shared among many subscribers. Use of dial-up circuits for frequent data calls, or for long holding times, or for many hours of use per day, ties up the central office equipment and results in the local telephone company complaining about inappropriate usage.

The other concern with any dial-up configuration is security. The ability of "hackers" to break into computer systems has been widely reported, and cases of inappropriate or unsafe messages being displayed on VMSs through dial-up access have been documented. The use of dial-up/dial-back, encryption, security passwords, and other safeguards reduces the risk, but at the expense of increased system complexity and additional inconvenience for the personnel who have to support and maintain the system.

Integrated Services Digital Network - The technology for integrated services digital network (ISDN) was developed by the telephone industry during the early 1980s, but has seen a very slow deployment. In the past few years, however, the penetration has increased significantly in many areas. The key benefit claimed for ISDN is the availability of 144 kilobits per second, Kbps (divided into two 64 Kbps data channels and one 16 Kbps control channel) of switched digital data over two pairs of wires. Another benefit is the reduced switching/interconnect time, making it feasible to support more field devices on dial-up connections. There are two ISDN user offerings, the basic rate interface (BRI), and the primary rate interface (PRI). Basic rate ISDN is the digital equivalent of dial-up analog service. Primary rate ISDN is the equivalent of T-1 service, it provides the user with 23 channels of 64 Kbps data and one control channel operating at 64 Kbps. Interface boards (equivalent to modems) for certain types of computers are coming down in price (into the $1,000-$2,000 range) and increasing in availability.

For the current generation of incident traffic management system equipment, utilization of ISDN circuits is probably not feasible due to the lack of interface boards for the equipment. Circuit availability is also a limiting factor. However, the next generation of equipment may well be able to take advantage of ISDN. Since ISDN was developed as a digital service, its error characteristics and operational parameters will result in excellent performance. The current lack of interface boards, and limited availability of ISDN service limits the usefulness for current projects. Furthermore, since ISDN is basically a dial-up service, its use for full-time channels, as typically used for traffic monitoring applications, may not be effective

Video devices, on the other hand, are coming on the market with ISDN compliant interfaces. It may be feasible to utilize this technology to access remote cameras and transmit the video images to the TOC or to transmit video images from the TOC to emergency responders. The bandwidth available on a single BRI circuit is probably not enough for most applications to show traffic motion. Some manufacturers are providing inverse multiplexing capabilities in their equipment that obtains the required bandwidth from the inclusion of additional BRI data channels.

Dedicated Voice Grade Analog Channels - These circuits have been the backbone of many traffic management and arterial control systems over the past twenty years Modems to utilize these circuits are included in the design of 170 and NEMA equipment. They can be configured as either point-to-point or multi-point circuits, and can support speeds in excess of 9600 bps with current modem technology. There is a wide range of equipment available for interface to these channels. There are reports of telephone companies changing their tariffs and pricing policies to discourage use of these channels over the long term, in an attempt to move customers to digital channels. The primary advantages of these circuits is their wide-spread availability and their low cost for low speed circuits. Since these channels are designed for voice, they are not optimized for the transmission of data.

Digital Data Channels - The telephone companies offer a range of digital channels running from 2.4 Kbps to 64 Kbps. They are often referred to as DATAPHONE Digital Service (DDS) circuits. These circuits are primarily dedicated circuits, but are occasionally available in a switched configuration. One difficulty with these circuits is that they are usually configured as synchronous data circuits, while most communications for incident/traffic management systems are asynchronous, requiring adapters at each end of the circuit. Since these channels are designed for data transmission, their reliability and operational characteristics are very good. The principle disadvantages are the fundamental synchronous nature of the channels and the limited availability of the data/channel service units (DSU/CSU) needed to connect to the circuits.

Digital Carrier - In the mid-1960s, the telephone companies began converting their long haul trunk circuits from analog technology to digital technology. The basic deployment was the DS-1 (digital service 1) channel, operating at 1.544 Mbps. Note that this channel is commonly referred to as a T-1 circuit. This T-1 circuit is configured to support 24 voice grade channels, each requiring 64 Kbps of digital bandwidth. There is a hierarchy of faster digital circuits, each built upon various combinations of T-1 circuits. A typical combination is DS-3 (T-3) at 43.232 Mbps, or 672 voice grade channels. The emerging Synchronous Optical Network (SONET) standard builds upon DS-3, and is defined in various combinations as high as OC-48 (Optical Carrier 48), which operates at 2,488 Mbps, or the equivalent of 32,256 voice grade channels. Within the past few years, T-1 service has become more readily available to end users, driven by the demand for higher speed communications channels to link computers and local area networks together. The primary interest in T-1 for traffic/incident management systems is digital transmission of video signals. T-1 provides a reasonable option to agency owned fiber optic cable for a few circuits and limited period of time, but quickly becomes quite expensive if large numbers of circuits are involved.

Cellular Telephone - Cellular telephones have rapidly expanded their market penetration over the past five years, pushed by the convenience and declining prices The cellular telephone network now covers over 93 percent of the United States population Off-the-shelf cellular modems permit the transmission of data over the cellular network. Note however, that cellular modems utilize different techniques for error correction and circuit initialization, and thus are often not compatible with landline modems. The use of cellular telephones by field personnel has simplified many maintenance and incident response procedures.

The ready availability of service and capability to locate equipment anywhere within the coverage area provides a high degree of flexibility, especially for temporary installations and portable or mobile equipment. Cellular equipment eliminates the need to connect to a telephone company service point. This capability of establishing a circuit on an as needed basis may prove cost effective for infrequent communications.

The primary disadvantage of cellular service is its cost. Each cellular "telephone" incurs a monthly service charge ranging from $15 to $45 per month, and a per-minute airtime charge ranging from $0.10 to $0.50 per minute. Due to competition, increasing numbers of users and the resulting additional volume, prices are falling. These price decreases are being driven by reduced unit cost reductions and "innovative" service plans. However, even if costs were as low as 10 cents per minute, airtime costs $144 per day, making full-time cellular communications prohibitively expensive. Since the existing cellular network utilizes analog transmission, it is somewhat noisy and thus limits the speed of data transmission.

Packet Radio - Packet radio is a wireless technique that is designed specifically for the transmission of data. Commercial suppliers utilize radio base stations to communicate with multiple field transceivers via time synchronized bursts, or packets, of data. Since many field transceivers share the same frequency pair for transmitting and receiving data, a cooperation strategy (or communications protocol) is utilized to coordinate this sharing. Because of this sharing, there can be delays of several seconds in delivering a packet. The pricing structure of packet radio is based upon the amount of data transmitted, measured either in bytes or packets. This pricing structure, and the basic architecture of packet radio, is most effective when transmitting short messages, and not large quantities of data. Typical prices are $0.03 per 100 bytes transmitted, which results in a cost of about $5.00 per hour for real-time communications with a traffic monitoring processor. This cost is prohibitive for continuous communications, but may be attractive for occasional use to some remote VMS or other field equipment that would have been reached by cellular telephone. Considerable development may be required to convert the remote device and central processor to communicate in packet network protocol.

Satellite - Satellite communications services have been available for many years, and have proven cost effective for long distance point-to-point circuits and for wide area broadcast applications. However, for "local" applications (distances less than a few hundred miles), the costs of ground stations and satellite transponder rentals are prohibitive for traffic management applications. A typical monthly cost for a 56 Kbps circuit is $10,000, however, this is essentially independent of circuit distance, with a 200 or 2,000 mile circuit costing the same.

The one case where satellite communications has proven useful for traffic management is incident response in rural areas. The ability to deploy an incident response vehicle, with voice, data and limited-motion video communications to a central control facility, has proven effective in field trials. The flexibility of this approach is a significant benefit, but the cost needs to be weighed against other communications channels.

AGENCY OWNED FACILITIES

In an effort to reduce monthly operating costs, and to provide the communications bandwidth needed for large numbers of video cameras, many agencies install their own communications facilities. For cable based land line systems, the cable and electronics are moderately priced; but the cost of trenching, installing conduits and ducts, backfilling and patching is significant. Depending upon construction conditions, conduit installation costs can range from $20 per foot to $40 per foot This translates to between $100,000 and $200,000 per mile. If structures need to be crossed, or if roads must be bored under, these costs can even be higher The cable, installation costs, splicing, and electronics termination equipment costs from $5 per foot to $15 per foot, depending on the specifics of the installation. The costs can be born by private agencies in exchange for use of roadway right-of-way. This kind of public/private partnership was used by the Missouri Highway and Transportation Department (MHTD) to obtain fiber on all interstates in Missouri, and the Kansas Department of Transportation (KDOT) plans to explore the feasibility of such an arrangement in Kansas.

Twisted Pair - Twisted pair cable has been the backbone of "the last mile" in communications systems for decades. It provides a simple, straightforward and low cost method for the short haul circuits from the termination of high capacity backbone (long haul) circuits to the individual vehicle detector cabinets or VMSs. Twisted pair works well for speeds up to 9600 bps for distances of several miles. It is usually installed in combination with a fiber optic long haul system to interconnect the field equipment to the communications hub.

Fiber Optic - Fiber optic cable, which is often agency owned, was discussed in earlier segments of this section.

Coaxial - Coaxial cable was previously used for transmission of video images from CCTV cameras into a control center. Due to the need for active amplification every half mile, image degradation over long cables, and maintenance problems, coaxial cable is no longer recommended for this application.

Conduit Installation Standards - A major cost element of a cabled communication system (twisted pair, fiber or coaxial) is the installation of conduit. Conduit can be installed at minimal cost during highway construction and re-construction activities. It seems reasonable to provide for future needs by placing conduit during any major roadway construction, provided that a means of record keeping can be utilized to locate this conduit when it is needed. Innerduct can be added at a later time if necessary. Conduit may be stacked on top of each other or buried side by side.

Several agencies include innerduct in their conduit. This provides extra non-obtrusive space for additional cable to be pulled through the conduit. There are different types of conduit with innerducts. Fiberglass conduit has four chambers molded right into the conduit. With the standard rigid metallic and non-metallic conduit, innerduct must be pulled through the conduit to provide separate raceways for cable.

Microwave - Point-to-point microwave is an attractive alternative for initial or limited usage transmission of video images from CCTV cameras For those cases where it is neither technically feasible nor cost effective to install conduit and fiber optic cable, microwave can be utilized. Depending upon performance, a microwave system (transmitter and receiver, usually with a reverse direction control channel) for video transmission costs from $20,000 to $40,000 This equipment is very useful in the initial stages of system deployment, before a fiber optic system can be installed. As the fiber optic system is installed, the microwave equipment can then be re-used to extend CCTV coverage out beyond the end of the fiber optic network A key limitation of microwave is the requirement for line-of-sight Another problem with microwave is its degradation under adverse weather (heavy rain, etc.) conditions. A microwave installation must receive a license on a site by site basis from the Federal Communications Commission (FCC)

Wireless Video - A recent development in video transmission equipment is wireless video. This equipment transmits full motion video over a radio circuit, in a manner similar to that used by microwave, but without the stringent installation requirements. Wireless video does require line-of-sight, but the antennas are much less sensitive to alignment. The wireless video also does not require the licenses needed by microwave, because the equipment is class licensed by the manufacturer.

Spread Spectrum Radio - Spread spectrum radio transmission was developed nearly 50 years ago by the military as a security measure. These techniques were commercialized starting in 1985 when the FCC assigned frequency bands to spread spectrum radio. The technology spreads the signal bandwidth over a wide range of frequencies at the transmitter. The receiver knows the technique (or coding) utilized, and it thus able to recover the transmitted signal and reconstruct the original message.

Because each communications circuit within a given band utilizes a different coding technique, multiple, simultaneous circuits can co-exist. Spread spectrum generally requires line-of-sight, limiting its range to about six miles. The signal is attenuated by vegetation, so a site survey is recommended before committing to this technology. Field equipment can be placed anywhere within the range of a base station, thus very flexible installations can be developed The basic technique of spreading the transmitted signal over multiple frequencies results in high noise immunity. The FCC has assigned the 902-928 MHz band for which no facilities license is required. However, spread spectrum equipment operating in this band cannot interfere with licensed equipment and must accept interference from licensed services.

For traffic management applications, there is significant potential for spread spectrum radio. The work that is currently under way to evaluate spread spectrum for the next generation of digital cellular telephones may result in a wide spread application of the technology. If this occurs, there will be an increased availability of equipment and resultant price reductions. However, technological advances may result in the need for increased personnel training and specialization, as well as more sophisticated equipment.

Traveler Interface Technologies

Traveler interface technologies commonly used and discussed in this section include VMSs, HAR, information kiosks, and dial-in information systems As technologies become increasingly sophisticated, the potential applications of traveler interface technologies will increase. For example, in the future route guidance systems may automatically query the TOC for real-time and projected travel speeds, incorporating this information into route selection algorithms. In the meantime, proven technologies such as those discussed next may be used to keep the motorist informed about current conditions.

VARIABLE MESSAGE SIGNS

Variable message signs (VMSs), both fixed and portable, are widely used to provide motorist information during an incident. The ability to quickly alert motorists of a problem ahead and provide for diversion to an alternate route is a successful strategy for minimizing the impact of an incident.

A VMS consists of a matrix of dots or pixels, each of which can be individually controlled. The minimum group of dots for a single character is five dots horizontally and seven dots vertically. Larger "character cells" are often implemented for improved character resolution, the use of lower case letters, and "double stroke" characters. Since individual characters on a VMS are composed of discrete dots, the "sharpness" of a character is controlled by the number of dots per character. The tradeoff is cost, with cost of the sign being proportional to the number of dots on its surface. The human eye fuses together the adjacent dots in the character pattern, and recognizes the character as a whole. In general, the legibility of a 5 by 7 character cell dot VMS is very acceptable, especially if only upper case letters are used, which is typical for roadway applications. When lower case is required, or other effects are needed, larger character cells, and proportionally more expensive signs, are necessary.

If the VMS is intended for text messages only, adjacent "character cells" can be separated by a blank space to minimize the cost of the sign. An alternative approach is the "continuous matrix" sign, in which the separating blank space is deleted, resulting in all locations on the surface of the sign being controllable. This permits moving text, "exploding" and "collapsing" images, roller blind, horizontal shutter, and other types of special effects to be implemented. These special effects are more commonly used in commercial displays than in roadway applications. Use of a proportional font for improved readability or graphics is a common use of continuous matrix signs on a roadway.

Various display philosophies are in use by different agencies. Some feel that a VMS should only be used when necessary to display instructions or information about roadway conditions, feeling that if routine messages are displayed, driver awareness of the sign becomes numbed. Other agencies display a routine or safety message on the signs to confirm operability, while some agencies use their signs to advertise events. Because a VMS can display a wide variety of characters in each character cell, dynamic messages can be created by manipulating the timing of the display of individual characters, or groups of characters. Simple effects that are quite effective for roadways include blinking text, moving arrows, and the cyclic display of a sequence of messages with delays between them. An example of the latter is displaying a repeating series of safety messages, such as "BUCKLE UP", "DRIVE 55 FOR SAFETY" and

"USE YOUR SEATBELT" Message complexity, information acceptance rate, and driver attention span all must be considered when utilizing these features on high speed roads.

Two fundamental technologies, light reflectance and light emission, are used to form the individual dots that create the letters of the message on VMSs. These technologies are discussed in the following two sections.

