New York State Department of Transportation

Intelligent Transportation System (ITS) Study for the Buffalo and Niagara Falls Metropolitan Area Erie and Niagara Counties, New York

ALTERNATIVE TECHNOLOGIES
Working Paper # 6
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1.0 INTRODUCTION AND SCOPE

Working Paper #5 outlined the Buffalo ITS data sources, system users and their needs. The current paper, provides a discussion of the technologies available to collect/transmit/process and disseminate the needed data in order to meet these needs. The technologies which could be used in the Buffalo/Niagara Falls Intelligent Transportation System (ITS) are discussed, evaluated and recommendations are made.

1.1 DOCUMENT ORGANIZATION

In Chapter 2 of this document, a review of the system architecture is presented and from there, Chapter 3 provides a discussion of the strategy used to comply with the system architecture. Chapter 4 presents the heart of the paper where individual technologies are reviewed and evaluated, and the recommendations are made.

1.2 ACRONYMS, ABBREVIATIONS & DEFINITIONS

ATIS - Advanced Traveler Information System - A system that utilizes transportation system information in real-time to provide information to travelers. The system includes data collection efforts (from other agencies) and field equipment (detectors, CCTV), the data processing and the transmission/distribution network to provide this data to the travelers.

ATMS - Advanced Transportation Management System - A system that provides overall coordination and control of the transportation elements.

AVI- Automatic Vehicle Identification - A system that combines an on-board transponder with roadside receivers to automate identification of vehicles for purposes such as electronic toll collection and stolen vehicle recovery.

AVC - Advanced Vehicle Control - This system provides improved safety within vehicle control systems, including cruise control, anti-lock brakes and more futuristic elements such as headway controls and anti-crash controls.

AVL- Automatic Vehicle Location - The installation of devices on a fleet of vehicles (buses, trucks, taxis, etc.) to enable the fleet to function more efficiently by knowing the location of vehicles in real-time.

CCTV- Closed Circuit Television - A system of video cameras positioned along a roadway or other system, allowing operators to remotely monitor travel.

DDS - Digital Data Service - A trademark of AT&T identifying a private line service.

HAR - Highway Advisory Radio - A radio system over which travel information is transmitted to vehicle drivers when their radio is tuned to the correct channel.

GPS- Global Positioning System - A method of determining the position of vehicles using communication with a satellite.

ISDN - Integrated Serviced Digital Network - An international standard that defines end-to-end transmission of voice, data and signaling.

LED- Light-Emitting Diode - A semiconductor device which emits incoherent light.

VMS- Variable Message Sign - Highway signs which can change the message they display.

VRC- Vehicle to Roadside Communications - Technologies include transponders, readers, cellular telephone and beacons among others.

1.3 PROPOSED STANDARDS

The critical links in any system are system interfaces. In an ITS, the interfaces tie together the different parts. For example, there is an interface between a vehicle and roadside equipment consisting of detailed communication of vehicle identity, status and related data, plus the reverse flow of subsystem status and instructions to the vehicle. The detailed content, format and information flow sequencing together constitute the interface between the elements.

Neither the National ITS Architecture nor the Buffalo ITS Architecture define interfaces in prescriptive terms at this point in time. They define the interfaces only in descriptive terms, meaning that there is not enough detail to have a hardware or software designer actually build the necessary interfaces. Nationally, there are standards being developed that provide the prescriptive definitions for these interfaces. The national standards will allow ITS systems throughout the country to be developed consistently. The National Transportation Communications for ITS Protocol (NTCIP) is one example of a national standard which is being developed for ITS. Other standards are currently being developed by the American Association for State Highway & Transportation Officials (AASHTO), the American Society of Testing & Materials (ASTM), the Institute of Electrical and Electronics Engineers (IEEE), the Institute of Transportation Engineers (ITE) and the Society of Automotive Engineers (SAE).

Compliance with NTCIP and other standards currently under development for the National Systems Architecture is recommended for the Buffalo ITS, to assure interoperability.

2.0 SYSTEM ARCHITECTURE REVIEW

A partially decentralized system architecture has been recommended for the Buffalo/Niagara Falls ITS. Working Paper # 5, “System Architecture,” provides a complete description of this architecture. For the purposes of this paper, the system architecture will be reviewed with respect to travelers and operators and how it would affect the technologies addressed herein.

