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Chapter 5

Technology Alternatives

5.1 INTRODUCTION

Surveillance technologies include vehicle detection technologies, closed circuit television (CCTV) and technologies for electronic toll collection (ETC). Vehicle detection technologies include both passive and active technologies. Passive technologies are those that do not require specially equipped vehicles to operate. Passive technologies include standard technologies such as induction loops, microwave detectors as well as newer technologies such as video detectors. Active technologies include automatic vehicle location (AVL) and automatic vehicle identification (AVI), as well as transponders for ETC.

Communications technologies include fiber optics, which is expected to become the primary medium for communications in Wichita. Other technologies that are discussed within this chapter will potentially be used for the initial system and in areas where fiber optics have not been installed.

Traveler interface technologies are critical since they allow the public to make informed decisions in their travel routes. These technologies include variable message signs (VMS), highway advisory radio (HAR) transmitters, information kiosks, and dial-in information systems such as traveler advisory telephone systems.

Data processing technologies are used to process the data collected by the detectors, such as volume, occupancy, speed and vehicle classification. This also includes incident detection algorithms which are used to analyze the data to identify incidents. However, agencies are finding that cellular call-ins regarding accidents are outpacing the incident detection algorithms.

Public transportation technologies assist public transportation agencies in improving their efficiency, reliability, and safety as well as providing accurate and timely information on transit services to passengers.

This chapter also presents various strategies of using these technologies effectively. These strategies 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. This leads into the potential improvement recommendations in the last part of this chapter.

5.2 SURVEILLANCE TECHNOLOGIES

The ultimate success of a traffic management system is largely dependent on the quantity, timeliness and accuracy of information that it is able to collect. The ability to carry out the functions of incident management and the dissemination of motorist information will be based entirely on this information. For the system to be effective and to achieve public acceptance, it is important that this information be accurate, timely, and easily accessible by the users of Wichita's roadways.

There are a number of ways in which the traffic management system can monitor the roadways, collect the information necessary to function properly, and carry out the objectives of the system.

Some methods of monitoring rely on technology, and the instrumentation of the roadway with monitoring devices such as cameras or vehicle detectors, while others, such as call-ins from motorists using cellular telephones, provide more anecdotal information based on driver observations.

Vehicle Detection

Roadside vehicle detection is the most frequently used method of traffic monitoring throughout the country. Vehicle detector data can be used in a variety of ways. The most important of these is the packaging of this data for system operators and emergency responders and for distribution to the general public. In most systems, vehicle detector data is presented in a color-coded graphical map of the roadway system, with segments of the roadways colored green, yellow, or red to indicate free flowing, moderately congested, or heavily congested roadway conditions.

Detection Technologies

Monitoring traffic flow on a real-time basis (at least every 20 seconds) is a key component to monitoring the roadway system for incident detection and provides the basis for effective management to optimize the efficiency and operational safety of the roadways. Over the past 10 years, numerous technologies for detecting vehicles have been developed, tested and deployed in the field. Considerable experience in the real world effectiveness of these various technologies has been accumulated, and provides the basis for the following evaluation. Two sets of controlled field tests of various detector technologies have recently been performed for the Federal Highway Administration (FHWA). One test was performed by the Hughes Aircraft Company and the other was performed by the Minnesota Guidestar program.

Inductive Loop Detectors

An inductive loop detector consists of two components: a loop of wire (two to four turns) embedded in the pavement, and an electronics module (commonly called a loop amplifier) that is mounted in a cabinet on the roadside. The loop embedded in the road is connected to the electronics module by a two conductor cable, typically installed in buried conduit from the shoulder of the road to the equipment cabinet. A vehicle passing over, or resting in, the electromagnetic field created by the loop changes the resonant frequency of a tuned circuit, which is recognized by the electronics module. The electronics module closes a "relay contact", which is monitored by a computer which converts the contact closure to vehicle counts and occupancy. Speed measurement with inductive loop detectors is obtained by measuring the elapsed time a vehicle takes to traverse two consecutive loops spaced apart by a known distance (typically about 20 feet).

On existing roadways, loops are installed by saw cutting a two (2) to three (3) inch deep groove in the roadway surface, cleaning the groove, installing the two to four turns of wire, and sealing the saw cut with "caulking compound" designed specifically for this application. The traditional saw cut technique has used a saw that cuts a straight line, forming a rectangular or octagonal groove for the wire. A recent innovation has utilized a circular "hole saw" about six feet in diameter to cut a groove for a circular loop detector; the benefit being the increased speed of cutting the groove.

For roadways that are under construction, loops that are encased in plastic conduit can be embedded in the roadway during the concrete pour, a technique used for the installation of loops on bridges. A related technique is used when a road is being resurfaced, and existing layers of paving material are ground off. The loop is saw cut into the ground down base layer, and new paving applied over the loop to encapsulate it.

Advantages: Inductive loops are a proven, versatile technology that have been in use for over 30 years, having been originally developed for vehicle sensing for arterial controllers. They are the primary method of traffic detection in Wichita for the traffic signal system and are used for the existing freeway traffic count stations. Inductive loops (either singly or in a pair) can provide all traffic parameters (count, occupancy, speed, vehicle length) required by a traffic management system. Loops have the highest accuracy of the currently available technologies, and are the baseline against which other technologies are compared.

Disadvantages: For installation in existing roadways, saw cutting requires that one, or several, traffic lanes be shut down for the duration of the installation. This can amount to several hours at a given location. Repair of a damaged loop similarly requires shutting down the lane(s) to saw cut a new loop. For bridge structures such as the section of I-135 between the Kellogg Expressway and 21st Street, in which the steel re-bar is close to the pavement surface, the saw cutting of a groove is not permissible since it will damage the structural integrity of the deck.

Experience in some locations has suggested that loops are not reliable, but in most cases that has been attributed to poor pavement which results in breakage of the loop wire, or to poor design or installation. Areas with freeze-thaw cycles, or other adverse weather conditions, exacerbate these conditions and lead to a higher loop failure rate. These problems are not an inherent deficiency in the technology itself, but evidence an improper application of the technology.

Magnetometers

Magnetometers detect a change in the vertical component of the earth's magnetic field caused by the presence or passage of a vehicle over a magnetic probe. When a vehicle passes over the probe, a voltage change causes the closure of an output relay.