Light Reflective Signs - Light reflecting VMSs consist typically of a matrix of mechanically changed dots. The individual dot can be a flat disk that is black on one side, and colored on the other, a ball or cube that has color on one half, or a split flap that exposes a colored surface when opened. Other deployments consist of a multi-part flap that some vendors have utilized to implement a "white" character for daytime usage, and a "fluorescent color" character for improved visibility at night. This technique has been extended by one vendor to allow display of six different colors for each pixel. A variety of techniques have been used to improve the visibility of these signs, including internal illumination and retroreflective surfaces. Because the dots are mechanically moved, a finite amount of time is required to change the message displayed on the sign. Different vendor deployments result in a range of timing characteristics. On the slow end of the spectrum, rates of 30 characters per second are typical. At this speed, a sign with three rows of twenty-two characters per row will require over two seconds to change its message. Faster character write rates are available, with some capable of changing the entire message in parallel, but tradeoffs of power consumption, dot inertia, overshoot, and flutter all enter into the dynamics of the deployment.

To provide stability during periods of power outage so that dots do not randomly change position and display "garbage" on the sign face, and to reduce power consumption, some method of latching the dots into a fixed position is normally used. A common technique is magnetic, where a small fixed magnet is attached to the shaft on which the dot rotates The dot is changed from its "dark" state to its "bright" state with a pulse of an electromagnet, thereafter remaining stable with no power input required. This has the advantage that a message that was displayed prior to a power failure will remain on the sign face.

These signs have a proven field track record, with a generally high reliability rate. Individual dots are rated in the range of 100 million operations. However, it is not uncommon to find individual dots stuck, either "dark" or "bright", as a sign ages. The signs are fabricated for easy repair, with each character cell being quickly replaceable, and individual dots repairable. The technology is easily scaleable, with character sizes ranging from 2 to 18 inches in height. A wide range of colors can be used on the "bright" side of the dot, with white or yellow being most common, but green, red, orange, gold, and others becoming available. Because of the mechanical nature of this technology, a weatherproof enclosure is required. Cost of these signs is in the medium to expensive range, depending on size, mounting, enclosures, and various options. For many agencies, these signs have accounted for the majority of their VMS deployments.

By mechanically rotating the disk, ball, or flap with different colors on the surfaces, the dots on the surface of the sign form letters. The key advantage of this type of sign is the maturity of technology, and the long experience of their usage. Another advantage is the continued operation of the sign during a power outage, since the dots are bi-stable, requiring power to change their state, but not to maintain them in a particular state. The disadvantages include limited visibility under some lighting conditions, fading of color contrast over time, and mechanical failures resulting in a "stuck dot".

Costs of these signs is a direct function of the number of characters on the sign face, the attention to detail and the quality Since this type of sign is electromechanical, operational experience and product refinement based on many years of development have an impact on long term reliability. Large signs (3 rows by 20 characters per row) range in cost from $50,000 to $90,000, including installation and commissioning Small signs (3 rows by 8 characters per row) cost $25,000 to $50,000. The cost of the support structure (sign bridge, attachment to overpass, or roadside poles) must be considered in addition to the basic sign cost.

A related type of sign is the changeable seven segment numerical display. This technology is useful for the display of variable speed limits. A sign may be fabricated in the form prescribed by the Manual on Uniform Traffic Control Devices for a speed limit signal with the numerical digits formed by remotely controlled displays. This technique produces an easily recognized, variable speed limit that is less costly than a full VMS.

Another related sign is the rotating drum sign, where several faces of a rotating drum (or several drums) can be used to display one of several messages. These signs can be configured with the same size, shape, and letter fonts as traditional static signs. Further advantages are their lower cost when compared to a "dot matrix" sign, and mechanical simplicity resulting in higher reliability. Their prime disadvantage is the limited number of messages that can be displayed on a single sign.

Light Emitting Signs - The use of an active light source at each dot (or pixel) of a VMS produces a light emitting sign. The original light emitting sign is the incandescent bulb matrix. This type of sign provides good visibility, and is currently used in commercial applications. However, it has fallen into disfavor for roadway applications due to the low reliability and high maintenance costs incurred due to bulbs burning out. Another major problem is the heat that is a result of the high bulb wattage and the high power consumption. Some agencies in warm climates have found that they have to limit the number of bulbs that are simultaneously on due to heat rise in the sign enclosure. In general, these signs are not favored because of these limitations.

Current technology developments utilizing "solid state" lamps over the past several years have produced signs with high brightness, simple control, and long life. The light source in these signs is the light emitting diode (LED). Until recently, the brightness of the LED was inadequate for bright daylight conditions. In particular, the "amber" LED, which is preferred for roadway usage, has been difficult to manufacture with the desired characteristics. Early LEDs suffered from variability in light output between "identical" LEDs, and aging effects which reduced brightness (often non-uniformly) over time. However, these problems appear to have been solved and the LED sign is finding acceptance in the field with many major manufacturers fabricating these signs.

A typical deployment utilizes a group of LEDs (on the order of 15) to form each individual pixel. This increases the brightness of each pixel and averages any small differences between adjacent LEDs. These signs have a very fast turn on and turn off time, eliminated the problems noted above with the rotating disk type signs. Because of the physics of the semiconductor junction and wavelength of emitted photons, LEDs have a limited range of colors. Red is the most common color, but yellow is preferred for most roadway sign applications. Green is also commonly available Combinations of different colored LEDs are being used to implement colored signs. The small size of the LED, coupled with computer type integrated circuits, can produce displays with large numbers of individually controllable dots for special effect applications The long life of the LED, combined with the inherent simplicity of the design concept, should result in very good reliability. Actual field experience, as these signs are deployed in large numbers, will have to be gathered to verify this expectation. Cost of these signs is moderately expensive, but that should change as usage increases.

Enhanced visibility is the key advantage of light emitting signs. The ability to mix various color light sources to produce differently colored messages is also useful. The biggest disadvantage of these signs is their requirement for continuous power, making them non-operable during power failures. If power failures are common, and the sign is critical to continued operations, some sort of back-up power is required.

LEDs have had some problems due to loss of light output intensity due to the aging of the light emitting active elements. Intensity reductions on the order of 50 percent have been observed after 30,000 hours of operation. A side-effect of this problem has been brightness differentials as a result of differing power-on times. This results in variations between different dots on the sign. Newer generations of LEDs appear to have solved these problems, with preliminary reports indicating either no intensity loss or even a slight gain. This is based on initial testing, with long term field results not yet available. Another benefit of these newer LEDs is their increased intensity, allowing a sign to be fabricated with fewer LEDs per pixel (resulting in a lower fabrication cost), a brighter sign with the same number of LEDs, or the ability to operate the LEDs at lower power (prolonging their life and reducing the aging effects).

Costs of LED signs is controlled by the size of the sign (number of characters on the sign face), the quality and reliability of the manufacturer, and the type of LED used. The newer, high-output amber LEDs are more expensive than older devices because of limited manufacturing yield and the need for the supplier to recover development costs. As with all semiconductor devices, component prices will decline fairly rapidly, especially as sales volumes increase. Large signs (3 rows by 20 characters per row) range in cost from $60,000 to $130,000, including installation and commissioning. Small signs (3 rows by 8 characters per row) cost $40,000 to $60,000. Cost of the support structure (sign bridge attachment to overpass, or roadside poles) is in addition to the basic sign cost.

Hybrid Technology Signs - The combination of a rotating disk or shutter in front of a light source produces a hybrid of mechanical motion and light emission. If the rotating disk is colored on one side, the light source enhances the message on the sign, providing additional visibility and contrast for longer distance viewing. Some vendors consider this an enhancement of the basic rotating disk/shutter sign, while others explain their product as a totally different technology.

The LED is often used as the light source, with the LED mounted behind the disk, and the disk serving as a shutter to permit the LED to be seen when the disk in the "bright" position, and masking the LED when the disk is in the "dark" position. One deployment mounts the LED off center, with a hole through the disk. When the "bright" side of the disk is visible, the hole is positioned over the LED. When the disk is rotated so that the "dark" side is exposed, the hole and the LED no longer coincide, and the LED is masked. Different vendors implement this same basic idea with a range of schemes, all effectively performing the same task.

A variation of this approach utilizes digital control technology that is connected to the circuit that controls the disk, and turns off the LED at each pixel when the "dark" side of the disk is exposed. This technique requires a location within each pixel that is constantly visible and works well with circular dots where the LEDs can be located in a "corner" of the pixel However, with split flap pixels that are square or rectangular in shape, the locations for mounting the LEDs are limited.

The approach of combining a light source with a light reflecting sign is an effective manner for increasing the visibility of the basic VMS, producing a good combination for daytime and nighttime usage. The prime reliability concerns are those of the basic sign. Cost is greater than that of the basic sign, and the performance enhancement must be considered within the constraints of the project.

A matrix of shuttered pixels, with each pixel containing a fiber optic bundle that is illuminated by a high intensity light source is another combination used by some vendors. The concept utilized with this design is that of a light source for several characters (on the order of three or more), and bundles of optical fibers to "pipe" the light to each individual dot on the sign face. One configuration utilizes a rotating disk as the shutter. In another configuration, the shutter is assembled with its rotational shaft perpendicular to the sign face. This shutter functions in a manner similar to that of a camera, alternately blocking or uncovering the light source. The mechanical orientation of the shutter, and its motion, seem to result in enhanced reliability.

The light source is a high intensity light bulb, similar to that used in a slide projector. The brightness of each individual dot is several times brighter than that obtainable with the hybrid LED sign. A useful design feature is to utilize two separate bulbs for each fiber bundle, with an automatic switch over circuit when a bulb fails. Monitoring the current flow of the small number of bulbs involved in this design is convenient, resulting in the ability to report a bulb failure to the central control station. The second bulb can also be used to produce an "overbright" condition for poor visibility conditions, such as fog. Another convenient feature utilizes a motor driven colored filter between the bulb and the fiber optic bundle to produce different colored characters on the sign face.

This type of sign has carried a higher price tag, making it the "Cadillac" of VMS applications. The prime selling feature of these signs has been their brightness and the resulting high visibility. Some vendors emphasize the reliability of their signs, which may be more a result of high quality manufacturing and engineering than the fundamental technology. Competition, other market forces, manufacturing efficiencies, and related factors may eventually push the price down to make it more competitive with other technologies. As more of these signs are installed and field experience gained, their relative merits will be more sharply focused.

The combination of devices (light source and mechanical shutters) used to create a hybrid sign increases the cost about 20 percent over either a light reflective or a light emitting sign. However, the increased visibility is a key benefit that is often required.

The cost of hybrid signs also depends on the size of the sign (number of characters on the sign face) and the approach taken by the manufacturer. The "flip-disk" signs, to which LEDs or fiber optic light sources are added as an enhancement, cost 15 to 20 percent more than the basic sign. Thus, for a large sign (3 rows by 20 characters), the cost will be in the $60,000 to $105,000 range. And a small sign (3 rows by 8 characters) will cost $30,000 to $60,000. The fiber optic sign that utilizes shuttered pixels is primarily available in a 3 row by 18 character configuration and costs about $135,000, including installation and commissioning The cost of the support structure (sign bridge, attachment to overpass or roadside poles) must be added to the basic sign cost.

VMS Control Systems - As the number of individually controllable elements on the sign face increases, the complexity of the control requirements increases. For all but the simplest rotating drum signs with just a few messages, some sort of computer based control is required. The manufacturers have selected a variety of microcomputers to meet this need. A few manufacturers have selected the Model 170 intersection controller as the microcomputer, which has the advantage of utilizing a standard item of hardware that is familiar to highway agencies. In other cases, the vendor has developed a special purpose microcomputer for controlling the specific sign they manufacture. In all cases, a unique software package has been developed for each deployment. Similarly, the command set used for communication between these signs and a control location is unique to each vendor's system This command set is called the "communications protocol".

For an agency getting started with VMSs, a fully packaged system from a single supplier is simpler because the vendor can be assigned total responsibility for the system. But the proprietary nature of each vendor's deployment (because standards have not yet been defined) creates difficulties when trying to integrate equipment from several vendors into an overall system. An agency can easily get locked into a single supplier, when there are superior or more cost effective products available. The agency may also suffer from poor support, or a product being "orphaned" when a newer model is introduced or a company is bought out.

In any application of VMSs where more than a few different messages are to be displayed, some form of central control and operator interface is required. The central control computer supplied by the vendor for remote access to and monitoring of the signs is usually a PC, but often with vendor specific hardware enhancements such as unique serial communications boards. The software that runs on the PC is unique to each manufacturer's deployment, and ranges from convenient to obtuse in its user interface. Prices for the central system range from little more than the cost of the PC itself, to many times that, depending upon the features, the total system size, and the vendor's perception of the value of the central control system. The complexity of this software must not be underestimated. There are a great many features, interdependencies, database management issues, and operating subtleties to be handled, all of which contribute to the deployment difficulty and resultant cost.

The challenges associated with the control system can be addressed by carefully understanding the operational needs of the system, considering the growth requirements and future needs. In all cases, the vendor must be required to supply full documentation of all system components. The details of the communications protocol are especially important, so that existing signs can be integrated into a larger system when the agency's needs evolve and expand. Another option that will be available in the near future is the specification of the National Transportation Controller/ITS Protocol (NTCIP). This protocol is currently under development by NEMA/FHWA for NEMA/170 controllers, and will be extended to VMSs after the initial traffic controller work is completed. Selection of a VMS on the basis of ease of integration into a future larger system will usually be beneficial as the overall scope of this type of traffic information system increases.

VMS Communications - The connection between a VMS and the central processor can be provided by a standard serial data communications link. Data requirements for signs are usually small. VMS systems are often implemented with a library of messages. An operator usually needs only to select a pre-composed message, resulting in a very small communication load. If a completely new message is typed in by an operator, the communication load is only slightly higher. A complex message with graphics will require a larger amount of data to communicate the display to the sign The communication link to a VMS will not generally need to operate above 1200 bps. This data rate will allow roughly 120 characters per second to be transmitted.

When a secure closed communications system is required to prevent unauthorized access to VMS control capability, an owned or leased communication link is necessary. Although the public switched telephone network is an open system, security measures can be added. Security measures could include the use of encryption devices and/or call-back security. Encryption involves the transmission of messages in a code that cannot be easily reproduced with a personal computer. Call-back security involves the placement of a call to the VMS and entry of an identification code. The VMS then places a call back to the control point before allowing access to changes in the sign message.

HIGHWAY ADVISORY RADIO

Highway advisory radio (HAR) is widely used to provide motorist information to travelers in a limited geographic area. Non-commercial information services include construction and traffic congestion information, possible alternate routes, traveler advisories, parking information at major destinations, safety information, and availability of lodging, rest stops and local points of interest. AM broadcast-band, low power level equipment has been used to provide this information on two frequencies, 530 kilohertz (KHz) and 1610 KHz. Presently, the standard broadcast frequencies between 530 KHz and 1700 KHz are available in 10 KHz increments, provided there is no interference with existing stations. The transmitter signal must also be low pass filtered in the audio range, to about 4 KHz resulting in a voice quality much like telephone transmission (between 3 KHz and 20 KHz the filter must attenuate at 60 log (f/3) decibels, dB where f is the audio frequency in KHz). The HAR transmitter consists of a device to record and playback messages, a radio transmitter, and an antenna. There are three different configurations used for HAR: vertical antenna, "leaky cable", and micro-transmitter. Regulations governing the operation of HAR systems are defined by the FCC rules in Part 90.242.

Vertical Antenna - Probably the most commonly used HAR system utilizes a vertical antenna. This type of HAR is termed a traveler information system (TIS) and must be appropriately licensed. A single vertical antenna produces an omnidirectional (circular) radiation pattern that diminishes uniformly as the square of the distance from the antenna, provided there are no geographical obstructions.