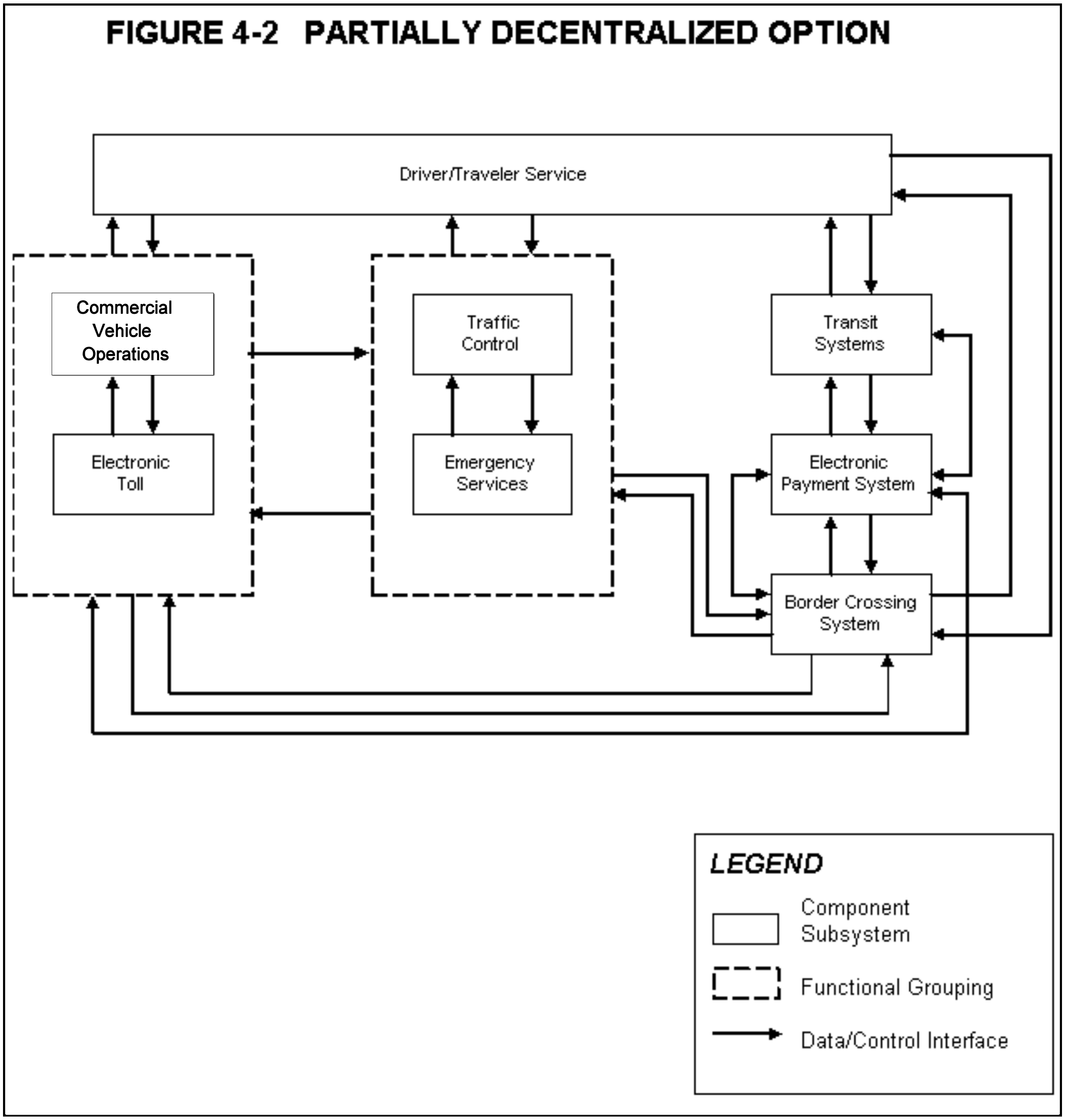

Figure 2-1 Recommended Buffalo ITS System Architecture

The recommended architecture, as shown in Figure 2-1, allows simultaneous information to be received and provided to the driver/traveler service subsystem which is the main external interface of the ITS system. The key feature of the architecture is that all ITS elements in the region will be controlled from the regional operations center (ROC) during core hours (6:00 AM to 7:00 PM) and all the while not precluding distributed control by respective physical subsystem operators such as the New York State Thruway Authority and the Niagara Frontier Transportation Authority, as they see necessary. Each operating agency would be linked to the Regional Operations Center.

The Buffalo/Niagara Falls system architecture defines data transfer interfaces between the various subsystems. The functional groupings (see Figure 2-1) are Commercial Vehicle Operations/Electronic Toll; Traffic Control/Emergency Services; and Border Crossing; Transit; and Electronic Payment. Various dissemination technologies to implement the driver/traveler service could be used, ranging from variable message signs, highway advisory radio, and radio broadcast to telephone call-in, computer bulletin boards and cable TV. Section 4 discusses these technologies.

2.1 TRAVELERS

Travelers using the Buffalo area ITS have a wide variety of data needs. Travelers can be vehicle drivers, passengers, transit users or pedestrians. Those travelers that have not yet left home or are in a transit station require pre-trip travel information. Pre-trip travel information needs to be accurate and timely. Obviously, this information needs to be available to the user in different formats than for travelers who are already on their way. Vehicle drivers and transit passengers need to receive real-time data at critical junctions in their trip, in order to be useful to them.

2.2 OPERATORS

In order for the various subsystems and operators of these subsystems to provide timely and real-time data to the travelers, the subsystems need to monitor the transportation system and process collected data. There are several ways to monitor the transportation system including detectors, probes and CCTV. Section 4 discusses these technologies. Operators are key users of the ITS System and they will request and receive information that will be used in a variety of ways to facilitate efficient transportation throughout the region. Operators range from traffic and road information providers to transit information providers as well as, independent service providers who will provide enhanced features and functions to the traveling public.

3.0 ITS STRATEGIES

This section briefly presents some of the basic considerations and issues that are raised when an analysis is done of ITS strategies. Note that the costs given are for equipment only and do not include installation.

3.1 INFORMATION COLLECTION

The ITS system data needs include system travel times, volumes and speeds as well as incidents, road construction and maintenance. The data can be collected via a variety of means. Much of the data can be provided through vehicle detection equipment. The equipment can range from devices in the roadway (eg. inductive loops) to overhead detectors such as CCTV and microwave. Other aspects of the data can be collected from computer aided dispatching subsystems (eg. 911), roving service patrols and other data sources.

3.2 COMMUNICATIONS

Communications will be necessary to transmit field data to the appropriate controllers and processing units, from the various operations centers to vehicles or the roadside infrastructure, as well as between the various operations centers. There are several strategies that can be used to provide communications for the ITS. Major strategies include leased line communications or agency owned lines, and each of these can be either shared or dedicated. The media could also have a wide variety including wireless, wireline, fiber optic, twisted pair, etc.

In addition to electronic transfer of data from, in essence, one processor to another, there will also be a need to manually transfer data from one operations center to another. Examples of this in the Buffalo area include, construction and maintenance information. Initially at least, such data will be faxed to the management centers and will need to be manually input if it is to be part of the database or used on a display map.

3.3 PROCESSING

The system architecture has a great deal of impact on processing. Processing can be centralized, distributed or completed in the field. Each option impacts the communications loads differently. The greater the number of smart field processors, the lower the communications capacity needed. If detectors, controllers and cameras have the ability to process data in the field and transmit only the necessary data to the processing subsystem, the communication load is reduced significantly and there is less dependency on the communications subsystem. The tradeoffs that need to be considered involve the cost and reliability of remote processing and cost of data transmission.

3.4 INFORMATION DISSEMINATION

The key elements of data dissemination are that the data must be accurate and timely. There must be a means to process the necessary data and transmit that data over the appropriate media to the users. Each user group has a different means of receiving the information. Pre-trip users will need access to data away from the roadway, for example, in their homes, businesses or at transit stations. En-route users need access to the data directly from the roadside, or from within their vehicle.

In most instances, the dissemination will be done electronically. This can include variable message signs, highway advisory radio, Internet (eg. World Wide Web) and television. In some instances however, data dissemination may be via newspapers (eg. for construction and maintenance information), when it is not necessary to provide real-time information or such data supplements real-time information.