Advantages: Magnetometers can be installed in a relatively small area, such as required in between the rebar of a bridge deck, or on a severely deteriorated roadway. Also, because the probes are buried several inches below the surface of the pavement, magnetometers are less susceptible than loops to deteriorating pavement conditions. Therefore, magnetometers are primarily used in northern states that suffer pavement deterioration due to freeze-thaw cycles.

Disadvantages: Although magnetometers are a proven technology, unlike inductive loops or micro-loops (described below), probes and sensor units from magnetometers are not interchangeable among different manufacturers.

Micro-Loops

Like magnetometers, micro-loops also detect a change in the vertical component of the earth's magnetic field caused by the presence or passage of a vehicle over a small probe. The difference is that they translate this change into inductance that a standard loop sensor unit can detect. This allows micro-loops to be connected in series with standard loop detectors.

Microwave Radar

Microwave radar detectors have been used in both law enforcement and traffic management for several years to monitor vehicle speed. For traffic management, radar detectors are mounted either above or beside the road and direct a beam of microwave energy onto a detection area.

Most radar detectors transmit electromagnetic energy at the K-band (24 GHz) or the X-band (10 GHz). The form of the electromagnetic wave transmitted by the detector determines the type of data that can be obtained by the unit. Two types of microwave radar detectors have been used for traffic management systems in the past, including continuous wave and frequency modulated continuous wave (FMCW) detectors. Continuous wave detectors are commonly used by law enforcement, and use the Doppler effect to measure vehicle speed. However, continuous wave detectors are unable to measure very slow moving or stationary vehicles, which is when detector information is the most critical. In the congested areas, where speeds are expected to often fall below five miles per hour (mph), these detectors will not accurately reflect the traffic characteristics of the roadway.

FMCW microwave radar detectors, and other detectors using variations of the FMCW waveform, have the capability to measure both presence and speed for stationary and moving vehicles. They can be mounted in either a forward-looking configuration (one detector mounted over each lane), or in a side-fire configuration (one detector mounted at the side of the roadway looking across all lanes). Studies performed by Hughes Aircraft Company for the FHWA[1] indicate the forward-looking configuration yields more accurate results, however, the side-fire configuration may be adequate for its purpose in traffic management systems, depending on the number of lanes to be covered and the percentage of trucks on various segments of the project roadways.

Advantages: One of the biggest advantages of microwave radar detectors is their ability to perform adequately in all weather conditions. Maintenance costs of radar detectors have also proven to be relatively low. One study showed only a two percent failure rate for radar detectors over two years. This compares with a 34 percent failure rate of loop detectors over a five-year period. Costs are also kept lower because maintenance of the detectors typically does not require lane closures.

Disadvantages: For microwave detectors mounted in the side-fire configuration, vehicles in the far lanes can sometimes be occluded, or blocked, by large trucks passing by the detector in the near lane. The effects of occlusion typically result in a drop in detection accuracy of approximately five percent, depending on the percentage of trucks in the vehicle stream and the number of lanes to be detected. The effects of occlusion can be eliminated by mounting microwave detectors over the roadway, however this would require one detector per lane, increasing the cost of a single detector station significantly.

Ultrasonic Detectors

Ultrasonic detectors used for vehicle detection emit sound waves with frequencies between 20 KHz and 200 KHz, which are above the human audible range. They are pressure waves which are propagated through the air and travel at about 740 mph at sea level. Ultrasonic detectors generally transmit pulse and continuous wave energy, and use signal processing techniques analogous to those for microwave radar.

Advantages: Ultrasonic detectors can be mounted in either the side-fire or overhead position to provide single lane or multi-lane coverage.

Disadvantages: Because the ultrasonic waves are propagated through the air, ultrasonic detectors are subject to attenuation and distortion from a number of environment factors including changes

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[1] *Evaluation of Traffic Detection Technologies for IVHS,* Lawrence A Klein, Micheal R. Kelley, Milton K. Mills, SPIE Vol. 2344 Intelligent Vehicle Highway Systems, 1994

in ambient temperature, air turbulence, and humidity. These detectors also did not perform well in the Hughes studies[1].

Active Infrared Detectors

Active infrared (IR) detectors use a laser or light emitting diode (LED) to transmit electromagnetic energy in the near infrared spectrum. They operate similar to microwave radar, but transmit energy at higher frequencies (shorter wavelengths). They detect a portion of the energy reflected from objects in their field of view.

Advantages: Active IR detectors can be mounted in either the side-fire or overhead position, but because of their short range are suitable only for single lane detection. Overhead installation is required for vehicle classification.

Disadvantages: Active IR detectors are vulnerable to fog, mist, and rain which can scatter and attenuate the energy. The alignment of the detector is difficult to maintain on vibrating structures, which means they would be unsuitable for installation on overpasses.

Passive Infrared Detectors

Passive IR detectors do not transmit energy themselves, but rather measure the energy emitted by objects in their field of view. The amount of energy emitted is a function of the physical characteristics of the vehicle and its temperature. By measuring the difference in emitted energy between the road and the vehicles, vehicle presence and passage can be detected.

Advantages: Passive IR detectors can be mounted in either the side-fire or overhead position to provide single lane or multi-lane coverage.

Disadvantages: Passive IR detectors can be affected by fog and precipitation which scatter and emit energy of their own.

Video Image Detectors (VIDs)

Video image detectors (sometimes referred to as machine vision systems) are comprised of fixed CCTV cameras aimed at the roadway, coupled with a processor that analyzes the video images to detect vehicles that pass through the camera's field of view. VIDs can collect volume, occupancy, speed, and vehicle length over multiple detection zones covering several lanes. More advanced VIDs can also use features derived from the video images to classify and track vehicles.

VID cameras can be mounted at the side of the road covering both directions of traffic if the mounting height is up around 45 to 50 feet. For lower mounting heights around 20 to 25 feet, the cameras need to be mounted in the median, or on an overpass.

Advantages: VIDs have proven to be a reliable and accurate form of detection over the past several years and have gained considerable acceptance among public agencies across the country. Compared to other detector technologies, video detectors cover a much larger area from a single detection point, and offer the potential to perform incident detection and other advanced operations such as vehicle tracking and travel time calculation.

Disadvantages: Some video detectors may not measure occupancy well at dusk or during periods when weather reduces visibility. Vehicle shadows can sometimes cause over-counting.

Acoustic Detectors

Acoustic detectors use an array of small microphones and audio signal processing technology to "listen" for passing vehicles. The sensors "hear" sounds from vehicle engines, tires and transmissions. The acoustic technology used by these detectors was originally developed for military defense purposes, such as tracking enemy submarines. Acoustic detectors are capable of measuring volume, occupancy, speed, and can even provide limited classification information.