FCC regulations for vertical antenna HAR/TIS stations include the following requirements:

- A separation of at least 15 kilometers from the 0.5 millivolt/meter daytime contour of any AM broadcast station operating on the adjacent frequency

- A separation of at least 130 kilometers from the 0.5 millivolt/meter daytime contour of any AM broadcast station operating on the same frequency.

- The height of the antenna must not exceed 15 meters above ground level

- The radio frequency (RF) output of the transmitter must not exceed 10 watts.

- A minimum distance of 15 kilometers must be maintained from any other vertical antenna HAR/TIS station.

- A minimum distance of 7.5 kilometers must be maintained from a "leaky cable" antenna HAR/TIS at the same frequency.

- A frequency stability of ±20 hertz (Hz) must be maintained

- Signal field strength of antenna emission at the operating frequency must not exceed 2.0 millivolts/meter at a distance of 1.5 kilometers from the HAR antenna.

"Leaky Cable" Antenna - A specially designed lightly shielded coaxial cable is used to provide the antenna for this type of HAR/TIS transmitter. The signal transmitted from this arrangement is strong near the antenna, but dissipates rapidly when the distance from the antenna increases. Compared to a vertical antenna system, much more control of the emission field strength is available. There is less chance of interference with other radio services. Multiple HAR/TIS systems could be operated along a roadway with different messages for traffic in each direction.

FCC regulations for a leaky cable antenna HAR/TIS stations include the following requirements.

- A separation of at least 15 kilometers from the 0.5 millivolt/meter daytime contour of any AM broadcast station operating on an adjacent frequency.

- A separation of at least 130 kilometers from the 0.5 millivolt/meter daytime contour of any AM broadcast station operating on the same frequency.

- The maximum length of the cable antenna must not exceed 3 kilometers.

- The RF output of the transmitter must not exceed 50 watts.

- A minimum distance of 0.5 kilometers must be maintained from any other HAR/TIS leaky cable station.

- A minimum distance of 7.5 kilometers from a vertical antenna HAR/TIS at the same frequency .

- A frequency stability of ±20 Hz must be maintained.

- Signal field strength of cable antenna emission at the operating frequency must not exceed 2.0 millivolts/meter at a distance of 60 meters from any part of the station

Micro-Transmitter - Very low power HAR transmission is permitted by Part 15 of the FCC regulations without requirements for a license. The area covered by a micro-transmitter is usually defined by a radius of 0.15 to 0.4 kilometers (0.1 to 0.25 miles) although some manufacturers claim that their systems cover an area with a radius twice as large. Part 15 of the FCC code includes the following requirements.

- The lead length of antenna and ground may not exceed 10 feet.
- Any standard AM frequency between 530 KHz and 1705 KHz may be used.
- The RF output of the transmitter must not exceed 100 milliwatts

Message Record/Playback - Messages to be broadcast on a HAR are usually recorded on an audio tape recorder and more recently in digital memory. Digital memory is preferred since it uses no moving parts, and thus does not require periodic cleaning or maintenance. Some devices offer features that include:

- Message capacity of nearly half an hour.
- Ability to retain messages during power failures.
- Ability to provide a series of previously recorded messages strung together in any order to form the broadcast message.
- Double buffer to allow playing one message while recording another.

Digital memory is available in several varieties:

- EEPROM (Electrically Erasable Programmable Read Only Memory).

- DRAM (Dynamic Random Access Memory), a low cost alternative, but one that is inefficient and sensitive to power fluctuations.

- SRAM (Static Random Access Memory), which features low power consumption and can be battery backed-up with on-board lithium battery. Decreasing costs make SRAM a good candidate for digital memory.

Transmitter - The function of the transmitter is to convert the audio signal from the message record/playback subsystem into a modulated AM radio signal to be transmitted from the antenna. Various classifications of transmitters are available. The power amplification stage of the transmitter is characterized by an alphabetic letter A through D to describe the linearity and efficiency of operation. Class A is the most linear and least efficient, while Class D is essentially switched on and off for various parts of the output signal and hence is the most efficient. Class D transmitters have a typical efficiency of 75 percent. Greater efficiency results in less heat loss and hence better operation. Efficient transmitters can be kept in sealed enclosures to protect them from dirt and moisture, thereby extending their useful life. Highly efficient transmitters will be more conservative with respect to use of battery power during power outages.

Vertical Antenna Systems - It is desirable to place a HAR antenna in an area that has few obstructions to radio signals. Large buildings, geographic obstructions, trees, metal towers and overhead power lines should be avoided An ideal site is a flat open field that is several hundred feet across. Good soil conductivity is another important factor. A radio ground plane can be improved with radials composed of heavy gauge copper wire buried about one foot below the surface and extending about one hundred feet in all directions from the base of the antenna. Ground rods are usually attached at the ends of the radials as well Special chemical systems are available to provide a ground plane where available space may be as small as 10 feet in diameter

The antenna must be tuned to the operating frequency. Both electrical and mechanical means are usually used to adjust the antenna and lead in cable to the transmitter output, since this provides maximum radiation from the antenna.

"Leaky Cable" Antenna Systems - Cable antenna systems are usually run in conduits and either suspended near the roadway or directly buried. A cable antenna is generally considered to be more expensive to install than a vertical antenna. If buried, the antenna is easily damaged by roadway construction, roadside guiderail, sign and delineator installations as well as attack from rodents.

System Control - Most systems allow remote control that can be provided either from a touch-tone telephone or a personal computer. Telephone control is accomplished by interpretation of dual tone multi-frequency (DTMF) tones as commands from a touch-tone phone. Some systems utilize voice prompts to instruct the operator to utilize the remote control features of the recorder and provide status messages. Under computer control, all functions and diagnostics can be controlled from a PC. The control software could incorporate a graphical user interface (GUI) to make system operation clear and intuitive

Some systems allow the message to be composed and digitized at the PC before transmission to the HAR. The use of such a digital transmission reduces noise that might be introduced by this transmission. The resultant broadcast is clearer and more easily understood.

The communications link between the HAR site and the control point could be standard telephone, cellular telephone, owned cable, radio or fiber optics. Multiple HAR micro-transmitters could be utilized on the same frequency, transmitting the same message, provided that they are carefully synchronized. A fiber optic interconnect could be utilized to provide this means of synchronization.

Most HAR systems are able to operate in a mode that provides live message broadcast should the need arise.

Notification Signs - Signs advising drivers to tune their radios to the frequency required to receive a HAR broadcast should be placed near the edge of the reception area. Signs with flashing attention lights that are activated when an important message is being broadcast (such as those implemented by MHTD) would be expected to enhance the effectiveness of HAR.

KIOSKS

Another medium for traveler information is the use of information kiosks. Kiosks, in this instance, are video screens that display maps and/or text information regarding traffic, incident and/or transit information. Placed strategically at shopping malls, schools or large places of business, kiosks can provide pre-trip information and en-route information for transit strips. Pre-trip information can be used by motorists to plan alternate routes around congested areas or around incidents. Transit users can plan alternate routes with information provided on the status of transit vehicles. Communications from the TOC to the kiosks is vital to the success of a kiosk system. The application of kiosks in Kansas City may be limited due to the lack of concentrated trip origins. However, placement of a kiosk with real-time traffic information at a shopping mall (such as Bannister Mall or Oak Park Mall) or at an office complex may be beneficial in terms of public information and public support for ITS.

DIAL-IN SYSTEMS

A useful pre-trip informational tool is the dial-in system, or highway advisory telephone. A telephone number is established for the public to call for current traffic conditions. Usually, the messages are pre-recorded with the time and date so the caller knows the age of the traffic information. This system could be set up as a toll-free number or as a toll call. Once the call is placed, choices could be given to enter the highway route number, or in the case of transit, the bus route number. The recording would provide details as to traffic conditions at various interchange locations. Information from the TOC must be fed to the dial-in system operator to update the recordings.

Data Processing

Data processing functions primarily consist of analysis of the data gathered by detector equipment in the field, and the use of incident detection algorithms, which use the data gathered by detectors to identify potential incidents. The data processing for each of these functions is discussed in the following sections.

DETECTOR DATA PROCESSING

The processing of the data collected from the vehicle detection system requires that a balance be maintained between the location of data available for processing, processing capability, communications circuit loading, and access to the data for analysis and presentation. Three options are typically considered:

1. Transmit the data to a central location every second.

2. Aggregate the data in the field for a specified time period (typically 20 seconds, 30 seconds or 1 minute) and transmit the aggregated data to the central location at the end of the collection interval.

3 Aggregate the data over a collection interval (20 seconds, 30 seconds or 1 minute), store this data in the field for an extended time period (up to several hours), and transmit it to the central location when required. The requirement for the data can be based upon an "event" occurring in the field, such as the detection of an incident, or upon the request of the central system.

The first option requires relatively few bits to transmit vehicle counts because of the limited number of vehicles passing by a detector in one second. However, lane occupancy and vehicle speeds require about 10 bits per data item in order to maintain accuracy. This combination of number of bits to transmit and the one second transmission frequency places a heavy burden on the communications network (typically 1200 bps). It also requires a central computer system able to handle the data volumes and the data updates every second.

A second by second update is required when monitoring an arterial intersection controller or an individual freeway monitoring computer. This monitoring is typically required for only a few such controllers simultaneously, so the overall system design need not provide the capability for every location to communicate with the TOC every second.

Option two utilizes the power and processing capabilities of currently available microprocessors. As the processors that are deployed in field locations become more powerful and less expensive, distribution of the data processing is advantageous. This lessens the load on the communications network, and reduces the need for a larger central computer. The dynamics of traffic flow, and the rate of update of status maps and displays at the TOC establish the frequency of data transmission from the field devices. Operational experience has shown that updates every minute are not frequent enough, and updates every 10 seconds appear to be too frequent. This range has resulted in a 20 or 30 second communications time interval being utilized by several operational systems.

With this option, the field processor collects data for the selected time interval and stores it in an intermediate data buffer until polled by the central computer at the TOC There are numerous operational results, levels of service and summaries that can be calculated from the collected data. Since these calculations can be performed at either the field processor or the central computer, there is no advantage of transmitting these derived values to the central system. They can be computed on an as-needed basis at the TOC (or other location) from raw field data less expensively than they can be transmitted. If they are needed at the field processor, for example by a technician reviewing the operation of field equipment, they can be calculated at that time in the field. This requires that the field processor have sufficient memory to store several hours (or days) worth of data. Computer memory in the megabyte (million byte) range is now very inexpensive, allowing this strategy to be implemented.

The data collected from an induction loop in a 20 second period can typically be represented with three bytes of data, and speed/length/classification counts obtained from a speed loop pair require less than six bytes of data. Thus, with six mainline lanes, one entrance ramp and one exit ramp being monitored, six speed pairs and four individual loops would be utilized. This results in about 48 bytes of data, plus overhead of about 20 bytes, being transmitted between the central computer and the field controller each 20 second period.

The case noted above, where second by second monitoring of a controller is required, must be included in the design of a periodic data collection/polling system. Since 20 second data collection and second by second reporting are both equally important, the communications system must be designed to permit 20 second data collection to be interwoven with second by second reporting. This interweaving must occur in a manner that does not exceed the delay requirements of either data stream, and fits within the available bandwidth of the communications channel.

The third option is useful when routine, periodic refreshment of status maps or data displays is not required. A data collection example would be the transmission of stored volume/occupancy data from the second loop of a speed loop pair only on as requested basis. Another example would be an incident detection algorithm running in the field microprocessor based upon variations in speed of individual vehicles, detailed data that is lost when speeds are averaged over a 20 second period. Error reporting also falls into this category, since errors are infrequent events and need to be reported only when they occur.

The goal of most traffic monitoring and management systems is to reflect the real-time status of the roadway at the TOC or other centralized location. This requires that data be transmitted from the field to the central computer on a regular basis. However, as noted in the examples above, there are categories of information that are infrequent (errors or detected incidents), stored data that is needed only on an occasional basis (on demand), or data that is available in the field processor but normally not used at the central computer (for example, the standard deviation of speed.) All of these situations require that the communications protocol and data formats be flexible enough to allow the system user to request or receive notification of this data when needed.

Example Application - One example of an intelligent transportation system for incident detection is the Tunnel Operations Monitoring And Control (TOMAC) project in Baltimore, Maryland. In this case, a TOMAC system was implemented for the Hampton Roads tunnel complex. This control system has been applied at several facilities including the Elizabeth River Second and Third Downtown Tunnels, and the new four tube I-95 Fort McHenry Tunnel in Baltimore.

The system operates with automatic incident detection based on a modified California algorithm using absolute and relative occupancy. Detector communication is performed in one second increments, with a small degree of pre-processing, to convey accurate occupancies. When the software determines that a detected occupancy is likely to have been caused by an incident, the suspected incident is reported to the operator. An adjustable threshold of sensitivity is used. An excessively low threshold can result in a high false alarm rate, however, an overly high threshold may result in missing a real incident. The occupancy threshold is automatically adjusted every four hours to compensate for recurring traffic conditions such as morning and evening peak periods.

When a suspected incident is detected, the location of the suspected incident is identified and the operator is notified. The operator examines CCTV monitors to determine the nature and validity of the reported condition. The required emergency operation procedures are then manually entered. The Fort McHenry version of TOMAC is capable of entering emergency operation procedures without operator intervention, however, the system is not operated in a fully automatic mode. The emergency operation procedures have been developed in a rudimentary expert system that controls variable message and lane use signs in the tunnel. The course of emergency action depends on the current state of the tunnel and the location of the incident. The TOMAC System assists in changing all signs forward and behind the incident to appropriate status. Variable message signs and changeable speed limit signs that have been pre-programmed are commanded for display under the appropriate circumstances

The ability of TOMAC to detect possible incidents and direct an operator to a specific monitor to observe and verify a possible incident is beneficial in the operation of an automated incident detection and management system

INCIDENT DETECTION ALGORITHMS

An incident is usually defined as any event that causes a temporary reduction in the capacity of a facility or roadway. Incidents may result from occurrences that physically block a portion of the active roadway or from occurrences entirely off the roadway that cause rubbernecking or friction effects (such as an accident on the shoulder). When a roadway is operating at a level below its capacity due to an incident that reduces capacity but leaves the roadway with enough capacity to handle the existing traffic, there are few effects on operating characteristics and it will be difficult to detect by traditional means. However, if capacity is adequate, the impact of a longer response time (with respect to traffic delay) is less significant.

Various algorithms have been developed to perform automated incident detection. Different traffic parameters are measured and compared in a number of ways, each variation results in a new algorithm.

Traffic Parameters - The standard parameters used to quantify traffic are occupancy, speed and volume.

- Occupancy - The percentage of a given time period that a vehicle covers a particular point on the roadway.
- Speed - The average velocity of vehicles passing a point on the roadway during a given time period.
- Volume - The number of vehicles passing a point on the roadway during a given time period.

Comparisons of different types of time averages considering new data as well as data from adjacent detector stations are the basis for incident detection.

Recurring congestion, due to operation of a roadway above its capacity, may be detected as an incident by some algorithms. A means of incident verification is needed to determine the cause of detected congestion. Incidents that occur on an already congested section of roadway are also difficult to detect, because operation is already below capacity.