4.0 REVIEW AND EVALUATION OF ALTERNATIVE TECHNOLOGIES

The alternative technologies to be discussed and evaluated in this chapter include field equipment that will provide the Regional Operations Center (ROC) and other operations centers with effective decision making data to optimize transportation operations. Various transmission media for this data are also evaluated. Communications is important to ensure that appropriate agencies have access to the data pertinent to their operations.

4.1 INFORMATION COLLECTION

The information collection functional requirements that will be addressed by these technologies were established in Working Paper # 4 and are shown in Table 4-1. These data facilitate the Network Surveillance, Probe Surveillance and the Incident Detection Market Packages as well as the Weigh-In-Motion Market Package. These data provide support for the Broadcast Traveler Information Market Package and the two electronic clearance market packages.

Table 4-1 Functional Requirements

SENSOR	REQUIREMENT	AGENCY RESPONSE
Traffic Sensors	Volume, occupancy and speed for freeways Incident detection Volume, occupancy and speed for surface streets	Required Required Desired
Vehicle Status	Vehicle Classification (length, weight, number of axles)	Desired
Rail Sensors	Detect presence for preemption / warning	Required

There are several detector technologies available today for traffic flow. “Non-intrusive,” or out of the roadway, detectors have been improving and are being deployed more often than in the past. Section 4.1.1 provides a discussion of these detectors. For the purposes of this paper, non-intrusive detectors have been grouped into three categories: video imaging, microwave/radar, and acoustic/ultrasonic. More traditional in-pavement detectors like inductive loop detectors and magnetometers are discussed in Section 4.1.2.

The latest detector technology to be used in ITS applications involves moving detectors, and these are discussed in Section 4.1.3. Moving detectors could include probes, vehicles equipped with electronic toll tags or other transponders. Some transponders are deployed as part of a fleet tracking subsystem for agencies like police, transit or commercial vehicles. Both private and commercial vehicles may use electronic toll collection transponders or tags. These can all be used as probes if there is sufficient deployment.

For incident detection and incident confirmation, closed circuit television (CCTV) is a basic technology, as discussed in Section 4.1.4.

While each data collection technology has its benefits, it is necessary to determine the ability of these detectors to provide the necessary data for the ITS deployments. The following sections discuss the capabilities and shortcomings of these technologies.

4.1.1 Fixed Detectors: Non-intrusive

This section describes some of the options available for video imaging detection, microwave/radar detection and acoustic/ultrasonic detection. The costs quoted are exclusive of communications.

4.1.1.1 Video Imaging

There are currently two basic methodologies for screening traffic data from a video image. One method uses loop emulation where a screen line is set up to represent a detection zone. The screen line can take various shapes which represent different detection zones (similar to the area covered by a loop in the pavement). The zone is monitored frame-by-frame and pixel-by-pixel looking for changes to indicate a vehicle is crossing the zone.

The second method uses vehicle tracking. With vehicle tracking the entire video image is scanned for pixel changes, looking for a vehicle to follow along the roadway. The advantage of vehicle tracking is that even with a moving background (moving tree leaves, snow, etc.) the detection algorithm can pick out a true vehicle. In both video methodologies, a far vehicle can be occluded by a near vehicle in the camera field of view, but the effect of vehicle occlusion is lessened by utilizing vehicle tracking. Additionally, vehicle tracking can determine when a vehicle is changing lanes.

The video detection subsystems presented below use either loop emulation, vehicle tracking or a combination of the two.

One example of a loop emulation product is the **Odetics Vantage Video Traffic Detection System.** Odetics uses loop emulation for volumes, occupancies and speeds and to perform vehicle classification by length (3 classes). Output can be used as input to an incident detection algorithm. The Odetics system is being used for both freeway and intersection applications. Camera installation can use existing poles or overhead sign supports. The camera angle, with respect to traffic flow, is important to system performance. The system performs best when the camera is aimed parallel to traffic and the angle from a horizontal position is dropped between 45º and 55º. The camera can view between 3 to 4 lanes of traffic and those lanes can be traveling toward the camera, away from the camera or a combination of the two. Camera height can be between 20 and 30 feet.

The processor unit is housed in a field cabinet. Cameras are connected to the processor unit with coaxial cable. Each Odetic processing unit can handle up to 4 camera inputs and each camera can have up to 8 detection zones. Hardware costs are approximately $25,000 for a processor with 4 cameras.

Autoscope Video Imaging 2004 is one of the earliest video detection technologies to be deployed for ITS use. Autoscope 2004 can be operated to enable direct interface to a 170 controller, or Autoscope can be used to provide all processing. The latest version of Autoscope uses loop emulation for volume and vehicle tracking for speed. Autoscope can assign up to 100 detection zones per processor. Autoscope 2004 is able to collect volume, occupancy, speed and classification by length (3 classes). The detection zones can be linked together by "and", "or", "if", etc. to allow intelligent data collection. These functions can be used to count the number of right-turns on red or the number of intersection sneakers. Basic incident detection is performed by assigning queries to the detection zones such as stopped vehicles, queue length, wrong-way traffic movement, or by creating detection zones on the roadway median or shoulder similar to the PEEK System. Shock waves and changes in occupancy and volumes can also be electronically monitored. In this way, incident detection can occur without constant monitoring by an operator.

For intersection control, the system is set up (typically) with one camera per approach viewing upstream traffic. An Autoscope processing unit is housed in a field cabinet and can be interfaced with telephone lines and a modem or a laptop computer in the field. Hardware cost for a typical intersection application is approximately $26,000. Autoscope has recently been installed at the intersection of Transyt and Broadway in the Buffalo area and is under observation until January, 1997. Autoscope units installed in Poughkeepsee, New York did not perform well apparently due to camera placement. There are several hundred Autoscope units installed for traffic signal control in Oakland County, Michigan. Results there have shown reliable detection in all types of weather.

For freeway monitoring, the system is set up on existing poles looking upstream and can cover up to 6 lanes (3 in each direction if set up in the median). Mounting heights of at least 30 feet are recommended. Hardware cost for a typical freeway monitoring system is $20,000 to $26,000.