Advantages: Acoustic detectors can be mounted in either the side-fire or overhead position to provide single lane or multi-lane coverage. The manufacturer claims the performance of the detector is unaffected by rain, snow, fog, temperature, humidity or light conditions.

Disadvantages: Acoustic detectors can only detect vehicles separated by 10 feet or more, and cannot detect stationary vehicles.

CCTV Surveillance

CCTV cameras provide the eyes for the operator at the traffic operations center, 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. One agency has reported the installation of a spare optical fiber to each intersection so that they can install a CCTV camera on an as-needed basis during trouble shooting and problem isolation. This saves them many trips to the site when they are trying to correct intermittent failures.
- Utilizing the CCTV camera to monitor adjacent parallel streets to a freeway to determine current operating conditions. This allows verification that the arterial streets have adequate vehicle capacity to handle added traffic prior to implementing a freeway diversion plan. Monitoring of the operation of the streets during the diversion to insure successful operation is also available.
- Monitoring motorist response and traffic movements on the mainline and entrance and exit ramps. In some cities, CCTV is also used to verify compliance with ramp metering or HOV restrictions, or observance and response to messages posted on a VMS or transmitted on HAR.

CCTV cameras, lenses and typical mounting heights (40 to 50 feet above the roadway surface) allow monitoring of roughly one-half 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 problem to overcome with CCTV is the transmission of the image from the camera location to the control center. Full motion 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 (every 1/30 sec), 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 between each CCTV camera and a multiplexing hub. With 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

CCTV cameras used for freeway surveillance systems have several basic characteristics that determine how they perform, and are dependent on the specific purpose for which they are used, and the environment in which they are deployed. A few of the rudimentary camera design parameters examined here include color versus black-and-white cameras, and digital versus analog cameras.

Color Versus Black-and-White

One of the most basic design decisions required in surveillance systems has traditionally been whether to use color or black-and-white cameras. Color cameras are more visually pleasing for operators to view, and they offer additional capabilities for incident management. With color cameras, operators are better able to analyze a crash scene, and are able to distinguish vehicle colors, colors of flashing lights (thereby distinguishing emergency from non-emergency vehicles), characteristics of cargo spills, and the colors of nearby roadway signing.

On the other hand, black-and-white cameras have the singular advantage of extreme sensitivity under low light conditions. This sensitivity allows black-and-white cameras to generate a clearer and more detailed image during nighttime operations. For many years, color cameras had markedly inferior nighttime performance, and on unlit or poorly lit roadways, black-and-white cameras were used exclusively. However, with recent advances in image sensor technology, nighttime performance of color cameras has gotten closer to that of black-and-white cameras. This, coupled with the fact that most operators simply prefer to view color images, has led to widespread use of color cameras in surveillance systems today.

Black-and-white cameras are still used when ambient roadway light levels are very low. In fact, one manufacturer has developed a dual camera configuration that uses a color camera during the day, and then using a photoelectric cell, automatically switches to a black-and-white camera for nighttime viewing. The two cameras are contained within a single environmental housing, and pan and tilt as a single unit. This "dual-headed" camera configuration offers the best attributes of both color and black-and-white cameras.

Digital Versus Analog

Digital Signal Processing (DSP) cameras began to enter the freeway surveillance market in 1994, and are now a viable alternative to the analog cameras. The major benefit of DSP camera technology is the minimization of analog circuitry which is susceptible to adding noise to the video signal. Firmware within the DSP camera replaces discrete components, and allows the application of image enhancements and remote parameter adjustment. This component reduction can potentially improve reliability, and results in smaller and lighter weight cameras that consume less power. Correspondingly, these cameras require smaller housings that use smaller and more inexpensive pan and tilt motors.

Zoom Lens

Freeway surveillance cameras are typically equipped with a motorized zoom lens that allows operators to view images some distance from the camera. The most common zoom lens power for traffic surveillance is a 10:1 ratio. Most cameras with a 10:1 zoom and adequate mounting height have a viewing range of 0.5 miles in all directions. Full coverage of the roadways would therefore require a nominal camera spacing of about one mile.

Camera Housing

To protect roadside cameras from rain, dirt, dust, heat, and wind, they are installed in an environmental enclosure. A variety of enclosures are available, each with several options including windshield wipers, defoggers, and sunshields. Most of the camera installations also include pressurized housings Pressurized housings offer improved resistance to the elements by completely sealing the housing and pressurizing it with dry nitrogen, thereby keeping air particulates and pollutants from contaminating the camera assembly. Pressurized housings from some manufacturers offer the ability to monitor the pressure level in the housing remotely from a control center. This feature cuts down on the number of periodic maintenance checks required to keep all housings at the proper pressure level.

Camera housings are typically mounted on "pan-tilt" units to enable operators to position the camera for a variety of roadway views. The most common pan-tilt units for roadway surveillance cameras are slow moving, heavy duty units that are designed to accommodate the relatively large weight of a fully loaded camera housing. A new type of housing recently introduced for traffic surveillance systems is the "dome" housing. Dome housings have been used for years in the security industry, and are now gaining popularity for freeway installations.

Dome housings allow the camera to pan and tilt inside the housing, as opposed to traditional pan/tilt units that move the entire housing to position the camera. Because there is significantly less weight to be moved by the pan/tilt mechanism, DC servo or stepper drive motors can be used instead of the larger AC motors employed by traditional pan/tilt units. The smaller DC motors are capable of faster pan speeds and more accurate and drift-free positioning of the camera.

The disadvantage to dome housings is that, because of the camera orientation inside the dome, they must be cantilevered off of their support pole. In Wichita, where high wind speeds are encountered, the moment force created by the cantilevered configuration will result in excess vibration in the housing at the top of the pole and will have a corresponding effect on video images.

CCTV System Control

Functions

Historically, CCTV equipment manufacturers have developed proprietary control protocols to control the pan/tilt/zoom/focus (PTZF) features of their cameras. This has led to incompatibilities between different products, and difficulties in integrating and interoperating products from several vendors. In order to solve this problem, the FHWA, in cooperation with other agencies and the ITS industry, has developed the National Transportation Communications ITS Protocol (NTCIP). The protocol for VMS's has been approved, while the protocols for other ITS elements are in the draft stage.