Incident detection algorithms measure and compare various parameters of the traffic stream to parameters demonstrated during typical conditions. Traffic tends to flow with a direct linear relationship between volume and occupancy (See Figure 5-2, line segment ab) under normal conditions. In congested operation, the relationship is shifted to restricted flow, resulting in a decreased volume and higher occupancy (See Figure 5-2, line segment cd. Point d represents standstill conditions.)

Examining Figure 5-2, if an incident occurs at a time that the roadway is operating at point b, the volume will be reduced and occupancy will be increased to provide operation at point c Downstream of the incident, operation shifts from b to e.

Direction of Incident Conditions - When a queue develops from an incident, a shock wave travels upstream as additional vehicles are added to the queue and a metered wave travels downstream due to decreased volume and occupancy in the free flow after the restriction The waves eventually reach detector stations where their effects can be sensed

Detection of the metered wave that travels downstream at the highway flow rate may provide a rapid indicator of the occurrence of an incident. Detection of the shock wave resulting from a queue traveling in the upstream direction provides further indication of an incident. Normal traffic flows that result in detection of parameters similar to the effects of both the metered and shock waves could be a result of normal bunching of traffic or "noise" in the flow causing false alarms.

The time taken by an algorithm for calculations to provide incident detection is usually not a major factor in detection time. The comparisons between algorithms usually depend on the time that it takes the parameters at the detection stations to reach values that the particular algorithm requires before declaring an incident.

California Algorithm - The California algorithm relies on the detection of three parameters or features between an upstream and downstream detector that are specific to incidents. These features must exceed all three specific thresholds:

- Spatial difference in occupancies (OCCDF), the absolute (arithmetic) difference in occupancies, from data in the same time period, between upstream and downstream detectors.

- Relative spatial difference in occupancies (OCCDRF), a test to determine the relative size of the difference by dividing the absolute difference by the occupancy found at the upstream detector.

- Relative temporal difference in downstream occupancy (DOCCTD), similar to OCCDRF except the test compares downstream occupancies at different times, time (0) and time (-5) seconds.

The modified California algorithm simply uses a different time period for comparison of DOCCTD, the times used are time (0) and time (-2) seconds. This results in a shorter interval used for the comparison test. There are a number of variations that improve some aspects of, or provide additional features for, the basic California algorithm. Some of these variations allow the detection of incident termination, others provide less sensitivity to compression waves in the traffic stream, and others offer improved detection or have lower false alarm rates. A combination algorithm could be developed to provide the features desired at the project site.

Time Series Models - Another class of algorithms uses recent past occupancy history to model, through time series, the near future values of occupancy parameters. When the projections differ by more than the threshold, an incident can be declared. Various statistical measurements of traffic parameters are used to detect incidents. The standard normal deviation algorithm considers the mean and standard deviation of occupancy over a period of about five minutes. An incident is declared when the measured value differs by more than one standard deviation from the mean. The double exponential smoothing algorithm employs absolute error between the observed and predicted value of volume and occupancy for one minute intervals. The ARIMA, or autoregressive integrated moving average algorithm, declares an incident when the observed occupancy is found to be outside the 95 percent confidence limit. The time series approach will detect congestion as well as incidents and does not offer any advantage regarding false alarms

McMaster Algorithm - This is a single station algorithm that operates on two-dimensional classification of flow and occupancy. The algorithm basically relies upon the determination of the roadway operating volume-occupancy region as shown in Figure 5-2. A congestion flag is raised when operation is in area 2 or 3, or a slow highway speed is detected. When the flag is present for a specific number of consecutive periods, a potential incident is signaled Since speed calculated from a single loop detector is unreliable due to a non-homogeneous traffic stream, most systems use paired loops to extract speed. The logic is more efficient if data is collected from a lane with few or no trucks, as trucks tend to disrupt normal traffic flow. This algorithm tends to be successful at detection of congestion, however, video confirmation is recommended to determine the cause of the detected congestion. Later developments of the algorithm apply comparison logic. Once congestion is detected, a check of adjacent station conditions is used to test for the incident that caused congestion.

HIOCC - Developed for the British United Kingdom Transport and Road Research Laboratory, HIOCC seeks to identify slow moving and stopped vehicles. When several consecutive seconds of instantaneous occupancy are found to exceed a threshold, an incident is identified. Separation of incidents from other types of congestion is not performed by the algorithm.

Other Algorithms - There are numerous other algorithms that are either variations on standard algorithms or are experimental and still in development. These include the Minnesota algorithm, which utilizes data filtering and assumes that a large deviation in a system parameter must be caused by a malfunction; the Willsky algorithm, which uses macroscopic modeling of traffic flow; the Cremer algorithm, which models the reduction of capacity at incident locations by considering an imaginary volume input at the incident location; and Algorithm #7, as it has been referenced in the literature, which is an adaptation of the California algorithm. The availability of these and other algorithms is noted although it is not considered here.

Video Incident Detection - Several approaches to incident detection described in the literature are being applied as a result of video detection capabilities. Video detection offers the possibility of wide area detection from a camera location. One algorithm, called Speed Profile Incident Evaluation System (SPIES) employs several speed traps in each lane of traffic. The speed traps are positioned a few hundred feet apart to allow the system to analyze speed changes within view of the camera. Speed data is gathered and smoothed on the basis of volume, resulting in samples every 15 seconds or so. The samples are compared with 15 minute data in a historical database. An incident is detected by comparison of speeds measured at the upstream and downstream detectors, with expected speeds from the database and an alarm threshold.

Another video detection algorithm called Autoscope Incident Detection Algorithm (AIDA) uses the variation of traffic flow data with regard to both time and distance. A rapid breakdown such as a speed-drop or occupancy increase and speed thresholds are used to determine congestion levels.

A new type of incident detector has recently been developed for Autoscope by Image Sensing Systems Inc This incident detector is designed to reside within the Autoscope and can be configured on the unit's monitor in a fashion similar to the way standard detectors are configured. The incident detector will sense an unusual drop in speed coupled with an increase in occupancy. Comparisons are made with recent history using a dynamic threshold which automatically adjusts with the amount of traffic detected. Incident detection is expected to be available as an upgrade to older Autoscope models. Detected incidents will be reported on a serial communications port of the Autoscope using a non-proprietary multidrop protocol.

An evaluation of a traffic scene concentrating on the two dimensional data provided from a video camera is performed by another prototype system, Image Processing for Automatic Traffic Monitoring (IMPACTS). This system evaluates the spatial distribution, movement, and stops of traffic in the field of view. The roadway is divided into small areas called cells. The algorithm determines the magnitude of change for three variables in each cell. Spatial occupancy, weighted occupancy and lane state are tracked and relational changes in these variables are used to detect incident congestion. In a test near London, Great Britain, which ran for 170 hours, a total of 74 incidents were properly detected, two incidents were missed and four false alarms were logged. This system shows promise for further development.

Conclusions - It appears that for the present, if a high percentage of incidents are to be detected, a high false alarm rate will need to be tolerated. A false alarm rate of one percent will result from one false detection in one hundred tests. A technique is described in the literature which proposes a means for distinguishing between recurrent and incident congestion. This approach is good for single station algorithms but will not prevent false alarms. If data from the IMPACTS tests is reliable, systems of this type may provide true wide area detection. Since there is little experience with video detection and its ability to perform incident detection, the use of this technology may involve some degree of risk.

Detection algorithms cannot be expected to find every incident, nor can they be expected to perform without false alarms. Automatic detection of incidents provides the operator with a source of information about possible incidents on the roadway. The information obtained must be confirmed and dealt with no differently than any other source of information that may need to be questioned.

Several major factors surface from a study of incident detection algorithms:

- Single station algorithms detect congestion. A secondary means must be used to verify conditions and determine the cause of the congestion.

- A multistation algorithm depends upon the continued operation of each detector. When one station fails, three comparisons cannot be performed. If detector stations are placed every quarter-mile, a half mile section would be lost with a single failure. It should be possible however, to bridge over the failed section and perform the comparisons with data from the adjacent detector stations.

- Incident detection requires that traffic parameters be checked for operation outside of certain thresholds. When data is found that exceeds some threshold by a large margin, an incident could possibly be reported without the need for additional testing If the threshold is exceeded by only a small margin, further testing is justified This type of magnitude testing might allow some incidents to be reported more quickly. Some algorithms consider overly large margin variations as probable hardware faults. Tests could be included in any developed algorithm to consider this possibility.

- Variable thresholds may be applicable for various levels of traffic and may be adjusted by time of day and day of week. For example, it may not be desirable or necessary to detect the recurring congestion during the typical peak periods.

Strategies Evaluation

The heart of a transportation management program is the monitoring sub-system This sub-system supports three different types of functions: counting and monitoring individual vehicles, analyzing vehicle flow information for incident and subsequent congestion detection, and providing visual images for confirmation, interpretation and analysis.

Various algorithms have been developed to detect incidents (as discussed in the previous section). Most algorithms compare traffic parameters such as vehicle occupancy (the amount of time a vehicle's presence is detected at a particular point on the roadway), speed or volume between adjacent detector stations. The California class of algorithms which do this type of comparison have been used with reasonable success for many years The McMaster algorithm has been developed to operate with single station detection where specific characteristics of the measured speed, occupancy and volume are used to indicate the existence of congestion. The determination of whether this congestion results from an incident or excess volume also needs to be performed. This determination is not necessary if the highway has excess capacity and is not subject to recurring congestion.

Incident detection and management relies on accurate real-time traffic flow data. A hybrid of automated detection, with computers monitoring detector locations, and human observation using closed circuit television is commonly used for advanced traffic management systems (ATMS). Although each of the sub-systems can work independently, automated detection and visual verification are functions that complement one another. The best performance results from an automated detection system that calls upon a human observer to view a possible incident and determine an appropriate response. As more progress is made in ITS technologies, including image processing, artificial intelligence, and expert systems technology, it is inevitable that computer systems will augment the capabilities of the human observer.

Transmission of information to the motorist is an integral part of an incident management system. This provides the mechanism to alert the motorist of problems ahead, so that an alternate route can be taken. The most commonly used technology installed along the road is the VMS, Another commonly used method to communicate with motorists is HAR. Effectiveness of HAR is improved when signs alert drivers to new messages with flashing lights. Dial-in telephone services have been implemented in various forms, and highway advisory telephone (HAT) is becoming common. An innovative traveler interface has been utilized by some systems involving public kiosks and terminals Units might be located at convenient locations such as hotels, shopping malls and major workplaces. Direct information about highway congestion and travel time can be provided for user designated routes. General information about area highways might be displayed without specific requests Cellular telephones are often used to inquire about roadway congestion and to report incidents. Commercial radio and television stations broadcast periodic traffic reports in many metropolitan areas and studies have shown that this is presently the most commonly used source of traffic information.

Computer equipment and software located at the TOC collects and centralizes all the various types of data and information generated by the monitoring sub-system. It also provides a control interface for motorist information sub-systems. Modern computer technology has reduced the size and cost of the computer hardware. However, the complexity of the software continues to increase as the functional demands for graphical user interfaces, and other state-of-the-art features, are included in the overall computer system.

POTENTIAL IMPROVEMENT OPTIONS FOR TRANSPORTATION MANAGEMENT

Potential improvement options for a transportation management system range from capital and operating expenditures to institutional and jurisdictional measures. A wide variety of options are used successfully elsewhere. Although all of these options may not be applicable in Kansas City, it is useful to review them prior to selecting a recommended system.

Potential system components can be categorized by the incident management process: detection and verification, response, site management, clearance, and traveler/motorist information. Congestion management options are also important This section provides information on potential options considered for the Kansas City area.

Detection and Verification Options - The sooner an incident can be detected and verified on the primary route, the less impact the incident will have on the normal flow of traffic. Statistics have shown that every minute of roadway blockage can result in five to six minutes of congestion and delay prior to recovery. The following options for detection and verification may be used to bring an incident to the attention of the responsible agencies or authorities:

Dedicated Freeway Service Patrols: Dedicated freeway service patrols (also called motorist assistance patrols), such as the ones currently operating in both Kansas and Missouri, are important in areas where timely incident detection and response is particularly critical or where other electronic detection equipment is not available. Many minor accidents and incidents can be cleared with the patrol vehicle, eliminating the cost and delayed response of tow trucks. The supplies carried by service patrols are sufficient to clear many incidents related to vehicle breakdown. In addition, push bumpers mounted on the service vehicle allow for quick clearance of small accidents. Once the patrol stops at an incident scene, its detection capability on the rest of the primary routes is eliminated. Several private companies have successful organized service patrols. They train the personnel, equip the vehicles, and operate the service. Other freeway service patrols are operated in a similar manner by transportation agencies, such as the one operated by MHTD in Missouri, or by enforcement agencies, such as the one operated by the Kansas Highway Patrol in Kansas.

Motorist Aid Call Boxes/Telephones: Motorist aid call boxes/telephones are appropriate in isolated areas, where detection times are lengthy Reporting can be done 24 hours a day directly to the responding agency. The units can be solar powered with cellular communications There are, however, sometimes problems such as crank calls and vandalism

Incident Reporting with Cellular Telephones: Incident reporting with cellular telephones is similar to a "911" system, but may use a different phone number. In many cases, these systems can be monitored by existing dispatch staff, requiring no additional training Motorists usually provide timely information about a particular incident However, the use of the system is limited to cellular telephone owners, the workload of the dispatcher is increased dramatically, and roadside signs are required to inform motorists of the system and to locate the incident Capital, operating and maintenance costs are relatively low and the benefits are generally high. To increase these benefits, cellular telephones should be distributed to the transportation agency personnel who frequently use the freeways during commuting hours in return for calls at regular intervals to track travel speeds and report incidents If the system is set up such that a different number is used for non-injury freeway incidents, a disadvantage of the system is that it requires the motorist to make a decision as to whether the incident is an emergency (in which case 911 should be dialed) or not.

Citizens' Band (CB) Radio Monitoring: Citizens' Band (CB) radio monitoring is similar to the cellular telephone system. Over a dedicated CB channel, these communications can be monitored by service patrol vehicles on patrol as well as by existing police dispatchers. Multiple transmissions will help to verify and locate the incident. Much of this potential is focused on the truck driver. As with the cellular system, there will be an increased workload for the dispatcher and roadside signs are necessary to inform the CB user of the system. This can also be used to broadcast information of incident related congestion to CB users.

Volunteer Watch: Volunteer watch involves citizen observation of the freeway from vantage points in high incident areas or directly in vehicles calling in observations on a periodic time basis. The advantages of a volunteer watch include visual verification and initial assessment of the incident. Disadvantages might include lack of available volunteers for a particular high incident area, as well as the need for training or instruction to acquire reliable information.

Ties with Transit, Taxi, and Shuttle Companies: Ties with transit, taxi, and shuttle companies can take advantage of vehicles already on the road with two-way radio communications. This method of detection would allow the system to expand to cover the entire city street system in addition to local freeways. Travel times and roadway conditions could be determined from the KCATA Automatic Vehicle Location (AVL) equipment, which will be operational again in the near future. This method of detection and verification requires very little training. Incident data would be reported to the transit, taxi or shuttle dispatcher and relayed to the TOC. The dispatcher would then relay the information to the appropriate agency. This improves the efficiency of transit, taxi, and shuttle operations in that the dispatcher shares the information with the other vehicle operators. This is a very low cost option that has produced significant benefits in other areas. The benefits of this option in the Kansas City area would, however, be limited by the fact that there are relatively few services that regularly use the freeways, which is the focus of the system in Kansas City.