The **Rockwell TraffiCam** video imaging system utilizes loop emulation technology. The TraffiCam system can collect volumes, occupancies and speed. Incident detection algorithms can be incorporated using the speeds output from the system. An important difference between this system and the others is that the processing occurs in the camera unit. This eliminates the need for a field cabinet. A less expensive camera is used that is said to cause a decrease in image quality (more blocky) over that of Autoscope and PEEK units. As a result, occupancies and speeds are less reliable and no vehicle classification can occur even if it is only by length. TraffiCam is used to detect up to 4 lanes of traffic and the camera is installed parallel to the direction of travel (upstream traffic). For parallel field of view the camera is mounted on a mast arm that extends over the pavement. Distributors reported reduced ability to discern certain colored vehicles during dusk and dawn when the ambient light is changing quickly and vehicles do not yet have on their headlights.

Hardware cost for the Rockwell TraffiCam system is approximately $4,000 for 4-lane coverage on a freeway system.

The **PEEK Vision Video Trak-900** system utilizes a vehicle tracking algorithm for volume, occupancy and speed and to perform vehicle classification by length (5 classes). The output from volumes, occupancy or speed can be input into an incident detection algorithm. Built-in loop intelligence leads to some internal incident detection processing. The system can be set up to determine whether a speed threshold has been surpassed, or a vehicle has stopped too long, is driving the wrong direction, or is on the shoulder. A great amount of information and performance measures can be derived for individual vehicles using the vehicle tracking capability; saturation flow rate, individual stopped vehicle delay at an intersection, etc. To fulfill this capability, special software would need to be developed.

This system can be used for both surface streets and freeway applications. The system is unique in that it has an automatic field of view reset so the cameras can be used as CCTV cameras, and returned to the exact pre-sets to allow the virtual loops to be in the correct position. For both freeway and intersection applications, camera placement is critical to accuracy. Cameras can be mounted on existing poles as long as they provide optimal camera placement. Mounting height is recommended at 30 feet or more. The system can have up to 8 video cameras per processor unit and 32 detection zones per camera.

For intersection control, the system is typically set-up with one camera viewing each upstream approach. A camera interface unit and the CPU tracking unit are housed in a field cabinet and can be interfaced remotely with telephone lines and a modem or a laptop computer in the field. Hardware cost for a typical intersection application is approximately $31,000. PEEK Vision is performing intersection control in Lackawanna, New York.

For freeway monitoring, the system is set up to view up to 4 lanes from an existing pole or overhead structure. A typical installation would use 4 cameras and cost approximately $31,000. The four cameras could be set up to view both directions of traffic and the interchange ramps or an intersecting highway. There are currently no freeway systems using the PEEK Vision.

4.1.1.2 Microwave/Radar

The capabilities of these detectors range from basic motion sensors to true presence radar capable of collecting volumes, occupancies and speeds. Most equipment available in this category capitalize on the Doppler Effect that can be observed for returned radar beams. When a radar beam is transmitted and reflected by an object due to the Doppler Effect there is a shift in frequency as a function of the speed of the object. If an object is moving slowly or stopped, the difference in transmitted and reflected beams is too small to be measured accurately. True Doppler radar cannot perform presence detection.

MicroWave Sensors TC-26 Series detectors are an example of a simple motion detector and are used mainly for traffic signal control. By using Doppler radar, these detectors determine whether a vehicle has arrived at an intersection approach, as long as speeds are not excessively slow (less than 5 mph). The TC-26 is overhead mounted at a forward or backward looking angle, one per lane. Existing mast arms, overhead sign gantries, or lighting standards can be used. The TC-26 detector is capable of storing speeds in speed category bins. Hardware cost of the TC-26 detectors are approximately $800.

Whelan TDN Tracker Series detectors are more advanced than the MicroWave Sensors. There are two models: narrow and wide beam. The narrow beam is an overhead lane sensor that is aimed straight down at the roadway. These narrow beam detectors also use Doppler radar and cannot detect slow moving or stopped vehicles. The narrow beam detectors can only measure volumes and speeds and require an overhead sign structure or overpass. Output can be RS-232 and can be input to a processing unit that interfaces with controller cabinets or incident detection algorithms.

The wide beam detectors can be used for side-fire, multi-lane detection and can be mounted on an existing pole at approximately a 14 to 20 foot height. These units cannot distinguish between lanes and only record one vehicle at a time. Therefore, the wide beam detectors cannot be used for volume counting and only report typical speeds. This detector cannot be used reliably for incident detection.

Hardware costs for the Whelan detectors are approximately $3000 which includes either the narrow or wide beam detector ($1000) and a processing unit ($2000). The detectors can be multiplexed so that only one processing unit is necessary for several detectors.

EIS RTMS True Presence Radar Detector. The RTMS by EIS, Inc. improves upon Doppler radar by using a frequency modulated continuous wave and measures the difference in time for a given frequency emission to return to the source. This increases the ability to detect a slow moving or stopped vehicle. The units need to be calibrated to the site. The RTMS unit can accurately record volumes and speed and estimate occupancy. Occupancy is more difficult for radar detectors because the detection zone boundaries are not as precise as for loop detectors. Incident detection can be obtained by using the volumes and speed outputs in an incident detection algorithm.

The RTMS also improves upon side-fire, multi-lane detection by providing individual lane detection. Aside from occlusion of far lanes, the volumes and speeds are obtained for every vehicle in each lane. The speed is calculated by using an average vehicle length (much like a single loop configuration). Detection can be for as many as 8 lanes of traffic (4 in each direction). Care must be taken to ensure occlusion or other blocking of vehicles does not occur. If a jersey barrier is on the camera side of a traffic lane, then the sensor should be high enough to aim above the barrier. Results in the Toronto metropolitan area for volumes indicate that the RTMS volumes were at least 95% accurate compared to loop volumes. Due to occlusion, the volumes are generally lower than loop volumes. Speed accuracies were within 15% of loop speeds. Costs per unit range from $3500 to $5000 depending on quantity.