Organizational issues will need to be addressed. With the different agencies that require CCTV access (i.e., fire, police, EMS.), the priority of control access will need to be resolved. Some agencies have utilized a matrix in which each organization will be granted a range of privileges (from "View Only" to "Full PTZF Control", with a series of gradations between the limits) that will enable and/or limit what CCTV actions an individual system user can perform. These privileges can be assigned when a user logs on to the system, based upon their organization, rank within the organization and other operational policies. Typical operation of a privilege system of this type allows a user with "higher" privilege to override control of a camera currently being used by another user and to retain control of that camera for a minimum time-out period.

Features

Besides implementing control functions that activate motors to pan, tilt, or zoom the camera, camera controllers offer several additional features including presets, titling, and position feedback.

Presets allow an operator to pre-program specific camera views that are of interest, such as a variable message sign or a high accident location. With a single touch of a button, or click of a mouse, the camera automatically pans and tilts to the specified position.

A titling feature can be used to overlay text characters directly on the video image that describe the location of the camera. This would allow the operators to easily identify a particular camera location that they are viewing..

A position feedback feature provides the operator with even more information about the image being viewed by reporting the actual direction in which the camera is pointed. This information also appears as a text overlay on the video image.

Communication Requirements

Since video requires much more bandwidth than camera control functions, the video frequently becomes the dominant factor in the communications design for CCTV systems. Control communications require a separate bi-directional low-speed RS-232 or RS-422 channel. Control communications are typically point-to-point, in contrast to the multipoint communications used by most detection systems.

Video Image Transmission

Video images from roadside cameras may be transmitted to the control center using either full motion or compressed video. Using full motion video, real-time video is transmitted at a rate of 30 frames per second. This transmission option results in no information loss; however, it requires a large communication bandwidth (4.2 MHz analog, and nearly 45 Mbps digitized). The large bandwidth requirements of full motion video typically require the installation of dedicated fiber optic or coaxial cable.

In areas where it may not be cost effective to install the cable and conduit required for full motion video, compressed video offers an attractive alternative. Compression allows transmission of a full motion digitized video signal at rates as low as 56 Kbps, although such low rates may result in noticeable video quality degradation. The rates and formats of commercially available video compression equipment have been compatible with digital hierarchy standards, and therefore can be transmitted by telecommunication service providers.

Video compression techniques take advantage of data redundancy and human visual limitations to reduce the transmission bandwidth required to transport video signals. One of the more popular coding techniques, interframe coding, eliminates redundancy between successive frames of video images by transmitting only the parts of the image that change from frame to frame. This technique is very effective for traffic surveillance, because the only part of the image that changes is the vehicles as they pass through the camera's view. The majority of the traffic surveillance image remains the same from frame to frame.

Compression also reduces frame rates, and because some information is lost between picture frames, the resulting image may appear slightly "jerky". The image, however, may be more than adequate for the purposes of the traffic monitoring and incident management required for the traffic management system.

Standard cameras, monitors, and control hardware can be used with video compression, and therefore, can be reused in the future if the communications medium is upgraded to allow for full motion video transmission.

Camera Pole

Camera pole heights generally vary from 25 to 50 feet. Fifty-foot poles are preferred by most agencies because of the unobstructed views and increased viewing distance they provide. Shorter pole heights are typically used to save on the cost of the structure itself, or when the agency does not have a bucket truck tall enough to reach a 45- or 50-foot pole.

A few alternative pole types and camera mounting configurations allow for servicing of the camera from ground level, rather than from the top of the pole. These include tilt-down poles, climbing poles, and camera lowering systems. Tilt-down poles have a hinged joint that allows the pole to tilt over, bringing the top of the pole down to ground level for service. These poles are more expensive than standard poles, and require a substantial area adjacent to it in order to tilt.

Climbing poles have rungs installed from about 10 feet above ground level to the top of the pole, and allow a technician to climb the pole without the assistance of a bucket truck. Climbing poles typically have a safety cable installed down the side of the pole to which the technician clips the safety harness. These poles also have a maintenance platform at the top that allow the technician to move around the camera assembly once he reaches the top.

Camera lowering systems use a fixed pole and lower the camera assembly to the ground using a steel cable. The technology for camera lowering systems is similar to that commonly used to lower high mast lighting. This configuration is also more expensive than a standard pole arrangement and the slip connector that powers and controls the camera may be sensitive to corrosion.

Video Switching/Distribution

A key component of the CCTV system is the video switch that allows any CCTV camera to be viewed on any monitor and at any physical location that has access to the CCTV system. A variety of switch configurations are available, from fully centralized to fully distributed.

Some larger systems employ field switching systems at locations where several video signals are concentrated. This distributed switching arrangement reduces the number of images that are sent to the control center at any given time, thus reducing the transmission bandwidth required.

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 communications. Since the cost of these switches does not increase with the number of inputs and outputs, they have the potential to be cost effective for larger systems. However, because of the high bandwidth and transmission speeds required, these devices are still more expensive than comparable analog switches.

Digital switches and other digital distribution equipment have the added advantage of not adding any noise or loss to the video signal as it is received and distributed throughout the system. For images that are received and distributed several times a noticeable improvement in the quality of the video images can be realized from digital video distribution.

Sharing video information among various agencies will help to facilitate incident management, allowing more than one agency to be involved in responding to and clearing incidents. The video images will help dispatch personnel to identify exactly what emergency services are required, and can prepare emergency personnel for what they will encounter at the incident scene, thus making the response more efficient.

In addition to facilitating incident response, video images can be distributed for the purpose of providing pre-trip motorist information. For this purpose, video images may be sent to local news media to a dedicated cable channel. Also, freeze-frame digitized video images could be transmitted directly to motorists via the Internet.

Cellular Phone Call-Ins

Motorists using cellular telephones can call in valuable incident information and can potentially serve as vehicle probes providing general traffic information and travel times.

Capital, operating, and maintenance costs of this system are relatively low and the benefits are generally high. Cellular call-ins do not require any roadway infrastructure. The only facilities required are the equipment and staffing to receive the calls, and additional mile markers to help motorists locate the incident.

Other traffic management systems have used cellular incident reporting with great success. In fact, it is estimated that half of all incidents are reported via cellular telephones. To increase the effectiveness of the system, a campaign to inform drivers about the cellular call-in system and the benefits of reporting an incident is also recommended. Roadside signing can also be used for this purpose.