Aircraft: A fixed wing aircraft is currently used in the Kansas City area for commercial radio traffic updates. This method has potential for monitoring shifts in traffic to diversion routes and visually analyzing traffic distributions. One disadvantage of patrols is the high cost, which typically limits patrols to peak periods. Also, weather conditions can reduce flying times The aircraft patrol would provide timely information by calling directly into the TOC. Data compiled at the TOC would be made available to the operators of the aircraft patrols and as well as to operators of vehicle probes providing information to the TOC. Since these types of commercial patrols are not often funded by the transportation agency or police, the exchange of information can result in a high return

Electronic Detection: Electronic detection includes inductance loops, radar detection units, infrared detection units, microwave detection units, and video imaging detection systems (VIDS). These systems vary in cost, accuracy, and proven reliability. Traffic flow information collected by these devices is sent through a communications link (leased telephone lines, twisted pair wire, fiber optic cable, coaxial cable, etc.) from the detector's roadside processor to a central computer with incident detection software. The advantages of electronic systems include 24-hour operation and traffic data collection capability. Some disadvantages are high initial cost, false alarms, and potentially high maintenance costs.

Closed Circuit Television (CCTV): Closed circuit television provides quick incident assessment and promotes proper response to incidents. This system also provides a method to record selected incident response activities for later review. Full system coverage of the freeway would require one to two cameras per mile plus additional cameras at interchanges. Manually monitoring these cameras is ineffective. Cameras can be linked directly to detection subsystems to automatically activate an alarm and call up the appropriate camera. Other potential users of a fiber optic cable system, such as universities and private industry, may be contacted to explore the potential of shared funding. Or partnerships with the fiber optics company may be directly pursued, as was the case in Missouri.

Traffic Operations Center (TOC): The TOC is a central information processing, dispatch and control site for the management of a transportation system. In a multi-jurisdictional situation, it is advisable to develop one overall TOC, providing better service than several uncoordinated centers. Since the primary function of TOC is information sharing, it is best to link its operations with existing agencies. Ideally, it would include all of the decision makers involved in a major incident. Some of the service patrol vehicles and personnel could also be housed at this center.

Response Time Improvement Options - Identifying the proper response to an incident and getting the appropriate equipment to the scene as quickly as possible are the keys to efficient and reduced response times. Interagency communications and cooperation are very important where fast response is needed.

Personnel, Equipment, and Materials Resource Lists: Personnel, equipment, and materials resource lists provide information on who should respond in each particular jurisdiction. Police, fire, emergency medical responders, transportation, media, and private agency contacts, as well as the method of communication, should be specified. Radio channels and telephone numbers should be clearly identified. This list would be distributed to the appropriate responding agency personnel. The same type of list would be compiled for equipment and materials in the area. These relatively inexpensive tools will save time and effort in the event of an incident. These lists are being developed in conjunction with the incident management activities being spearheaded by KDOT, but efforts will need to be made to assure that they are updated (and distributed) regularly.

Dedicated Freeway Service Patrols See previous section in *Detection and Verification Options*.

Personnel Training Programs: Personnel training programs emphasize the coordination aspect of incident response, making each agency aware of the other agencies' needs and requirements. A demonstrated willingness to participate and cooperate is required by all agencies if the incident response team approach is to be successful.

Tow Truck/Removal Crane Contracts: Tow truck and removal crane contracts may be established with private firms to reduce the response times at frequent incident locations, and to allow immediate use of necessary equipment. These contracts eliminate the question of who to call when specific equipment is required. Agency owned tow trucks are typically costly to purchase and operate. Private contracts offer financial incentives for the tow truck company to clear the freeway as quickly and safely as possible. Heavy duty wreckers stationed at key points allow for the quick removal of major equipment, debris, and spills. Generally these are warranted for short sections (usually bridges and tunnels) with high truck volumes.

Improved Interagency Radio Communication. Improved interagency radio communication may require the purchase of compatible two-way radio equipment and the use of a common nomenclature or terminology This would improve site management and provide better information to the responding personnel. However, it may not be feasible for all agencies to participate and to invest in new equipment. Costs vary depending on specific equipment needs. Command posts such as mobile command centers may be needed at incidents where two or more agencies are involved. This facilitates communications and saves time by reducing repetition of commands.

Ordinances Governing Travel on Shoulders: Ordinances governing travel on shoulders will be possible only in areas where shoulder widths are wide enough for emergency equipment. In order for emergency vehicles to reach the scene of an accident, it may be necessary for vehicles to travel on the shoulder. In some situations during incidents, travel by the public on shoulders to circumvent the incident may be necessary. It would be a wise decision to incorporate sufficient shoulder widths in any redesign projects.

Emergency Vehicle Access: Emergency vehicle access, such as movable barriers and U-turns at key locations along the freeway, reduce response times for emergency vehicles. These techniques are useful for response vehicles when one direction of the highway is completely blocked and access is only possible by approaching the scene contraflow to the travel direction. However, unauthorized motorists may be tempted to use these U-turn facilities, and movable barriers are expensive.

Diversion Route Planning: Diversion route planning is useful when the capacity of the primary route is reduced by an incident. It is important to plan routes that avoid low overpasses or severe turns. Either temporary or permanent signing is required at junctions and along the route to reduce confusion and provide for smooth traffic flow. Use of VMSs and/or HAR to inform motorists of the alternate route is very effective.

Diversion Route Management: Diversion route management is needed to adjust traffic signal timings to accommodate additional traffic flow after a diversion plan is implemented. The computerized arterial traffic signal system should incorporate a feature to automatically recommend and/or implement an incident response timing plan. Diversion route management techniques can also be used to locate underutilized alternate routes and redirect traffic to them on a real-time basis.

Equipment Storage Sites. Equipment storage sites would reduce response times by providing special removal equipment at high incident locations. Costs are minimal if this space already exists, but it may be difficult to find additional space at some high incident areas. Large equipment to be stored might include wreckers, sand trucks, and other large vehicles. Smaller items include cones, signs, flares, portable barriers, and other equipment for traffic control.

Administrative Traffic Management Teams: Administrative traffic management teams include officials from transportation, police, fire, and rescue agencies. This strategy requires a willingness to cooperate by all participating agencies. The intent is to provide a forum for discussion of unresolved incident management issues, preplanning for response, and improved communications.

Public Education Programs: Public education programs inform motorists of their rights and responsibilities when they are involved in a traffic accident. Motorists may be permitted to move their vehicles from the scene of an accident according to Kansas and Missouri state law, but may not do so. Most are reluctant to do so in any case because of misconceptions regarding the legality or liability of the action.

Traffic Operations Center: See previous section in *Detection and Verification Options*.

Closely Spaced Reference Markers: Closely spaced reference markers, as well as other landmark and directional markers, help in locating incidents. These markers aid cellular telephone callers in reporting incident locations, and provide improved record keeping for analysis of incidents. The markers could be located on the center median barrier to enhance visibility and reduce costs of sign posts. For ramps and collector-distributor roadways, special numbering, colors, and/or patterns would be necessary, due to the potential for confusion. Utility poles might also be designated with markers to identify locations along the freeway. These markers might be placed every 1/10 of a mile or every 2/10 of a kilometer.

Site Management Options - Incident clearance can become more effective if the site management techniques are well executed. Coordination of personnel and control of traffic help to reduce the likelihood of secondary accidents.

Incident Response Teams: Incident response teams would be comprised of personnel from various agencies. These teams would be trained to handle unusual incidents and would be familiar with one another. Incident response teams might improve site management and clearance efforts in special circumstances, but they are likely to be ineffective if not properly trained and equipped. Similarly, the effectiveness of incident response teams is limited if refresher courses are not provided frequently, and if there is high turnover in agency staff.

Personnel Training Programs: See previous section in *Response Time Improvement Options*.

Improved Interagency Radio Communications: See previous section in *Response Time Improvement Options*

Properly Defined Traffic Control Techniques: Properly defined traffic control techniques are standard guidelines for lane closure which are identified and agreed to in advance. The guidelines should be consistent with the Federal Highway Administration's (FHWA) Manual on Uniform Traffic Control Devices and any superseding state guidance. This action requires cooperation among agencies. The incident management team would provide an appropriate forum for this activity.

Properly Defined Parking for Emergency Response Vehicles: Properly defined parking for emergency response vehicles is a technique of identifying, in advance, the appropriate place at an incident site for placement of response vehicles. This placement depends on the nature of the incident. As with the traffic control techniques, this is a cooperative action. In a related policy, some cities recommend that emergency vehicles be positioned so as to close no more travel lanes than those already blocked by the incident.

Flashing Lights Policy: Flashing lights policy would be considered to reduce distraction to non-involved motorists. Flashing lights may not be required when the responding vehicles are on the shoulders. The drawback is that the response team members may not feel as safe. Field testing may be necessary to get reactions from incident response team members and the public, and legislative work may be required.

Administrative Traffic Management Team: See section in *Response Time Improvement Options*

Traffic Operations Center: See section in *Detection and Verification Options.*

Diversion Route Planning: See section in *Response Time Improvement Options.*

Incident Response Manual: An incident response manual would be developed to increase the efficiency of responders activity at the incident site. Input by all involved agencies is required to produce a document that accurately defines all procedures for site management. It should be specific to the facility, roadway or corridor it deals with. Frequent updating and training are also required.

Clearance Time Reduction Options - A reduction in clearance time results in a reduction in vehicle delay. Options to reduce clearance time are presented below.

Policy Requiring Fast Removal of Vehicles: A policy requiring fast removal of vehicles is a low cost method of returning the roadway to normal operating conditions where shoulders exist or where there is adequate space for a holding area. Liability may be an issue if damage to the disabled vehicle occurs. Generally, however, this policy has no cost to the transportation agencies, and would make police and other response personnel available to perform other more important duties.

Accident Investigation Sites: Accident investigation sites allow operable vehicles involved in non-injury accidents to be removed from the travel lanes immediately. In many situations, secondary accidents occur due to blockage of travel lanes With the use of off-road or out-of-sight accident investigation sites, secondary accidents are less likely. Accident investigation sites are used to interview those involved, fill out police reports, and make necessary telephone calls. The area should be flat and well lighted with a telephone or call box Finding an appropriate location may be difficult, and site preparation, signing, and publicity will require some investment. Signs along the freeway are needed to inform motorists of accident investigation sites, and education would be required to inform motorists of the use of these sites. These sites are only effective to the extent that they are used by motorists. Some cities have indicated that motorists are reluctant to use them, these motorists believe that they should not move their cars until the police come.

Dedicated Freeway Service Patrols. See section in *Detection and Verification Options.*

Push Bumpers: Push bumpers can be added to the tow trucks, emergency service patrols and police vehicles. They are especially beneficial for quick clearance along elevated roadways and sections with inadequate shoulder widths.

Responsive Traffic Control Systems: Responsive traffic control systems, such as the computerized traffic signal system currently in use in some cities, will aid in diversion route management. When diversions become necessary, the traffic operations staff implement or request implementation of a pre-determined traffic signal timing plan which provides more capacity to the diversion route for the duration of the incident.

Ordinances Governing Travel on Shoulders: See section in *Response Time Improvement Options.*

Emergency Vehicle Access: See section in *Response Time Improvement Options.*

Diversion Route Planning: See section in *Response Time Improvement Options.*

Incident Response Teams: See section in *Site Management Options.*

Personnel Training Programs: See section in *Response Time Improvement Options.*

Incident Response Manual: See section in *Response Time Improvement Options.*

Administrative Traffic Management Teams: See section in *Response Time Improvement Options.*

Public Education Program: See section in *Response Time Improvement Options.*

Total Station Accident Investigation Equipment: Total station accident investigation equipment is a combination of electronic surveying and distance measuring devices developed exclusively for the investigation of accidents. This type of equipment reduces delays, personnel requirements and exposure of personnel to traffic hazards since accident investigations can be carried out more quickly.

Traveler/Motorist Information Options - Communication with travelers is an important component of any intelligent transportation system. Options for communications include the following

Highway Advisory Radio (HAR): Highway advisory radio is a powerful instrument to share information with travelers in their automobiles. Information regarding planned lane closures due to construction or maintenance is broadcast repeatedly over the HAR Advanced warning to motorists of lane closure schedules, incidents, or special events will help to reduce the traffic demand at the closure, and may reduce the number of accidents in the area. HAR transmitters would be needed to provide coverage for motorists in and around the metropolitan Kansas City area. If a high power transmitter is used, motorists can be informed prior to their trip

Variable Message Signs (VMS). Variable message signs are used alone and in conjunction with HAR to inform motorists of planned lane closures, incidents and special events. Truck mounted or trailer mounted VMS can be very effective in incident management These can be located and moved in response to a major long term incident.

Traffic Operations Center: See section in *Detection and Verification Options.*

Commercial Radio and Television Broadcasts: Commercial radio and television broadcasts are good sources of information for the traveling public in most cases. Commercial radio is a well known source for traffic information in the metropolitan Kansas City area. In some communities, commercial broadcasts have been known to provide outdated or incorrect information.

Kiosks: Kiosks may be used for special traffic generators such as shopping malls and large employment buildings, and could be used to inform motorists of traffic conditions. On-screen graphics and text could convey accident and incident information, travel times, or even provide suggestions for the best route to a motorist's destination.

PC/Modem: PC/modem systems could be used to tap into the TOC's computer from home or work. A telephone hotline would be established so that travelers could call in for conditions on the primary route. A caller would enter the route number, the entry and exit interchange number and the direction of travel using a key pad or mouse. The computer would dispatch information to the caller on current roadway conditions. Private sector firms could become involved in establishing this service. The information could also be located on an Internet home page, automatically being updated every few minutes.

Congestion Management Options - Several techniques exist for decreasing congestion on freeways. Ramp metering can be used to divert traffic that utilizes the freeway for short trips and can also smooth out the flow of traffic on the freeway. High occupancy vehicle (HOV) lanes can be implemented to move more people in fewer vehicles by providing exclusive lanes on the mainline and queue by-pass lanes at congested interchanges (including freeway to freeway). Predictive algorithms can be used to balance traffic between freeways and alternate arterials within a corridor.

Ramp metering requires analysis and determination of congested sections of freeways. A threshold of volume to capacity ratios would be determined to identify congested segments. Congested segments would be linked together to form a larger section. The ramps within this section as well as several ramps upstream of the beginning of the section will be field checked to determine the length of queued vehicles that could be stored. To properly deploy ramp metering, it may be necessary to reconstruct those ramps which have very little storage length. Detectors on the ramps for queues spilling back onto local streets, detectors at the stop bars near the signal heads, and the controller and cabinet are the equipment needed for ramp metering In some cases, detection in the right lane of the freeway upstream of the ramp is used to identify available gaps in the mainline.

High occupancy vehicle (HOV) lanes can be deployed in areas where existing carpool, vanpool and bus traffic would benefit from an exclusive lane. At interchanges where on/off ramps are congested, queue by-pass lanes could be implemented for HOVs. This would provide an additional travel time incentive Congested areas of freeways could be equipped with an HOV lane where travel time savings would be at least one minute per mile, and overall travel time savings would be at least eight to ten minutes per trip.

By instrumenting the freeways and the parallel arterials, predictive algorithms could be utilized to balance traffic flow between the freeways and the parallel arterials. Variable message signs and HAR could be used to send messages to the motoring public regarding which route is less congested or which route is more congested. The algorithm predicts when the less congested route will become more congested and relays the message to the VMS and HAR to stop shifting traffic. This balancing may change from time of day or time of year and may be based upon historic data as well as sensor information that counts the number of vehicles shifting.