4.1.1.3 Acoustic/Ultrasonic

The **MicroWave Sensors TC-30 Detector** is an ultrasonic sensor. It emits a high frequency sound wave that, upon hitting a vehicle, is reflected back. The sensor is tuned so that the sound wave dissipates before the pavement is reached (in overhead mount) or before the limit of the lane is reached (in sidefire mount). If a vehicle or other large object passes the wave within the detection zone, a presence will be detected. These sensors must be mounted perpendicular to the object being detected. Mounting in sidefire mode is such that it is very low (no higher than the height of the vehicles to be detected) and it could be vandalized. The TC-30 outputs a contact closure to the intersection controller. These units require an ambient heat source and are therefore equipped with built-in heaters. Costs for this ultrasonic sensor are approximately $500.

IRD SmartSonic Detector is a passive detector in that it does not emit anything, but instead merely listens for vehicles to cross its detection zone. The SmartSonic detector is capable of presence detection, volume, occupancy, average speed and vehicle classification (3 classes). The sensor can be mounted on the side of the road or overhead using existing poles and sign structures, one sensor per lane. Height is suggested to be between 20 and 35 feet. An input card is installed into the controller. Wireless connection can be used between the sensor and the controller. Hardware costs about $2200.

4.1.1.4 Recommendations

For non-intrusive detection, the EIS RTMS microwave radar unit is reported to perform well and provide volumes, occupancies and speed for a reasonable price. Further field testing is recommended. Most video detection subsystems are too costly for freeway installation; however, the Rockwell video system, because of its cost and capabilities (volumes, occupancies and speeds), should not be disregarded. If a non-video based detection subsystem is used for the freeways, a CCTV subsystem should be installed for incident verification.

Other video systems are more suited to intersection control and monitoring. Of the intersection control video systems, Autoscope comes out on top because of its proven experience. A hybrid system could utilize video detection for surface streets and the EIS RTMS system for freeways.

4.1.2 Fixed Detectors: In-Pavement

Some members of the ITS community consider in-pavement technologies such as inductive loops as yesterday's technology. While certainly the trend is toward off-pavement technologies, it is noteworthy that the vast majority of the existing installed base of traffic sensors in North America is in-pavement (i.e., loops). From a performance perspective, the in-pavement inductive loop is still regarded as a benchmark against which new and emerging off-pavement technologies are evaluated. The shortcomings associated with in-pavement technologies relate to the level of effort and traffic disruption associated with installing and maintaining the sensors within the pavement structure. The following is a discussion of candidate in-roadway sensor technologies.

4.1.2.1 Self-Tuning Inductive Loop

Loop detectors are relatively simple devices, consisting of multiple (usually 3-5) turns of wire embedded in the travelled lanes of the roadway. When connected to a suitable detector loop amplifier, an electro-magnetic field is set up in the immediate vicinity of the loop. A large metal object (vehicle) passing over the loop changes the inductance properties of this field. This change is registered as a detection by the detector loop amplifier.

Conventional Loop Detector Technology. Most conventional loop detectors are installed using a cut-and-wind process. A narrow sawcut in the shape of the loop (square, rectangular, diamond or circular) is made in the top course of existing pavement, or the base course of new pavement. The slot is then thoroughly cleaned and has all sharp edges chamfered. The detector loop is formed by winding a specified number of turns of No. 14-18 AWG insulated wire into the slot, and then sealing the slot with either epoxy or rubberized asphalt. Often a backer rod or other bedding is installed over the wire to hold it to the slot bottom during sealing and to help protect it from stones or other protrusions.

Installing loop detectors using the cut-and-wind procedure is relatively straightforward, requiring only a pavement cutter, cleaning apparatus, the loop wire (and backer rod if used), and sealant. A typical 6'x6' freeway loop takes about 30 - 45 minutes to install. Special care must be taken to ensure that the slot is absolutely clean and free of sharp protrusions. Poorly cleaned or chamfered slots often result in damaged loops. Where pavement is good and proper installation techniques are used, conventional loops can last several years.

Above and beyond the installation procedure which clearly impacts the performance of the detector installation, the selection of the proper detector amplifier is a major factor in determining the accuracy of detection. Detector amplifiers are commonly distinguished on the basis of the number of individual loops which the detector amplifier operates. Detector amplifiers are to operate in conjunction with one, two or four detection zones, designated as one-channel, two-channel and four-channel, respectively. Each zone can have one to several loops wired appropriately to make a channel.

The number of channels of a given detector amplifier type significantly impacts the loop functionality. With the intent of avoiding crosstalk between adjacent loops without having to set frequency separations, the channels of the amplifier are often scanned in sequence. Accordingly, the higher the number of channels, the slower and more variable the response time for initiation of a vehicle pulse. The detector amplifier unit allows for adjustment of sensitivity on individual channels. As the sensitivity is increased, the response time decreases.

Prewound/Preformed Detector Loop Technology. Prewound/preformed detector technology seeks to overcome some of the problems associated with conventional cut-and-wind loops. The loops are prewound at the factory (to the client's specifications) and may be enclosed in conduit in the desired shape and dimensions (preformed). They can be cut into existing pavement (as with conventional loops), tied to reinforcing steel prior to a concrete pour or directly paved over for new construction or overlay work with flexible pavements.

The use of a conduit provides added protection against both penetration (stones, sharp edges) and water ingress. Slot preparation for cut loops, although still important, becomes less critical for proper loop operation. The disadvantage is that typically a much wider slot (3/4" to 1-1/2" versus approximately 1/2" for a conventional installation) is required. This requires more sealant, and may increase susceptibility to sealant deterioration and pavement damage.

Where preformed loops offer the most advantage is for new or overlay pavement construction. In this case, no cut is required and installation time is significantly reduced. The loops can be placed in the correct configuration prior to asphalt or concrete placement. Preformed loops available on the market are designed to withstand a considerable amount of abuse during installation. If properly bedded, they should be able to withstand being driven over by construction equipment such as pavers and concrete trucks.

Loop Shape Characteristics. Three main loop shape alternatives can be considered for vehicle detection application. These alternatives have been applied to preformed loops. The following is a discussion of the loop shape alternatives including an assessment of the performance characteristics.

Rectangular/Square Loop. The loops of this geometric configuration are susceptible to cross-talk and adjacent lane pick-up as well as to interference from reinforcing steel. The adjacent lane pick-up is advantageous for application to one lane ramps for detection of vehicles partly on a shoulder. Loop designs have been developed that minimize the crosstalk but require additional saw cuts.