Vehicle Probes

With the recent advances in computer, communications and vehicle locating technologies, the vehicle itself can become a potential monitoring tool for traffic conditions on the project roadways. Vehicles, acting as moving sensors (or probes), can provide information about traffic conditions on each link traversed. This information can be transmitted to the control center where it can then be merged with information from other sources to provide an accurate representation of actual travel conditions on the project roadways. One advantage of probes over other traffic monitoring devices is that in addition to collecting volume and occupancy, individual link travel times and origins/destinations of specific vehicles can be determined.

Emerging technologies that utilize vehicles as probes include automatic vehicle identification (AVI) and automatic vehicle location (AVL).

Automatic Vehicle Identification (AVI)

AVI systems permit individual vehicles to be uniquely identified as they pass through a detection area. Although there are several different types of AVI systems, they all operate using the same general principles. A roadside communication unit broadcasts an interrogation signal from its antenna. When an AVI-equipped vehicle comes within range of the antenna, a transponder (or tag) in the vehicle returns that vehicle's identification number to the roadside unit.

Currently, the most common application of AVI technology is for automatically collecting tolls on tollways, such as the system being used by KTA. In this application, toll charges are electronically deducted from the driver's account when he or she passes through a toll plaza.

AVI technology may also be used as a means of automatically collecting travel time information along freeways. In Houston, Texas, AVI systems have been installed to monitor traffic operations on three major freeways. Vehicles equipped with transponders are used as probes to collect current travel time information. This information is used to alert freeway operators to potential incidents and congestion on both the main lanes and the HOV facilities.

Automatic Vehicle Location (AVL)

In contrast to AVI systems that identify vehicles as they pass a fixed point, AVL systems enable the vehicle's position to be tracked as it traverses the roadway network. AVL systems are comprised of vehicles equipped with locating and tracking devices, and central software that processes the information from vehicles to calculate speeds and link travel times.

There are numerous techniques and technologies than can be used for locating the vehicle, including the following:

- Dead-Reckoning and Map-Matching.
- Signpost.
- Ground-Based Radio Navigation.
- Loran-C.
- Global Positioning Systems (GPS).
- Differential GPS.

5.3 COMMUNICATIONS TECHNOLOGIES

Two primary alternatives are available for system communications; commercial circuits or agency owned circuits. Typical systems use a mix of these alternatives, driven by costs and requirements. Extensive discussions of this topic are provided in literature, in particular the "Communications Handbook for Traffic Control Systems" published by the FHWA in 1993.

Communications technology is 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.

Commercially Owned Facilities

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 (i.e., 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 (2 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 Kbps on dial-up phone lines. These units are inexpensive (about $250), and widely available with numerous features and options. They are extensively used on personal computers for data and fax transmission and are 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 VMS's through dial-up access have been documented. The use of dial-up/dial-back, encryption, security passwords, and other safeguards reduces the risk for these cases, but at the expense of increased system complexity and additional "hassle" for the personnel who have to support and maintain the system.

Digital Carrier

In the mid-1960s, the telephone companies began converting their long-haul trunk circuits from analog technology to digital technology. The basic implementation was the DS-1 (Digital Service 1) channel, operating at 1.544 Mbps. Note that this channel is commonly referred to as a T-l circuit. This T-l 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-l 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-192 (Optical Carrier 192), which operates at 2,488 Mbps, or the equivalent of 32,256 voice grade channels.

Within the past few years, T-l service is becoming 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-l for traffic/incident management systems is digital transmission of video signals. T-l 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.

Integrated Services Digital Network (ISDN)

The technology for ISDN was developed by the telephone industry during the early 1980s, but has seen a very slow implementation. 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 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 $1000-$2000 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. 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. 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.

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 control center. 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 back-bone 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 DDS (DATAPHONE Digital Service) circuits. These circuits are primarily dedicated circuits, but are occasionally available in a switched configuration. A difficulty with these circuits is that they are usually configured as “synchronous” data circuits, while most communications for incident/traffic management systems is “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

Cellular Telephone Service

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. However, the network is moving toward digital transmission, which will obviously increase transmission speeds. Some systems are now offering Cellular Digital Packet Data (CDPD) which is the first step in developing digital cellular communications.

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 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 and weather station controllers 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 Communications

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 2000 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 and cable installation costs can range from $20/foot to $45/foot. This translates to $100,000 to $250,000 per mile. These costs could be higher if structures need to be crossed, roads need to be bored under, etc.

However, 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. To save in trenching costs, conduit may be stacked on top of each other (for example, the New Jersey DOT stacks two 4" rigid non-metallic conduit one on top of the other in a 6 inch wide trench) or buried side by side (Washington State DOT has installed two conduits buried side by side in a 1 foot - 7 inch wide trench, and four conduits in the same size trench, side by side and stacked).

Several agencies also 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.

Twisted Pair Cable

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 back-bone (long haul) circuits to the individual vehicle detector cabinets or variable message signs. Twisted pair works well for speeds up to 28,800 bps for distances of several miles. However, if the system connects numerous nodes, a slower baud rate (approx. 1,200 bps) is suggested for faster synchronization. Twisted pair cable is usually installed in combination with a fiber optic long-haul system to interconnect the field equipment to the communications hub.

Coaxial Cable

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 1/2 mile, image degradation over long cables, and maintenance problems, coaxial cable is no longer recommended for this application.

Microwave

Point-to-point microwave is an attractive alternative for initial, or periodic, transmission of video images from CCTV cameras. Microwave can be utilized for those cases where it is neither technically feasible nor cost effective to install conduit and fiber optic cable. Depending on performance, a microwave system (including 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 implementation, such as 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 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 conditions. A microwave installation must receive a license on a site by site basis from the 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 since 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 6 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, the technological complications will result in increased personnel training and specialization, and more sophisticated equipment.

Fiber Optic Cable

Fiber optic cable is being installed in virtually all new communications systems used for incident/traffic management. Fiber optic cables provide very high data rates (2.5 Gbps) over long distances (over 25 miles) without amplification. Other advantages are the small cable diameters (a 0.5" 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.

Many private telephone and cable television companies are upgrading their systems to fiber optics. This may allow for a public/private partnership for the installation of the fiber optic system in order to reduce the installation and maintenance costs.

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 30 years, and today it is the technology of choice for essentially all new communications systems. Early implementations of fiber optic systems replicated the existing systems that were based on twisted pair, coaxial cable and microwave channels, specifically implementing digital carrier systems at DS-1 and DS-3 transmission rates.