ITS ACTIVITIES IN OTHER URBAN AREAS

Intelligent transportation systems have been implemented in many cities across the United States. While some of these systems are the result of recent programs and activities, many others have evolved from activities that were initiated years ago. Examining ITS activities and programs underway elsewhere provides an appreciation for the potential, and in some cases the limitations, of intelligent transportation systems. The following discussion is by no means all inclusive, it is merely intended to provide a brief look at various approaches to incorporating ITS into an urban area. Although many systems use common technologies, each urban area has tailored ITS applications to meet their needs.

Chicago, Illinois - Chicago's ITS system encompasses components managed by the City of Chicago, as well as Departments of Transportation in Illinois (IDOT), Indiana (InDOT), and Wisconsin (WisDOT). In terms of fixed equipment for traffic information, the Chicago area relies primarily on loop detectors in the pavement. The IDOT Traffic Systems Center has over 2,000 loop detectors covering 136 centerline miles.

Chicago has focused significant resources on one of the most extensive motorist assistance programs in the country. The "minutemen", also known as the IDOT Emergency Traffic Patrol, have been responding to motorist needs since 1960. The program was initiated with a couple pick-up trucks with push bumpers, and has expanded significantly over the last 36 years. It now includes emergency patrol vehicles with relocation tow rigs, light 4x4s, heavy duty tows, a crash crane, tractor-retriever, sand spreader, heavy rescue and extrication truck, and trailer mounted variable message signs. The minutemen provide service 24 hours a day, seven days a week. Chicago's incident management program has reduced the time to clear an incident by

50 percent. This reduction in incident duration can have a significant impact not only on delay but also on safety, particularly when secondary accidents are considered. Secondary accident rates are six times higher than primary accident rates

In Chicago, ITS technologies are used not only for incident management, but also to support traffic control activities such as ramp metering and to inform motorists. Motorist information is provided through VMSs, highway advisory telephone, and the Internet. Deployment of ITS technologies is facilitated by the fact that the Chicago metropolitan area has one of four "Priority Corridors" throughout the country. The Gary-Chicago-Milwaukee (GCM) Priority Corridor is a joint effort of IDOT, InDOT, and WisDOT.

Minneapolis, Minnesota - The State of Minnesota has a statewide ITS program, Guidestar. Coordinated with this effort is the intelligent transportation system of the Minneapolis/St Paul Twin Cities metropolitan area. This system provides coverage of 160 centerline miles of interstate and state highway, monitoring traffic with autoscopes, loop detectors, more than 150 CCTV cameras, and aerial monitoring (via a partnership with private aircraft). The traffic management center uses this information to manage traffic through HOV lanes and over 360 ramp meters, and provides this information to motorists through almost 50 VMSs, metrowide HAR, and a cable television traffic channel. "Highway Helper" trucks, private tow trucks, and accident investigation sites are used to remove incidents from the roadway. This program provides $1.4 million in estimated benefits, at a cost of 0.6 million, resulting in a benefit cost ratio of 2.3.

The Minneapolis/St. Paul areas has seen significant benefits from the implementation of ITS programs and infrastructure. The incident management program in Minnesota has reduced incident clearance times by 8 minutes, wrecker response times by 5 to 7 minutes, and fatalities in urban areas by up to 10 percent. Accident rates have fallen by 25 percent since the comprehensive freeway management system was put into operation. Benefits accrue not only due to fewer incidents and faster response time, but also during non-incident conditions. Average freeway speeds in Minneapolis have increased by 35 percent and capacity has increased by 22 percent.

In addition to providing traveler information through more traditional means such as VMS and HAR, the Twin Cities area is also testing new technologies for communications with travelers through the Genesis system and the Trilogy system.

The Genesis system uses personal communications devices such as pagers and personal memo computers to provide information to travelers wherever they are Operators at the traffic management center receive the data, evaluate it, and announce roadway incidents on the Genesis system. Traveler messages include information not only about incidents, but also about special events such as parades or construction. Genesis users can receive up to 12 messages at one time, with older messages automatically overwritten. Information is accessed at the convenience of the user, to avoid the disruption of beeping pagers.

The Trilogy project provides traveler information through three different communications techniques: the Radio Broadcast Data System-Traffic Message Channel, an FM subcarrier, and a high-speed RF subcarrier. These devices will provide end users with area and route-specific en-route advisories on the highway operating conditions in the Twin Cities area.

The Twin Cities region has been aggressive not only with respect to ITS traffic applications and traveler information, but also with respect to encouraging transit and other high occupancy modes. One demonstration of the multimodal approach is the Travlink project Travlink, a partnership of public, private, and academic institutions, utilizes a GPS AVL system to monitor and dispatch buses for improved efficiency and on-time performance. The system also features a communication system that facilitates notification of either a mechanical problem or emergency situation (including a silent alarm to call for help).

The real-time bus status gathered through the Travlink project is used not only for fleet management, but also to keep transit patrons informed Real-time bus status messages are displayed via electronic signs at three commuter park-and-ride lots, allowing commuters to wait in their cars until the bus approaches. Bus status, route planning, carpool information, and traffic and road information are also available through kiosks and special videotext terminals. Benefits of Travlink include decreases in travel times. Travel time savings are estimated to be as high as 17 minutes during incident conditions, resulting in time savings as high as 1,900 vehicle-hours of delay per incident.

San Antonio, Texas - San Antonio has recently completed a transportation management center that will be the focal point for San Antonio's ITS system. The initial phase controls 25 centerline miles of the proposed 190 mile system. A unique feature of San Antonio's system is the extent to which it is centralized. The transportation management center, which represents an investment of at least $36 million, will handle freeway monitoring and control, and provide traveler information, incident management, transit management and emergency management. In addition to system operators and other traffic management personnel, law enforcement, transit, emergency response, and state and local engineering personnel are all housed in the same facility, which is in a three-story building in a major interchange. The close proximity of all affected agencies will presumably facilitate coordination and cooperation.

San Antonio's advanced traffic management system, TransGuide, depends on detectors at half mile intervals and high resolution color CCTV cameras (with remote zoom and focus capabilities) for information on roadway conditions. The San Antonio system boasts a complete digital communication network (voice, data and video), a fully redundant fiber optic network, a fault tolerant computer system, an incident detection goal of 2 minutes, and a system response goal of under 1 minute after detection.

Attainment of the goal for incident detection within 2 minutes will be facilitated by a central computer which controls detection, analysis and response, with over 34,000 pre-programmed solutions to specific incidents (as many as 128,000 solutions will eventually be developed and stored). Identification of an incident will trigger not only emergency response personnel, but also VMSs, lane-control signals, and signal timing. The frontage roads adjacent to most urban interstates in Texas provide an ideal diversion route in the event of an incident or lane closure.

In addition to providing motorist information through traditional technologies such as VMSs, the San Antonio system also has a direct link to local television stations. Funding for the television link was a unique public/private arrangement. The Texas Department of Transportation funded just over half, maintaining control. The remaining funds were obtained from a consortia of local television stations.

Los Angeles, California - Los Angeles has the largest roadway system and the most congestion of any urban area in the United States Los Angeles also has one of the most extensive and established ITS systems The traffic management center operated by Caltrans controls 700 centerline miles of interstate and state highway

ITS activities in Los Angeles have been enhanced by demonstration projects such as the Pathfinder project and the SMART Corridor program. The Pathfinder project, a cooperative effort by Caltrans, FHWA, and General Motors, was the first test in the United States of an in-vehicle navigation system for the provision of real-time traffic information to drivers Pathfinder provided drivers of 25 specially equipped cars with up-to-date information about accidents, congestion, highway construction, and alternate routes in the Los Angeles SMART corridor A control center managed the communication, detected traffic density and vehicle speeds via detectors and by using the Pathfinder vehicles as probes, and transmitted congestion information to equipped vehicles. The information was then presented to the driver in the form of an electronic map on a display screen or digital voice.

The SMART Corridor program, another ITS demonstration project underway in Los Angeles, is sponsored by the City of Los Angeles, the Los Angeles County Transportation Commission and FHWA. The objectives of the SMART Corridor, located along 12.3 miles of the Santa Monica freeway, are to relieve congestion, reduce accidents, reduce fuel consumption and improve air quality. This is to be accomplished by advising travelers of current conditions and alternate routes using HAR, VMSs, kiosks and teletext, by improving emergency response, and providing coordinated interagency traffic management. The goals and strategies of the SMART Corridor program mirror the goals and strategies of the ITS system in general.

The ITS system in Los Angeles includes a Freeway Service Patrol (initiated in July 1991), electronic monitoring via loop detectors and 27 CCTVs, citizen call-in and call boxes, more than 800 ramp meters, and incident management teams. Motorist information is provided through HAR, more than 70 VMSs, information kiosks, media partnerships, and the Internet. Incident management activities are also facilitated by the use of pre-planned diversion routes to manage traffic. In some cases, diversion routes utilize arterial street facilities. Use of arterial facilities as diversion routes is facilitated by a sophisticated signal control system.

Los Angeles also has one of the most advanced arterial control systems in the United States. The Arterial Traffic Monitoring and Control (ATSAC) system has an extensive detector system to obtain data on arterial traffic flow and color graphic monitors to display real-time information. To supplement the information from the detectors, CCTV is placed at critical intersections. This allows verification of congestion indicated by detectors, and helps the operator during manual override control during incidents. There are four modes of control used by the system: time of day, critical intersection control, traffic responsive, and manual override.

Los Angeles has utilized ITS technologies not only for traffic and incident management, but also to respond to planned events, such as the Olympics, and even to respond to disasters such as the Northridge earthquake. Variable message signs and other means of motorist information were especially critical following the earthquake, when many facilities were closed, and some of the ones that were open were restricted to HOVs. Another strategy used following the earthquake was information kiosks. As many as 80 kiosks were located in shopping malls, police buildings, business parks and community facilities such as the YMCA. Travelers could use the kiosks to plan transit trips, find carpools, check traffic conditions, and print itineraries. Although the kiosks were removed once Los Angeles recovered from the earthquake, they are being returned due to their popularity

Seattle/Tacoma, Washington - The Seattle/Tacoma area has a number of ITS activities underway, and at least $35 million has already been invested in monitoring, control and driver information components, including a traffic management center operated by the Washington State Department of Transportation (WSDOT), ramp meters, loop detectors, CCTV cameras, VMSs, HAR, and weather stations.

The benefits of ITS in the Seattle area have been significant. Ramp metering has proven particularly successful. Ramp metering in Seattle has cut accident rates to 62 percent of the previous rate, despite increases in traffic ranging from 10 to 100 percent (average approximately 20 percent). Speeds have remained steady or increased up to 48 percent, resulting in a 20 to 37 percent decrease in travel times Ramp delay has remained at 3 minutes or less. Travelers have also benefited from the provision of information. Thirty to 40 percent of travelers adjust their plans, and 5 to 10 percent of these travelers change their mode, based on the information they receive.

An interesting aspect of the Seattle area system is the approach to information sharing. The ITS Backbone Project, co-sponsored by the Puget Sound Regional Council (PSRC) and the WSDOT, is designed to create a common information pipeline over the Internet for advanced data collection systems. This system allows agencies and travelers to access a variety of travel data and use it to make decisions.

The ITS Backbone incorporates information from the North Seattle Advanced Traffic Monitoring System (ATMS) , the loop detection system run by WSDOT, Metro and Community Transit Traffic Signal Priority Project, and Metro Transit and University of Washington AVL systems. The Backbone gathers travel times for automobile, freight and transit traffic, involving many agencies and extensive use of the region's ITS data collection activities. For example, interfacing with existing AVL systems allows real-time transit vehicle locations to be obtained. Freeway congestion information is obtained by interfacing with the loop detection system owned and operated by WSDOT. Using data acquisition control systems, global Information system (GIS) command and control consoles, display systems and communication ports, the data from the AVL and loop sources are fused, yielding detailed information about the region's transportation system and travel conditions.

One advantage of the system is that the cost of making data available through the ITS Backbone and Internet connection is minimal to the agency, yet the benefits are considerable. Furthermore, it overcomes the barrier that independent agencies are often unwilling to share data for joint development if it means they must adjust current procedures or sacrifice the security and integrity of their data. The ITS Backbone also encourages regional cooperation, as each agency benefits by cooperating. Agencies can access information without delving into the operations, philosophies, or objectives of the agency responsible for gathering the data.

Despite the advantages, several issues must still be addressed. Some data collection systems are proprietary in nature, which complicates the design and development of information sharing techniques. Furthermore, real-time validations and processes for ensuring system maintenance must be addressed if real-time information is to be openly broadcast to transportation agencies.

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

Another ITS activity of interest in the Puget Sound area is the evaluation of technologies for emergency notification and personal security. A specially equipped two-way pager and cellular telephone are being tested as MAYDAY devices for notification of accidents, mechanical failure, or carjacking. The two-way pager offers three buttons, one for emergency situations, one for medical help, and a third for mechanical assistance. The pager device cannot transmit voice, but two-way communication is possible if a traveler pushes buttons in response to digital messages or questions.

The cellular telephone offers two-way voice communications with a silent alarm panic button activating a voice link that can be monitored until help arrives. Other buttons can be pushed to identify a situation as a accident, mechanical failure, or request for directions. Once activated, the MAYDAY devices automatically transmit a signal to a 911 dispatch center, where an electronic map pinpoints the signal location, generally within 30 feet.

Northern New Jersey - Northern New Jersey has been involved in what would now be considered ITS activities since the 1970s, when the Metropolitan Area Guidance Information and Control, commonly known as MAGIC, system was initiated. MAGIC, which is sponsored by the New Jersey Department of Transportation, focuses on I-80 (an east-west route into New York City via the George Washington Bridge) and parallel facilities (such as US 46 and New Jersey 4).

One notable feature of the MAGIC system is the choice of detection technology. New Jersey has used radar based detection every half mile. The primary disadvantage of radar is that it averages speeds across all three lanes, and in some cases, the average speed includes the HOV lane, which should have freeflow speeds at all times. For incident detection purposes, it is preferable to have speeds for each lane, otherwise the decreased speed in a single blocked lane may be obscured by the higher speeds in the open lanes. New Jersey is now also installing loop detectors. Loop detectors are being placed at 0.7 mile intervals, in an effort to increase coverage without increasing costs. The effectiveness of this strategy has not been evaluated.

New Jersey has also been active with respect to electronic toll and traffic management (ETTM) technologies. The implementation of ETTM technologies by three New Jersey toll authorities will permit commuters to use a single electronic toll tag, or EZ-Pass, throughout the region. In general, electronic toll collection systems have been shown to decrease operating expenses up to 90 percent, increase toll plaza capacities by up to 25 percent, and decrease fuel consumption by up to 12 percent, and decrease harmful emissions by 45 percent (nitrous oxides) to 83 percent (hydrocarbons). The effort to implement ETTM technology in New

Jersey is part of the larger EZ-Pass Interagency Group, which is a coalition of seven toll authorities in New York, New Jersey, Delaware and Pennsylvania.

In some cases, toll authorities have their own ITS systems For example, the New Jersey Turnpike Authority operates a TOC in New Brunswick, New Jersey This system covers almost 150 centerline miles of interstate and state tollway, monitoring traffic through loop detectors, video imaging, microwave detectors, and 2 CCTV cameras. Over 100 variable speed limit and speed warning signs and more than 100 variable messages signs are used to keep motorists informed

New York - New York has a variety of ITS activities underway, including both traffic and transit applications. One noteworthy project is the INFORM corridor traffic management system on Long Island in New York State. The major facility in this corridor is the Long Island Expressway, I-495. The INFORM system manages 35 centerline miles of interstate, parkway, and state arterial, including more than a hundred signalized intersections (on the service roads and selected arterial routes). An important feature of the INFORM system is the integration of the management of the arterial and freeway system.