Rectangular loops, because of their right angle corners, are somewhat susceptible to deterioration under heavy loads. During installation, efforts are made to eliminate the sharp edged corners by corner angle cuts or large drilled turn holes in the corners.

Diamond Loops. Diamond loops are used for mainline volume, occupancy and speed detection. Because the wires of a diamond loop do not run parallel to the nearest wires of adjacent loops either within the same lane or in adjacent lanes, diamond loops are less susceptible to cross-talk between loops than rectangular loops. Furthermore the loop edges also do not run parallel to reinforcing steel, making them less susceptible to this type of interference.

At the corners of the diamond loop a concentrated magnetic field is produced. Accordingly this configuration facilitates precise determination of both vehicle entry and departure from the detector zone.

As with rectangular loops, it is wise to avoid sharp corners where deterioration may become evident under heavy loads.

Circular Loops. Circular loops offer many of the advantages of diamond loops in terms of low susceptibility to both cross-talk and interference from reinforcing steel.

The proponents of circular loops claim that a more uniform field height is achieved and that this height can be increased with minimal corresponding increase in field spillover beyond the loop boundaries.

Circular loops can be less susceptible to deterioration resulting from the elimination of all sharp corners. Furthermore, the installation method using a circular cutter can result in a significant reduction in installation time and associated traffic closure requirements. Note, however, that very specialized equipment is required to cut circular loops.

4.1.2.2 Magnetometers

Magnetometers are passive devices able to sense changes in the earth's magnetic field. When a large metal object, such as a vehicle, passes over the detector a change in the earth's magnetic field results which is registered as a detection.

Magnetometers are not susceptible to interference from reinforcing steel or crosstalk from adjacent detectors. The probe and polyurethane jacketed lead in wires are also less susceptible to effects stemming from pavement deterioration.

Magnetometers are usually used in applications in which the only information required is that a vehicle has arrived at a given point. This detector is also well suited for vehicle count applications with minimal vehicle separation since the magnetometers can be closely placed.

The Hi-Star traffic analyzer is a proprietary detector incorporating a pair of successive magnetometers to determine vehicle count, speed, length and occupancy. Roadway temperature and weather can also be determined. The detector unit mounts to the roadway surface and uses a radio link to communicate with the roadside cabinet. The use of snow plows could damage the detector unit.

Magnetometers are not able to provide a consistent response time to vehicle entry or departure from the detector zone due to natural continuous variation of the earth's magnetic field.

4.1.2.3 Sensing Cable/Pressure Plates

Sensing cable consists of a piezoelectric polymer within or on the pavement which produces an electrical signal when compressed by the passage of a vehicle's wheels. Pressure plates are installed on the pavement and register vehicle presence when the vehicle's weight closes electrical contacts. These detectors are able to tally axle counts only and thus are subject to error due to multi-axle vehicles.

4.1.2.4 Recommendation

The inductive loop is the only in-roadway sensor technology which provides the range of measurement parameters as required to support a variety of ITS functions. Experience of many operating authorities, including NYSDOT, suggests that if properly configured and installed, inductive loops can provide accurate volume and presence detection, and support derived speeds and classification, particularly if “speed traps: are used (two loops set a fixed distance apart in a lane). However, the labor and traffic closure requirements required for installation do not render inductive loops as a long term preferred technology. Furthermore, the lifespan of a conventional sawcut loop installation is limited by that of the pavement. The exception is the placement of preformed loops in new pavement construction.

The experience of the Ministry of Transportation of Ontario in evaluating preformed loop installations at variable depths indicates that loops installed in the granular layer or concrete base layer perform comparably with loops cut into the asphalt surface. This suggests that installation of preformed inductive loops should be considered for new roadway construction.

With respect to in-pavement sensors versus non-intrusive sensors, inductive loops are recommended for the near-term. Design, however, should not exclude non-intrusive sensors as they gain more exposure in the field.

4.1.3 Moving Detection

Information collected from in-vehicle equipment may be used for various purposes:

- roadway monitoring and parking management
- toll collection
- CVO and transit fleet management
- vehicle operation.

This information includes link travel time, speed, queue length, turning movements, travel volumes for various vehicle classes, pavement condition, incident data, and related data. The equipment is installed in a vehicle and may require some combination of dedicated short-range communications with roadside subsystems and wireless wide-area two-way or one-way communications with center subsystems.

4.1.3.1 Probes and Fleet Vehicles

Useful information may be obtained from probes and fleet tracking through Automatic Vehicle Location (AVL) systems. Probes are mobile units that utilize wireless communication. They may be used to obtain link time, speed, delay, and O-D data collection via equipment or for custom reception of personal travel data. In-vehicle equipment for fleet tracking is designed, for example, to track vehicles that travel a large geographic area, such as trucks, tour buses, rental vehicles, taxis, transit, and paratransit buses. Emergency Routing and Response Market Packages also contain in-vehicle equipment for emergency fleet tracking. Fleet tracking can be used to track hazardous materials.

The AVL collection equipment falls into three categories identified by the type of technologies used. These technologies are Global Positioning Systems (GPS), cellular phones or radio transmitters, and tracking technologies (compare time-stamps of a particular vehicle at different receivers). Both of the latter techniques require extensive infrastructure investments.

GPS is a space based satellite navigation system which has its advantages and disadvantages. It does not need an extensive infrastructure investment and is not limited to a specific coverage area but it requires unobstructed views of the satellites to provide accurate and continuous coverage. GPS signals may be received when traveling along highways but may not be received in suburban areas or in downtowns among tall buildings, due to signal obstructions. The GPS positioning device has an accuracy of 30-100 meters under selective availability. To improve the accuracy and correct selective availability error of GPS, auxiliary sensors may be added or differential GPS may be used.

Another solution for overcoming selective availability is Motorola's Oncore GPS receiver, an eight-channel unit which tracks the best eight available satellites and is supported by special software developed by Motorola. The unit is credit-card sized and costs less than $200.

The Andrew Corporation's CPS (Continuing Positioning System) combines GPS receivers with the Andrew AUTOGYRO Navigator, a fiber-optics gyroscope ($1100) which measures vehicle turns and vehicle odometer input. The Navigator utilizes a microprocessor in a compact device that can serve as a vehicle data collection interface. This device improves upon position accuracy of a GPS-only system in urban and suburban environments. This system has been introduced for transit fleet tracking and data collection.