Within the past 10 years, the new SONET standard has been developed. The SONET standard is based upon 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-192 (9,953 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 range of features and capabilities, and very attractive costs. 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: 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 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 bps to 9600 bps) data streams from individual 170 controllers, VMS's, etc. to the much higher data rates of the SONET backbone. This interconnection is performed by devices known as multiplexers/demultiplexers. 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 multiplexers/demultiplexers 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) to link 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, VMS's, 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 $530 per fiber per mile). Similarly, the incremental costs of redundant equipment, when compared to the life-cycle cost of system failures is again quite small.

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

5.4 TRAVELER INTERFACE TECHNOLOGIES

In-Route Motorist Information

Variable Message Signs

One of the most fundamental technologies available for disseminating traffic-related information from the roadside is that of variable message signs (VMS). VMS's are sometimes referred to as changeable message signs (CMS) or dynamic message signs (DMS). VMS's allow agencies to visually disseminate travel information to motorists on a near real-time basis. They are extremely flexible and powerful traffic management tools in traffic operations.

VMS's are typically used for the following purposes:

- Provide specific information relative to the location and delays associated with incidents.
- Advise motorists on detour routes because of construction or roadway closure.
- Suggest alternate routes to avoid congestion.
- Inform motorists of varying traffic, roadway, and environmental conditions.

Types of VMS's

VMS's can be conveniently classified into three categories, light-reflecting, light-emitting, and hybrid.

Light-reflecting signs reflect light from some external source such as the sun, headlights, or overhead lighting. In comparison, light-emitting VMS's generate their own light on or behind the viewing surface. Some manufacturers have combined VMS technologies (e.g., reflective disk and fiber optic) to produce hybrid displays that exhibit the qualities of both. Some agencies have also combined VMS's with static displays to form what can also be considered to be hybrid displays.

Light Reflecting Signs

There are two basic types of light-reflecting signs, including rotating drum and reflective disk matrix signs. Rotating drum signs are made up of one to four multifaced drums, each containing two to six messages. Each face of each drum portrays one line of a fixed message, and pivots about its axis in order to display the appropriate face for a given message. Colors and lettering characteristics that conform to the MUTCD can also be used on rotating drum signs.

Reflective disk matrix signs were very popular for freeway management purposes in the 1970s due to their low energy requirements relative to light-emitting VMS technologies, which at that time were primarily incandescent. The viewing face of a reflective disk matrix VMS is comprised of an array of permanently magnetized, pivoted indicators (pixels) that are flat matte black on one side and reflective yellow or a similar color on the other. The indicators may be square, rectangular, or circular in shape. An electrical current, activated when a given pixel is to be turned, flips the indicator from a black matte side to the reflective side.

The key advantage of this type of sign is the maturity of its technology, and its track record of performance. Another advantage is the continued operation of the sign during a power outage.

Reflective disk signs, with many moving mechanical parts, are subject to sticking disks and other mechanical problems. They also require an aggressive maintenance schedule, and often signs are displayed with random blank pixels, resulting in an unpleasing appearance. Another disadvantage is the limited visibility of the sign when the sun is either directly behind, or shining directly on the face of, the sign.

Light Emitting Signs

Light emitting diode (LED) and fiber optic displays are the two most widely used light emitting VMS display technologies today, and are regarded as having the best visibility and lowest maintenance costs.

Of these two light-emitting technologies, fiber optic is the more mature. It is similar to the reflective disk technology, except that the moving element in each pixel acts as a shutter that blocks or exposes light from inside the sign. The light comes from incandescent or High Intensity Discharge (HID) bulbs located inside the sign. There is approximately one light module for every 100 pixels in the display. Light modules normally contain primary and back-up bulbs, both of which can be dimmed. Light is carried from the light module to the pixel via a glass or plastic optical fiber. Affixed to the end of the fiber is a plastic lens that directs the light from the fiber into a beam aimed at oncoming traffic. Signs can be made with lenses that focus the light into a narrow beam or a wide beam, depending on whether the sign needs to be legible over a wide range of viewing angles. To a viewer standing directly in front of the sign, a sign that uses narrow beam lenses looks brighter than one using wide beam lenses. Fiber optic signs provide excellent legibility, even when the sun is directly behind, or shining directly on the face of, the sign.

LED technology is changing more rapidly than any of the other display technologies. Today, virtually all LED signs for motorist information use "superbright" amber LEDs that came on the market a few years ago. These LEDs have replaced the combination red/green LEDs used in older systems. LED signs exhibit great diversity in mechanical and electrical details (cooling, number of LEDs in a pixel, encapsulation of the LEDs) among manufacturers. Each pixel consists of several LEDs that are turned on or off together.

The biggest advantages of the LED signs are their superior visibility and low maintenance costs. They also provide excellent legibility, under any sun orientation. The larger LED pixel size provides a more readable, full character stroke width as compared to the smaller, point-source light from fiber optic pixels. LED signs also have an equal or superior viewing angle to fiber optic signs. A 17-degree viewing angle provides the best balance of intensity, viewing angle, and electrical power cost.

LED signs are expected to require far less maintenance than fiber optic signs. A fiber optic sign has light bulbs to be replaced and a moving shutter in each pixel. The LED sign has no moving parts except the cooling fan or blower, and no bulbs. The LEDs are expected to last for at least a decade.

LED signs are more flexible than fiber optic signs with regard to the fonts they can display. Because each pixel is made up of a number of LED elements, letters appear to be smoother and more natural looking, as opposed to the "choppy" or rough-edged appearance that characterize most fiber optic signs, especially for letters that are comprised of diagonal lines. Fiber optic signs can achieve the same font flexibility, but only at a significant cost penalty.

Hybrid Signs

Hybrid signs, those that use reflective disks in conjunction with LED or fiber optic pixels, have the advantage of keeping the message displayed during daytime power failures without the need for backup power. The legibility of such signs is inferior at twilight, when the light emitting pixel is dominant but the reflective disk appears as a halo around the central point of light. Because the hybrid signs have moving parts, they are expected to require more maintenance than an all LED sign.