Although some of the system elements have been in use for many years, the design of the INFORM system has evolved and includes a higher level of corridor traffic management automation. Low level tasks include data collection and communication, computation of traffic flow characteristics, and reporting of traffic flow characteristics. Medium level tasks include intersection control, ramp meter control, and equipment failure monitoring. High level tasks include generation of messages for VMSs (delay messages are automatically activated), intersection control (upon diversion of traffic from the freeway the system adjusts the affected arterial timing plan based on a diversion database), ramp meter control (ramp metering becomes more permissive when congestion backs up on arterial streets), and incident management and diversion strategies (theoretically incidents can automatically be detected and diversion strategies implemented).

Delay savings due to motorist information are significant. Travel time savings of 17 minutes are estimated during incident conditions, this results in delay savings of 1,900 vehicle-hours for a peak period incident, and 300,000 vehicle-hours in incident related delay annually. Traveler information also provides important benefits. Drivers will divert 5 to 10 percent of the time when information does not include any action, and will divert 10 to 20 percent of the time when diversion messages are provided.

Basic elements of the system include vehicle detection through more than 2,000 loop detectors, monitoring through 34 CCTV cameras, an operations facility, radio communication monitors, intersection control, ramp metering (using 75 ramp meters) and more than 100 VMSs. The INFORM system also has a subscription service, the Video Traffic Information Program, which provides color computer graphics of traffic conditions. INFORM operators also monitor CB and police radio for incident detection and verification. This is considered critical due to the lack of corridor-wide monitoring by CCTV.

Monitoring capabilities may soon be enhanced by a traffic flow visualization and control program recently initiated. This program investigates a video-based vehicle detection, visualization and management system which employs technology developed in the military. Through advanced video data processing, neural network analysis and intelligent command

and control technologies, the traffic adaptive system will identify and alert the system operator to real-time traffic conditions such as recurring congestion, non-recurring incidents, and other traffic problems normally associated with freeway operations. Once the system has been demonstrated in the lab, the system will be field tested as part of the INFORM corridor.

ITS activities in New York are also underway on a larger scale The Transportation Operations Coordinating Committee, TRANSCOM, is a consortium of 15 transportation and public safety agencies in the New York, New Jersey and Connecticut area whose goal is to improve inter-agency response to traffic incidents. A number of project initiatives have been undertaken to support this goal, and to advance the use of ITS technologies in the metropolitan area. Activities include:

- Regionwide initiatives for coordinated deployment and operation of VMSs, HAR, and enhanced traffic monitoring including CCTV.

- Development of an ITS Regional Implementation Strategy, a program for coordinated implementation of ITS throughout the multijurisdictional area

- An enhanced traffic advisory/diversion system at the intersection of the New Jersey Turnpike and Garden State Parkway, which will focus on alternate routing for New Jersey Transit buses.

- Expansion of traffic monitoring along the I-287 Tappan Zee Bridge corridor.

- The TRANSCOM System for Monitoring Incidents and Traffic, TRANSMIT, an operational test project that will manage vehicles with transponders on a highway system equipped with readers and antennas, to collect travel times, speeds and with dynamic software, to detect incidents.

Washington, District of Columbia - There are a number of ITS activities underway in the Washington, D.C. area. Coordination of these ITS activities is very important due to the fact that the metropolitan area encompasses the District of Columbia, the States Maryland and Virginia, and many local jurisdictions. Many of the ITS activities in the region are conducted in Maryland and Virginia.

Many of the ITS activities in Maryland are affiliated with CHART (Chesapeake Highway Advisories Routing Traffic), which was initiated in 1989 as the statewide transportation management program. CHART originated to meet the need for monitoring, incident response, traveler information and traffic management. In conjunction with CHART, the State of Maryland has a 24 hour, 17,000 square foot traffic control command center which serves as an information hub. This center is coordinated with the activities of the Maryland State Police, who help staff the operations during morning and evening rush hours, extreme weather, and in other circumstances where additional personnel are warranted.

The traffic control command center is networked to CCTV cameras and other data gathering equipment such as radar and road-embedded traffic detectors, and pavement condition sensors Information is also received from a cellular call-in system. The detection system uses bi-directional overhead, wide-beam, radar based traffic detectors to monitor speeds at 1.5

mile intervals. Detection has been installed at 77 sites, and another 250 sites are planned or underway CHART is expected to have a benefit cost ratio of 10.

Information is displayed at the command center via six large-screen, rear-projection systems on the wall, a video bank of five 120 inch rear-projection units, a 4x4 matrix rear-projection video wall, and a dozen 20 inch color monitors. The traffic control command center responds to incidents through links to emergency traffic patrols and emergency response units, and notifies motorists via VMSs and HAR, which currently includes 25 permanent stations, and four more planned in the next 2 to 4 years

CHART also has regional TOCs, which are located at several State Police facilities, at the Fort McHenry Tunnel in Baltimore, and at the Chesapeake Bay Bridge during the summer. The state traffic control command center shares information, including video feed, with the Montgomery County traffic management center, which serves suburban Washington, D.C.

The Montgomery County traffic management center, which opened last year and is the result of an $8 to $10 million investment, has coordinated signals, loop detectors, and 22 CCTV cameras at 10 locations along the Baltimore-Washington corridor. In addition to aggregating data from sources such as freeway detectors, CCTV, and local street signals, the Montgomery County Traveler Information System provides real-time information to 180,000 homes via cable TV to show traffic conditions on major roadways.

Another $3 million is being used to integrate traffic and transit management activities. The resulting system will include an AVL equipped bus fleet, intelligent in-vehicle units, two-way communications, real-time graphics, relational database, monitoring, and control software, transit priority and system information dissemination.

Montgomery County is also exploring live aerial video monitoring. In this case, the video is shot from fixed-wing aircraft and video footage is sent to both the state and county traffic management centers. Maryland and Virginia are cooperating in this effort and will transmit video to traffic management centers in both states, and are beginning to transmit live video to mobile command centers.

Fairfax County, Virginia and the Virginia Department of Transportation are also exploring aerial monitoring. More specifically, a gyro-stabilized camera mounted on helicopters is being used for observing, evaluating, and managing major highway incidents and situations of a public safety nature. The live color video is transmitted to police and state highway traffic management centers and mobile command centers at incident sites. Communications technologies being used include microwave, community access TV, and state owned coaxial cable. It is expected that the use of real-time airborne video will serve as a valuable component of the advanced traffic management system, particularly during the management of major incidents.

Northern Virginia also has a number of other activities underway with respect to traffic management and control. ITS activities include the Northern Virginia freeway traffic management system and TOC, a statewide emergency operations center for the State of Virginia, Hampton Roads tunnel and bridge traffic management systems, the City of Richmond signal system, truck rollover warning systems on the Capital Beltway, wide area cellular monitoring operational test, and SCAN weather monitoring. The Northern Virginia traffic management center, which is operated by the Virginia Department of Transportation, manages

32 centerline miles of interstate with 550 loop detectors, almost 50 CCTV cameras, over 25 ramp meters, and 100 VMSs.

In addition to the ITS applications for traffic management, Northern Virginia is also conducting an operational test to evaluate an enhanced ridesharing route deviation transportation system integrated with conventional transit and ridesharing in the suburbs of Washington, D.C. The system provides on-demand service through an audiotext request system which uses scheduling software similar to the software used by the taxi industry Door-to-door transportation is provided using both public and privately owned vehicles operated by paid volunteer drivers using vans, minibuses, specialized public vehicles, fixed-route buses, and taxis. Users are charged a standard per mile rate regardless of the type of vehicle used. System cost not recovered by these fares are to be covered by local agencies. Smart cards are used to process transactions. It is hypothesized that this service may be provided at a much lower cost than conventional transit service.

Public Transportation Technologies

This section addresses ITS transit technologies and their applications in the Kansas City metropolitan area

Advanced Public Transportation Systems (APTS) is the program name describing the application of advanced navigation and communication technologies to transit system operations. APTS applications can assist transit system managers provide timely accurate information on transit services to transit passengers, and improve the efficiency, reliability and safety of the service.

APTS applications are often summarized into three categories:

- Smart traveler technology, which focuses on the provision of basic user information to transit users before they make decisions on how they will make a particular trip. An important objective is to make real-time information available through the use of advanced computer and communications technology.

- Smart vehicle technology, which involves the integration of various vehicle-based technologies to improve vehicle and fleet planning, scheduling and operations.

- Smart intermodal systems, which combine APTS technologies with traffic management and other non-transit applications. The objective is to create multi-modal transportation networks to optimize the transportation system as a whole

Many APTS technologies exist. The most popular APTS applications are·

- Automatic Vehicle Location (AVL) and Computer Aided Dispatch (CAD). AVL utilizes one of several technologies to determine the location of transit vehicles and relate this location information to scheduled location and time. Through specialized data processing and communications, this information is integrated with CAD to achieve improved operations control and management. AVL is the APTS technology with the most applications throughout the industry.

- Smart Cards These are personal debit cards that can be used for payment media for other modes and parking lots, as well as transit fares

- Automatic Passenger Counting (APC). APC employs devices that keep track of transit patrons as they board and exit vehicles, and relate this activity to a place (the specific transit stop) and time.

- Automatic Stop Annunciation This application provides audio announcements of the next stop, transfer points, areas of interest at stops, and other information useful to transit patrons. Automatic stop annunciation is often used to assist transit system managers meet Americans with Disabilities Act (ADA) regulations regarding the provision of stop information to persons with visual impairments.

- Passenger Information Systems. This area covers a broad range of applications that involve the provision of transit user information in an enhanced manner, including interactive systems and real-time information. APTS projects in this category include interactive kiosks at stops and stations, automated telephone systems and the use of various electronic media, such as cable television.

- Adaptive Traffic Signal Control. This involves providing transit or traffic managers a degree of control over traffic signals by transit vehicles to provide preference over general traffic, thereby reducing transit travel time and improving reliability.

Other examples of the use of technology in transit are not usually regarded as APTS or ITS applications. For example, automated fixed route scheduling systems are not usually included, although these automated management aids can be integrated with AVL systems and passenger information systems resulting in more effective application of these APTS technologies. Automated paratransit scheduling and dispatching systems are categorized as APTS if they employ advanced communications and navigational technologies.

AVL is the most widely used APTS-type application, probably because it is the only one that has been economically justified from a public investment standpoint. AVL's capability to make vehicle scheduling more effective can result in the amortization of AVL's initial cost in three to five years.

In addition, AVL represents infrastructure in that other APTS applications require data from an AVL system. For example, passenger information systems providing real-time service information integrate passenger displays with vehicle locational information from an AVL system.

The linking of APTS technological applications with similar applications relating to traffic management and control has the ability to enhance the operation of both modes, and generate greater benefits for transit passengers and automobile users.

Transit related ITS user services identified by representatives of the metropolitan area's transit operators as the highest priorities are:

- En-Route Transit Information.

- Public Travel Security
- Public Transportation Management

Ride Matching and Personalized Public Transit user services were identified as medium-high priorities

Several recent studies of public transportation in the Kansas City Metropolitan area have identified a perceived problem among transit users regarding coordination among the three primary operators. Although the KCATA, Johnson County Transit (JCT) and the Kansas City, Kansas, Public Transportation Office have coordinated many aspects of their services, the perception among the public is that it is difficult to travel from Missouri into Kansas, and transfers between buses operated by different service providers are not "user friendly". This perception was one of the significant findings of market research performed recently by the KCATA related to a comprehensive service review. As part of the Long Range Public Transit Planning Study being performed by the Mid-America Regional Council (MARC), the consultant assisting with the project held a transit planning workshop involving representatives of transit providers and municipal governments. The need for improved coordination was a theme expressed by a number of participants in the workshop.

The application of ITS Technology can assist with the task of interagency coordination to provide the public a "seamless" public transportation. However, technology alone cannot make up for ineffective communication or inadequate coordination between operators. Effective application of ITS technology in the public transportation sector requires a high degree of interagency cooperation, as is the case with highway related applications. Key agencies are the three public transportation providers, and the private companies providing scheduled service to the Kansas City International (KCI) Airport.

EN-ROUTE TRANSIT INFORMATION

Although the user service identified by transit agency representatives is termed En-Route Transit Information, it appears the need exists to improve and coordinate all forms of transit user information. A deficiency of accurate, readily available, user information appears to exist, especially for passenger trips that involve travel on services provided by more than a single agency.

Currently, each of the operators maintain separate telephone information services focusing primarily on the provision of service information relative to services operated by the agency. Information is available regarding transfers between systems, but the customer is directed to the other agency's phone information number for specific information. Each of the three public transportation operators distributes printed materials with information on routes, schedules, fares, transfers and other pertinent user information.

An alternative to the current situation would be the establishment of one telephone information system for all transit services in the metropolitan area. Several metropolitan areas served by multiple transit operators have successfully implemented regional telephone information systems. While this approach can be taken without an assist from technology, technology can enhance the operation of the regional transit information center by improving communication among the participating service providers. For example, service data could be made available to information center agents in electronic format for easier retrieval and updating.

Telephone information systems are very labor intensive and represent a significant operating cost. Budget limitations result in limited information services, in terms of the number of agents available to take calls, hours operation and days of operation. Technology is available to automate telephone information systems, making them more efficient and potentially reducing costs. A number of commercially available systems exist, ranging from automated tools to assist information agents, to full automation.

The majority of calls that are made to transit information centers are for simple schedule information, such as the scheduled time of the next bus on a specific route. These calls can be readily answered through a caller select key pad based system, or "audiotext". Areas that have used automated systems also maintain traditional information systems with agents who can address more complex requests for information involving transfers among routes, and other matters not readily addressed by automated responses.

The KCATA is in the preliminary stage of acquiring a system to automate the telephone information function. This project would include the acquisition of software to automate KCATA's scheduling and related functions.

An advanced traveler information system (ATIS), such as the one in place in the Boston metropolitan area, would provide information for highways as well as transit. An ATIS would be capable of providing the comprehensive transit user data desired by the public, but such a system would require transit operators to provide information in some type of electronic format for use by the ATIS.

User information can be provided en-route in a number of different ways. Several APTS operational tests have assessed the use of electronic kiosks at transit stops or high activity areas near transit stops. These interactive devices allow access to transit information while the user is making the trip. The results of these tests have been inconclusive. Other operational tests have explored the use of electronic signs and displays at stops with the capability of providing real-time information (e.g., through interconnection with an AVL system) or messages controlled by dispatchers (e.g., in the event of service interruptions or reroutes). These tests have also been inconclusive to date.

KCATA has preliminary plans for installing interactive customer information kiosks at the recently opened transit center at 10th and Main Streets in downtown Kansas City.

For the most part, the need for en-route information can be provided through low-tech solutions. For example, static displays of printed transit schedule materials provided at transfer locations can assist transit customers as they transfer from one route (or system) to another. Public telephones, or dedicated information center phones, located at bus stops and transfer centers can provide the important link between the customer and information needed to complete a trip.

PUBLIC TRAVEL SECURITY

Increasingly, concerns about security appear to be having a negative affect on transit's ability to attract and maintain customers. This concern was highlighted by the market research performed by KCATA.

Public travel security can be addressed through technology applications in several ways. AVL technology allows transit dispatchers to direct supervisory and law enforcement personnel quicker in response to incidents reported by bus drivers, often using a silent alarm feature KCATA dispatchers estimate that AVL reduces response time by up to half.