Another example of a GPS receiver is the 12-channel Rockwell Jupiter GPS receiver. The Jupiter provides a rapid signal acquisition and reacquisition, smooth ground tracks and works even among tall buildings and trees ($150).

An example of a system using a cellular network is the CELL-Trac automatic vehicle location system from Transportation Management Solutions, Dallas, Texas. This system is designed to track vehicles that travel in large geographic areas such as tour buses and rental vehicles.

Another example of a system which uses cellular phone technology for estimation of roadway travel conditions is the CAPITAL (Cellular APplied to ITS Tracking And Location), developed as an ITS operational test in Washington, DC. The CAPITAL system defines the vehicle position data and then transmits these data to the TOC through the existing cellular network and allows any vehicle equipped with a cellular phone to be a potential probe. The system does not require expensive roadside equipment and only needs modifications at the cellular tower sites. It can provide probe vehicle information not only on the instrumented road segments but on any road segment in the cellular coverage area. The system automatically detects phone call initiations, locates a given vehicle within a few seconds, and periodically plots the vehicle's location to determine its speed. Initial testing of the system showed location accuracy in the 500m circular error probability (CEP) range, but may be eventually improved to 11.5m CEP by using algorithms and network modification. The manufacture and use of the system is in compliance with the Telephone Disclosure and Disputes Resolution Act and FCC Docket 93-1. Privacy of individual callers is completely protected.

The information provided by the tracking system may comprise latitude, longitude, time, speed, and direction of a vehicle. This information is updated frequently and transmitted to the TOC and may be used to calculate parameters of traffic flow in the area. This information may be used for fleet management and planning. After processing probe/AVL data, the TOC may use this information to provide travelers with multimodal real-time information.

The tracking system concept has been successfully demonstrated, for example, in the Transmit system developed by PB Farradyne. In Transmit, in-vehicle toll tags are used to create an AVI-based surveillance system. Transmit has been installed on the New York State Thruway, and Garden State Parkway (New Jersey and Staten Island corridor). The system requires the installation of antennas and readers, similar to those used for toll collection, at regular intervals along the roads from which surveillance data is to be acquired. The vehicle ID is encoded to ensure privacy and transmitted to a central site where vehicle travel time is calculated between readers.

In terms of reliability, cellular phones and GPS are mature technologies which currently are demonstrating excellent hardware performance and configuration stability.

4.1.3.2 In-vehicle Environmental Sensors

In-vehicle environmental sensors can be used for collecting information about pavement condition. Sensor-equipped vehicles determine whether a surface is moist, dry or ice covered to provide information for travel advisories and for obtaining statistics. Enator Telib AB company (Sweden) reports 1□C accuracy for such sensors which are currently on trial in Sweden, however, these sensors are only at the experimental stage.

4.1.3.3 Vehicles Equipped with Collision Avoidance Sensors

Traffic information about speed, queuing, and turning movements at intersections may be collected by using in-vehicle sensors for intersection collision avoidance. The sensors measure presence, location, and speed of the vehicles. The data collection aspects of these sensors are still experimental.

4.1.3.4 CVO Equipped for Traffic and Border Crossing Management Data Collection

There are several Commercial Vehicle Operations (CVO) market packages that require in-vehicle equipment which may be used for data collection, planning and automation of CVO, pavement design and traffic research.

The market packages include in-vehicle equipment for:

- Automated credential reporting/pre-clearance,
- Automated border crossing,
- Automated safety inspection, and
- On-board safety monitoring.

According to the Architecture Standards Reference Model designed by the National Architecture Development Team, the major issue with Vehicle to Roadside Communications (VRC) and the message transaction set (covering electronic clearance, permits, reporting) is nationwide interoperability.

The in-vehicle equipment for these market packages usually contains VRC devices or transponders and message transaction devices. The transponder is a relatively small, self-contained, battery-powered, electronic device capable of two-way digital RF transmissions as well as limited digital data processing, data storage, and visual/audible signals to the vehicle operator. Transponders provide excellent hardware reliability and are rapidly incorporating communication standardization and interoperability.

Currently, there are several types of in-vehicle systems available and they may carry various types of information. For example, the HELP system uses transponders with an ID number and Automatic Vehicle Identification (AVI) reader. HELP stands for Heavy Vehicle Electronics License Plate and the system consists of AVI/AVC equipment along with weigh-in-motion.

The Automated Cargo Expediting System (ACES) (Port Authority of NY and New Jersey) is a large scale e-mail system for transmitting cargo-related information. Another aspect of the system uses smart cards (truck identification system) that also contain the operator's photo and social security number, and a code that identifies the trucking company. They are encoded with both bar code and magnetic stripe. Each of the terminals at the Port Authority has implemented variations on this system. One of the terminals, Mahler terminal, incorporates automatic equipment identification (AMTECH transponder) which is used with Motorola's Radio Frequency Identification system (RFID) and bar-coded truck operation ID. The Otay Mesa system for border crossing (Scientific Atlanta) uses in-vehicle units which contain a Data Processing Interface Unit (DPIU), transponder, and cellular phone. An on-vehicle tag may also carry Driver ID (immigration data), cargo manifest, and vehicle ID (I-75/Ontario border crossing system).

One of the major manufacturers of transponders is Mark IV Industries Ltd. The Mark IV technology provides interoperability within most of the northeastern United States by using the Interagency Group (IAG) standards. The on-board VRC device communicates with fixed facility equipment via a reader without requiring the vehicle to stop. Mark IV's transponder and corresponding AVI subsystems are proposed for the Buffalo and Fort Erie Public Bridge Authority and have been designed to be secure from possible tampering. This technology has 99.97% accuracy. Current cost of the Mark IV's transponder is $46. This may become cheaper in the future.

4.1.3.5 Electronic Payment Systems for Data Collection

Electronic payment is based on "smartcard" systems that may be used for collection of various data. Among in-vehicle systems are:

- Tags for toll collection provide data for toll management and traffic management, incident detection, and travel information (travel time, speed, vehicle identity, etc.).

- Tags for electronic parking payment provide information for parking management.

- Transit fare electronic payment cards may provide ridership data.