Full Matrix Versus Line and Character Matrix Signs

Full matrix signs have a continuous matrix of pixels over the entire sign, allowing the user to display characters that vary in height and font style. Line matrix signs have a continuous matrix across each line of text, but a gap between lines. By contrast, fixed character signs have defined areas of pixels that form characters, with empty spaces between characters and between lines of text. Although the full matrix signs offer an extra degree of flexibility in displaying messages, there are a number of drawbacks to their use including:

- *Maintenance* - The face of a dynamic message sign requires a "window" over each character to protect the sign face from dirt and spray coming off the roadway. The spaces between line or fixed character signs provide a convenient location for hinges and mounting hardware for individual sign windows, while a full matrix sign requires one large "picture window", that is harder to maintain, and more costly to replace.
- *Software Complexity* - The software required to drive a full matrix sign is more complex, and therefore more expensive. The user interface is also more cumbersome in that an operator has to type in more parameters (e.g. character height, position on sign, etc.) before the message can be sent. In an emergency situation, this may be undesirable.
- *Cost* - Because full matrix signs have more pixels, and consequently more LED elements, the cost of the sign is increased.

Proponents of full matrix signs argue that they also offer the flexibility to display maps or graphics to motorists. In practice, this is a feature that is rarely used because of the difficulty and time required to create a readable map, and the limited added benefit to the motorist. Character matrix signs are the least costly option, but are unable to correctly center text or use proportional spacing of the characters.

VMS Control Systems

As the number of individually controllable elements on the sign face increases, the complexity of the sign control requirements also increases. For all but the simplest rotating drum signs with just a few messages, some sort of computer based control is required. Although most manufacturers use a proprietary microcomputer-based controller, some use a Model 170 intersection controller to control their signs.

Similarly, most sign manufacturers use a proprietary communications protocol, that works exclusively with their control software. The proprietary nature of each sign system creates difficulties when trying to integrate equipment from different manufacturers. An agency can easily get "locked into" a single supplier, when there are superior or more cost-effective products available. Or the agency can suffer from poor support, or a product being “orphaned” when a newer model is introduced or a company is bought out.

There are a couple of options available to address this issue. The first option is to require the manufacturer to provide the communications protocol when the signs are initially procured. The controller software for future signs is then developed using the initial protocol. This assures that any future signs from any manufacturer can be integrated into the system.

Another option is to use the NTCIP. As discussed previously, the NTCIP is a standard communications protocol for ITS field devices, such as VMS's, that is being developed specifically to promote interoperability of equipment from different manufacturers. It is anticipated that over the next several years, most VMS manufacturers will begin converting their control systems to use the NTCIP.

VMS Communications

The connection between a VMS and the central computer(s) can be provided by a standard serial data communications link. Data requirements for signs are very small, and they typically communicate at rates no more than 1,200 bps. This data rate allows roughly 120 characters per second to be transmitted. Using an addressable VMS controller, multipoint communications can also be used.

Highway Advisory Radio

Although not as widely used as dynamic message signs, Highway Advisory Radio (HAR) is another means of providing highway users with information in their vehicles. HAR systems use a low powered transmitter to broadcast information to motorists through the radios in their vehicles. Upstream of the HAR signal, users are instructed to tune their vehicle radios to a specific frequency via roadside or overhead signs. Usually, the information is relayed to the users by a pre-recorded message, although live messages can also be broadcast. Message transmissions can be controlled either on-site or from a remote location through telephone or hardwire links. Some centrally controlled HAR systems offer various levels of automation, allowing users to record messages, store them in a computer database, and then automatically select them for transmission based on current traffic conditions.

Most HAR systems operate at a frequency of either 530 or 1610 KHz; however, any available AM or FM frequency can be used as long as a low enough power level is used, and the signal does not interfere with any existing radio stations. A license from the Federal Communication Commission is required to operate a HAR system.

HAR systems offer the ability to broadcast more detailed information than the VMS's, allowing longer and more complex messages. The HAR system is also unobtrusive, requiring very little field instrumentation. The only disadvantage of the proposed HAR system is that it requires motorist action in order to receive the information. Also, if a motorist misses one part of an HAR message, he or she must listen to the entire message again in order to obtain the missed part.

There are two types of HAR transmitter antenna systems, including vertical "whip" and induction cable. In both of these antenna systems, the signal strength diminishes uniformly as an inverse function of the square of the distance from the antenna. Vertical antennas are the most commonly used, and consist of a single antenna that produces an omni-directional (circular) radiation pattern. Vertical antenna systems are small, easy to install, and are less costly that induction cable systems. They do, however, require an extensive grounding system that consists of an array of bare copper underground cables, radiating out 100 feet from the antenna. Because of this grounding system, a substantial area is required for this type of installation.

Induction cable antenna systems use a "leaky" coaxial cable installed adjacent to the roadway. This type of antenna design produces a strong but highly localized signal. Inductive cable antennas offer the advantages of not requiring as much room for installation, and messages can be directed at vehicles in a particular direction of travel. They offer a viable alternative for areas where there is insufficient space to install a vertical antenna.

Commercial Radio Broadcast

The public has learned to depend upon the media to provide them with "almost" real-time traffic information. Commercial radio has proven to be a good means of providing travelers with traffic information both in and out of their vehicles. Traffic and roadway condition reports have become standard programming items on many commercial radio stations on Wichita, including KFDI and others. Commercial radio has the best potential of reaching the greatest number of commuters, since most of them have radios in the vehicles they drive to and from work.

The primary disadvantage of using commercial radio relates to the timeliness of the information. Traffic reports often are transmitted only when normal scheduling permits. This may cause considerable time delays between when an incident occurs and when it is reported by the media. Often, many incidents go unreported or are cleared by the time they are reported.

Video Display Terminals

One of the newer technologies for communicating with motorists in their vehicles is through a video display terminal (VDT) mounted in the dashboard. This is primarily a private sector initiative which has begun to be offered as an option in high-end luxury cars. Hertz Auto Rental also offers VDTs in some of their cars at limited locations throughout the country.

These systems are used to provide motorists with route guidance and navigational information in one of two different formats. One approach is to present the driver navigation and route guidance information in the form of maps or equivalent displays. With these systems, a global picture of the traffic network can be provided. Recommended routes can be highlighted on the video map display as well. In another approach, simple symbolic signals (e.g., arrows, text instructions, or a combination of both) guide the driver along a recommended route. Some prototype systems use a variety of displays depending upon whether or not the vehicle is in motion, the functions selected, and level of informational and navigational displays available.

In-vehicle VDTs offer a number of advantages over other available technologies in providing information to motorists while driving. Travel information is more readily accessible to the driver, providing continuous access to current position, routing, and navigational information.