Electronic video and audio monitoring is increasingly being used to monitor activity on-board buses. Two-way radio systems used by transit operators can be equipped with covert microphones that are activated when a silent alarm is engaged Conversations between the bus driver, passengers and persons causing disruptions can be monitored and used by dispatch personnel in responding to an incident. KCATA's communication system does have a silent alarm feature to allow bus drivers to covertly alert dispatchers of trouble on-board buses. It may be possible to modify the communication system's controls to add a covert microphone to provide the on-board audio monitoring feature.

Some transit systems in other metropolitan areas use video cameras mounted in the interior of buses. Typically the video is not monitored. Instead, the video is recorded, saved and can be monitored at a later time if an incident occurred on the bus. The video cameras have been deployed as a deterrent, but have allowed authorities to identify individuals responsible for criminal offenses, as well.

Video monitoring can also be used to monitor activity at transit stations and bus stops, and at facilities such as park-and-ride lots. With the large number of bus stops maintained by urban transit systems (5,000 to 10,000 individual stops) video monitoring is practical only at heavily used bus stops, such as transfer locations and downtown area stops. Video cameras used in this manner usually require monitoring by security personnel, adding to operating expense.

Whether or not ITS applications are used, coordination between transit agency dispatch centers and law enforcement control centers is a requirement for improved public travel security. Coordination including standard operating procedures, mutually accepted agency and individual roles, and improved communications between dispatch personnel.

PUBLIC TRANSPORTATION MANAGEMENT

Public transportation management, a high priority among transit operators in the metropolitan area, can include a large number of applications. Generally, technology applications that have the potential to reduce costs, improve service, and address specific problems or objectives in the Kansas City metropolitan area should be considered.

During the past year the KCATA has been working on a project to restore the capability of the Automatic Vehicle Locator (AVL) system initially installed in 1989. In November, 1995, KCATA's Board of Commissioners approved a contract with a local electronics firm to replace failed hardware. The contractor anticipates completion of the project by September 1996.

This is an important because KCATA's AVL system has been recognized by ITS America as one of the best examples of ITS technology applied to transit system management In addition to producing benefits itself, AVL represents technological infrastructure that can be built upon with other applications to produce even greater benefits.

KCATA has recently acquired an automated system to assist with scheduling and dispatching for KCATA's paratransit service, Share-a-Fare. In addition, KCATA is in the process of acquiring an automated scheduling system for their fixed route services. This system may include the automation of materials for the telephone information system.

Beyond these efforts, a number of other opportunities exist in the general area of public transportation management improvements.

Coordinated Dispatch - Each of the transit operators in the metropolitan area maintain separate dispatch facilities for their operations. All revenue vehicles and service vehicles are radio equipped. However, communication among the four separate dispatch centers is limited to telephone communication on an as needed basis. This contact is initiated at the discretion of dispatch personnel.

KCATA upgraded their dispatch capability in 1989 with the addition of CAD and AVL. KCATA experienced significant benefits from the AVL system, including a 12 percent improvement in on time performance, and productivity improvements in the form of a reduction in the number of buses required to operate a given service level. This resulted in the savings of several hundred thousand dollars annually. AVL and CAD applications may not be warranted for the smaller transit operators due to the relatively high initial cost and the nature of the service currently provided.

It would be possible to include buses operated by JCT and KCK in KCATA's AVL system, however, each bus would have to be equipped with the required communications and location monitoring equipment, and dispatch center equipment would have to be acquired to use the location data for dispatch purposes. A careful evaluation of the costs, benefits, and technological and institutional questions would be required.

However, some benefit may be realized simply by formalizing and improving communications between transit operators using readily available technology. For example, transfer connections between buses operated by the different transit systems could be made more reliable through coordinated dispatch.

Communication among various dispatch centers could be enhanced through the establishment of dedicated phone lines, along with standard operating procedures. Some type of improved communication among transit dispatch centers would be required to insure effective coordination between transit and the highway TOC.

Paratransit Scheduling and Dispatching - Another opportunity to use technology to improve public transportation management is in paratransit scheduling and dispatching. Various forms of paratransit services for elderly and disabled persons are provided by multiple operators in the metropolitan area. Little coordination exists among various operators, and overlapping service areas and a diversity of eligibility requirements results in confusion among users and potential users. This lack of coordination has been cited as a problem in recent studies of public transportation in the metropolitan area Coordination and even consolidation of public information, reservation, scheduling and dispatch functions holds potential for significant improvements in service from the public's perspective.

Paratransit services are much less productive in terms of passengers carried per hour, compared with traditional fixed route transit service. This low productivity is a result of the tailored nature of the service. Typically each passenger trip is individually reserved and scheduled. The number of trips per hour is a key variable in the cost of these demand responsive paratransit services. Currently, tasks associated with accepting trip reservations from the public, scheduling these trips to available vehicles and dispatching the vehicles is performed manually, with little or no automated support. Experience from other metropolitan areas has shown that automation of these tasks can result in significant improvements in the productivity of demand response paratransit systems. For example, one large operator of demand response service in the St. Louis metropolitan area reported a 75 percent increase in productivity, measured in passengers per mile, after implementing a fully automated scheduling and dispatch system.

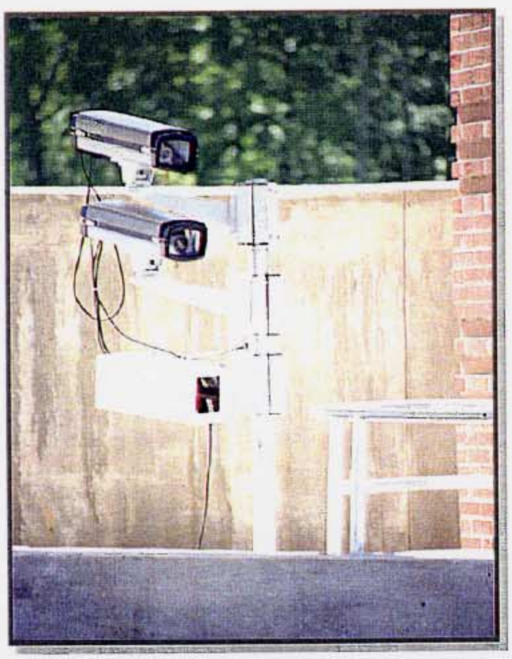
Political, institutional and operational barriers exist, but the technology exists to assist with the coordination of paratransit services in the metropolitan area. The automated scheduling and dispatching system recently acquired by the KCATA may have the capability to allow multiple paratransit operators access reservation, scheduling and dispatching capabilities Conceivably, the desired coordination of services and user information could be facilitated through the joint use of the paratransit scheduling and dispatching system.

The Americans with Disabilities Act (ADA) requires greater cooperation among paratransit operators to provide for inter-jurisdictional trips that were previously very difficult due to the limitations placed on paratransit users by services largely confined to a single jurisdiction. Conceivably, these inter-jurisdictional trips can initially be scheduled by the KCATA's automated system, with wider use throughout the metropolitan area in the future.

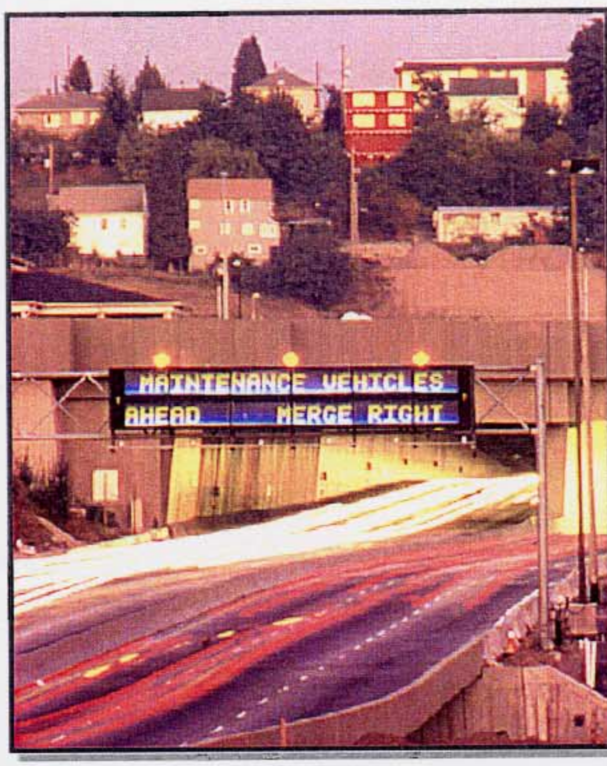
Personalized Public Transit - KCATA has implemented two MetroFlex routes in recent years, representing limited entry into the provision of alternative transit services tailored to suburban markets. JCT operates one route offering route deviation as a means to better serve dispersed trip origins. The difficulty in providing these types of services is the increased scheduling and dispatching tasks required to support the personalized nature of the service. KCATA's paratransit scheduling and dispatch system should have the capability of supporting MetroFlex-type services for the general public, as well as specialized paratransit service for elderly and disabled persons. Thus, such services could be deployed in more parts of the metropolitan area without the added operating cost for additional dispatch personnel.

Electronic Toll Collection (ETC)

Ramp Metering



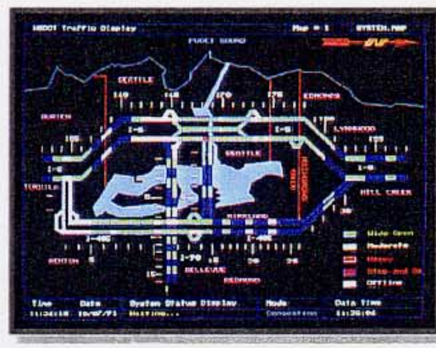
Closed Circuit Television Camera (CCTV)



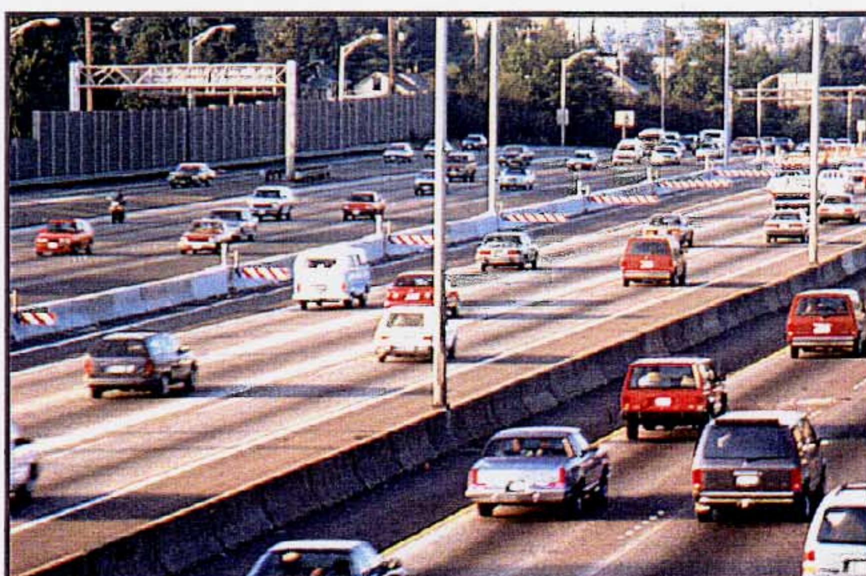
Variable Message Sign (VMS)

Figure 5-1. Examples of ITS Technologies and Applications

Traffic Operations Center (TOC)



Map of Freeway Speeds on the Internet



Reversible High Occupancy Vehicle (HOV) Lanes

Figure 5-1. Examples of ITS Technologies and Applications (Continued)

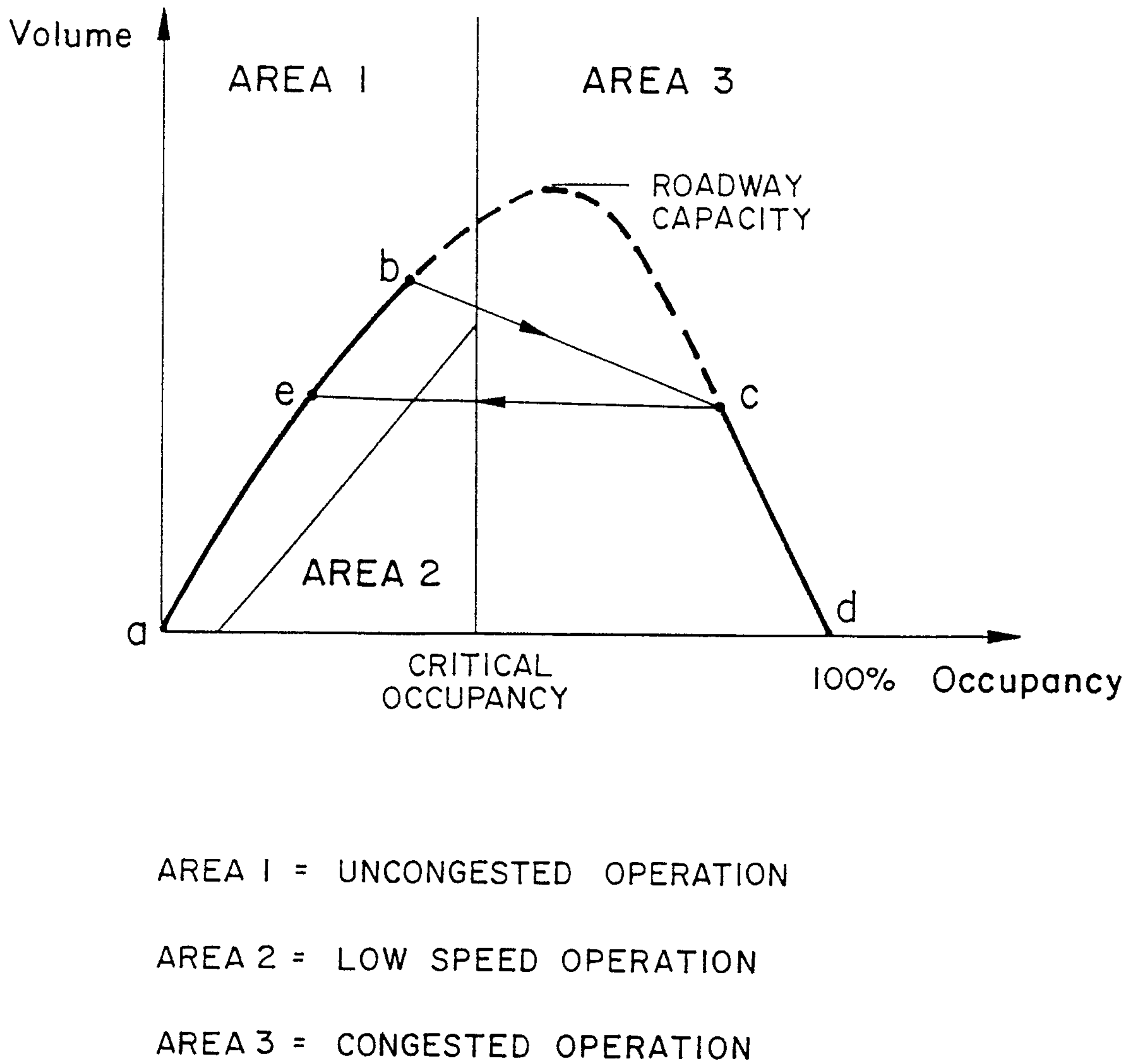


Figure 5-2. Fundamental Volume-Occupancy Relationship