There are also limitations to in-vehicle VDTs. These include the following:

- Drivers have to take their eyes off the roadway in order to receive the information (although future VDTs may have head-up displays that project images directly into the driver's field of view).
- In-vehicle VDTs present the driver with complex maps and diagrams that may create a potential to overload the driver with too much information.

In addition to commercial systems that offer static route guidance only, a few federally funded pilot projects are examining the possibilities of dynamically adjusting route guidance information based on real-time traffic conditions. One such project called ADVANCE in Chicago recruited several area drivers, and installed GPS-based navigational systems in their cars. By linking a central navigational system to the computer system at the Illinois Department of Transportation's Traffic Management Center, it is intended to allow routing algorithms to calculate shortest travel times and optimal driving routes based on current traffic conditions.

Pre-Trip Motorist Information

Highway Advisory Telephone

Originally, highway advisory telephone systems allowed motorists to call for information to assist in pre-trip decisions from their homes. Information can now be accessed en route via cellular telephone, and decisions can be made whether to alter travel routes.

One of the more successful examples of this technology are the SmarTraveler systems now in place in Boston, Philadelphia, Washington, DC and Cincinnati. These systems employ special telephone numbers to call to obtain traffic information. Touch-tone menus allow callers to receive route-specific traffic information (delays, construction activity, recommended alternative routes), bus and train scheduling, and special event transportation information. The Washington State Department of Transportation has a similar motorist advisory telephone system (206-368-4499), providing traveler information for western Washington.

Highway advisory telephone has the advantage of giving the motorist some control over the type and amount of information he/she wants to obtain through the touch-tone menus.

Television Broadcasts

Television (together with radio) was one of the first off-roadway motorist information technologies available to motorists. Commercial television stations provide traffic reports to viewers as part of their morning and early evening programming to indicate incident locations, traffic signal malfunctions, and other traffic "hotspots." These locations are usually shown on some type map or display. Some metropolitan areas have made agreements with the cable television providers for a dedicated channel showing the video images of the area's cameras.

The broadcast of live video images has a few significant advantages over radio broadcast traffic reports. The information viewers get from live video images depict real time traffic conditions, conveyed without any of the delay associated with radio reports. Motorists prefer live video shots because they give them a more intuitive indication of traffic conditions they will actually encounter.

Kiosks

Kiosks are essentially video monitors that display maps and/or text information regarding traffic, incident and transit information. Kiosks have also been used successfully to provide flight arrival/departure, weather, tourism, hotel, restaurant, bike, ferry, and carpool information. They may have input devices such as keypads, track-balls, or touch-screen displays. Placed strategically at shopping malls, hotels, airports, and truck stops, kiosks can provide valuable pre-trip information for planning alternate routes around congested areas.

For transmitting real-time dynamic information to kiosks, communications can be handled using a single point-to-point ISDN line. For the occasional download of static information to kiosks, a standard dial-up 56 Kbps voice grade modem can be used.

Research in Los Angeles has shown that kiosks placed in office buildings are not used very much because of the regularity of most commutes. By contrast, kiosks in airports, train stations, and rest areas have a high usage rate. This data suggests that kiosks may be better suited for motorists who have a need for new trip information, such as tourists.

There are some drawbacks to their use and some hurdles to overcome in their implementation. One drawback is that kiosks require frequent maintenance. Kiosk maintenance is typically contracted out to the kiosk vendor, however some agencies have had difficulties with the vendor's response times for maintenance problems. In addition to maintenance, agreements also have to be reached with the private businesses (e.g. hotel) owners or other government agencies for the installation of the kiosks.

Internet Websites

With the increased proliferation of personal computers, internet websites are becoming an attractive way to disseminate pre-trip information to more and more travelers. Internet websites have the potential to give more customized traveler information than other forms of information dissemination by allowing users to select only that information that pertains to their particular travel route.

Many state and local agencies currently maintain internet websites offering different types of information. Some agency sites offer general information about their organization, while others post real-time travel conditions on area roadways. The most common way that agencies post traveler information is with a graphics map that allows users to click on various roadways to see a text description of current traffic conditions. Others enhance the map by color-coding roadway segments to indicate various levels of traffic congestion. Some of the more advanced sites offer live video snapshots from CCTV cameras around the region.

Traveler information websites use information and data collected from a variety of sources, including loop detectors, CCTV cameras, cellular call-ins, police reports, and construction schedules.

Another internet use that has recently appeared is an e-mail "travel report" service where information is sent to motorists by e-mail. The e-mail is a customized travel report on specific user-selected routes, or simply a list of heavily congested areas or advisories. Similar services are in use by the airline industry, where flight information and fares for particular travel destinations are regularly sent to registered travelers.

Pagers

Another technology now used to help disseminate travel information to users away from the vehicle are personal pagers. In Bellevue, Washington, alphanumeric pagers provide their owners with hourly information regarding available carpools looking for riders, as well as current traffic conditions on the Puget Sound-area freeway system. The Genesis project of the ITS Guidestar program in Minneapolis, Minnesota, and TRANSCOM in New Jersey also utilize alphanumeric pager technology to disseminate real-time travel conditions. A key constraint of pager technology is that broadcast messages are limited to a small number of characters. Consequently, efforts are underway to determine which information is most relevant to pager owners and how to format that information succinctly, but accurately.

5.5 DATA PROCESSING TECHNOLOGIES

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.

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 1,200 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 or a freeway monitoring controller. 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 control center 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 control center 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 control center. 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 control center (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 range is now very inexpensive, allowing this strategy to be implemented.

The data collected from an inductive 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 main-line 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 control center, 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), or 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.

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, but the roadway is left 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 under normal conditions. In congested operation, the relationship is shifted to restricted flow, resulting in a decreased volume and higher occupancy.

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 queue build-up 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.

Incident Detection Algorithms vs. Cellular Phone and MAP

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.

However, many agencies are finding that incident detection algorithms are being outpaced by travelers notifying emergency responders through their cellular telephones and by motorist assistance patrols. In some cases, the incident notification is coming into the control center long before the incident detection algorithms trigger the alarms. This raises the question whether operation centers in areas with a high concentration of cellular phone users and good MAP coverage should spend the capital in obtaining the algorithm hardware and software. The limitation of relying on call-ins and MAP's is that they do not provide continuous monitoring of conditions, and thus they cannot always be relied upon. If the decision is made not to implement the incident detection algorithms, then the traffic detectors could be used for data collection, traffic monitoring, and information dissemination.

5.6 PUBLIC TRANSPORTATION TECHNOLOGIES

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 location 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.