A recent study of the performance of the various smartcards shows that the technology works at an acceptable level in most cases, and operators are willing to accept the technology. However, there are several barriers that have to be overcome before the technology will be widely implemented. These include standards, security, privacy, and cost.

The most widely accepted "smartcard" is an electronic toll transponder. Mark IV transponders are used for EZ-Pass in the Buffalo Area and is, as mentioned earlier, the most interoperable transponder within the northeastern United States' toll roads.

4.1.3.6 Recommendations

The overview of in-vehicle technology for data collection (performance, compatibility, cost) shows the feasibility of using in-vehicle equipment for information collection in the Buffalo area.

The Buffalo/Niagara Falls area has several features which make use of equipped vehicles suitable for traffic and operations management. The area has a well developed Electronic Toll and Traffic Management (ETTM) system (EZ-Pass). EZ-Pass will be compatible with the Peace Bridge border crossing system which is currently under design. The existence of these systems means that a large number of private vehicles and a majority of commercial vehicles traveling in the area are likely to be enrolled in the EZ-Pass and the Peace Bridge border crossing system. These vehicles could carry transponders for tolls, customs, immigration, and safety. Information obtained via transponders will be very useful for traffic management, travel information, and planning.

The advantages of using GPS (and GPS with auxiliary sensors technology) result in its use in transit operations. A significant number of private vehicles also may be equipped with GPS receivers for en-route travel information. This makes information collected from "probes" very important for traffic operations centers and should be considered during ROC design.

Increasing popularity of cellular phones and the encouraging results of the CAPITAL ITS operational test show the viability of radio geolocation techniques for traffic information collection. These techniques, when fully developed, might be more cost effective than other probe vehicle approaches and might then be recommended for deployment in the Buffalo area.

4.1.4 Closed Circuit Television

Closed Circuit Television (CCTV) has become a vital component to Intelligent Transportation Systems. Dating back to the early days of the Interstate system, CCTV has typically been used to monitor traffic flow. With the advent of ITS strategies, CCTV's role has expanded to that of incident detection, verification, management, data collection, and even traffic control.

This section will review current state-of-the-art technologies for complete CCTV subsystems. The results of this section will be used to determine the most appropriate CCTV technologies for the Buffalo region.

4.1.4.1 Facility Objectives

The CCTV subsystem is an important tool for effective traffic management and control. As such, it is necessary to identify the objectives of a CCTV subsystem for operation in its environment.

With a well thought-out design, the objectives of the CCTV subsystem can be met without the need for additional cameras for lower priority objectives. The objectives of the CCTV subsystem, in order of priority, are listed below:

- provide continuous coverage of all high accident/high incident highways intended for surveillance.

- provide view of other highways and connecting highways/arterials.

- provide night-time surveillance with minimum degradation in comparison with day-time operations.

In addition, and if it can be achieved at minimal or no cost:

- provide view of all ramps (and ramp metering operations) including signal indication, ramp queue, and acceleration lane.

- provide view of variable message sign (VMS) operation for message verification.

4.1.4.2 System Components

A closed circuit television system may consist of the following components:

- camera
- lens
- enclosure
- pan/tilt
- camera control system
- video switch
- monitor
- video recorder.

4.1.4.3 Functional Requirements

The proper selection and combination of the components listed above are necessary to achieve the desired objectives for surveillance in the Buffalo region.

The functional requirements of the CCTV subsystem and each component will determine the ability of the subsystem to meet the ultimate objective level.

Specific requirements that should be considered are as follows:

4.1.4.3.1 Continuous Coverage

Continuous coverage is defined as the ability to see any portion of any roadway in the system. There are several interpretations of continuous coverage. For example, one camera could be equipped to a traffic helicopter with the capability to go to any portion of the system for TV viewing, hence continuous coverage. The other extreme is to install sufficient cameras and monitors to view the entire system simultaneously from one end to the other.

Realistically, continuous coverage will be a function of camera spacing, mounting height, type of lens used, and the number of monitors at an operations center.

Nominal camera spacing along freeways should be 0.5 to 1.0 miles, with a camera height of 25 to 45 feet above the roadway. To provide continuous coverage, one camera should be able to clearly see to the next. The usable image range would be up to half the distance of the camera spacing.

4.1.4.3.2 Night-Time Operation

Night-time operation is often under-estimated for video surveillance in a traffic management system. There is a belief that night operations are less critical because they fall outside the crucial rush-hour periods. However, the seasonal changes bring the rush-hour periods well into the darkness during late Fall, Winter and early Spring.

The CCTV subsystem should be designed around available lighting conditions to ensure the performance is kept at a constant level. A typical 24-hour period can experience a light range from 100,000 lux (direct sunlight) to 0.0001 lux (overcast night). This is a considerable range for a CCTV subsystem (i.e., camera) to cover.

Freeway lighting is one means of offsetting the low end of this light range. A typical freeway lighting system can provide illumination of approximately 5-15 lux. However, only a percentage of this lighting is seen by the camera; this is the light reflected from the scene. If it is assumed that approximately 50% of the source light will be seen by the camera, the available light would be 2.5-7.5 lux.

Without freeway lighting, the CCTV subsystem has to rely on ambient light from automobile headlights, or other surrounding light sources for adequate performance. As the light-level might now approach 0.0001 lux (a starlit night), it becomes necessary to evaluate the desired level of nighttime viewing versus the available technology and accompanying cost.

An important point to remember is that the intended scene is to be of vehicular traffic. If the operator needs to focus on a disabled vehicle with no lights on, a high performance camera that can operate effectively within the specified light range will be required. However, the scene from a camera that can see under a starlit night will most likely be severely washed out once a vehicle's headlights come into view. This is due to the contrast of the scene. Headlights in complete darkness have a much worse effect on the camera's ability to display the scene than headlights at dusk or even during daylight. This condition causes blooming or streaking of the image, where a point source of light, such as headlights of an automobile or street luminaries, will "bloom" like a flower or streak horizontally or vertically on the video screen. It is important to minimize or eliminate this problem as it may render a scene unviewable.

4.1.4.3.3 Environmental Requirements

The climate in Buffalo is typical of northern U.S. cities, with cold winters and hot summers. The CCTV subsystem must be designed for operation in this climate.

In particular, the subsystem must be able to operate within the approximate temperature range down to -40ºF and up to 110ºF, and a humidity range of 0 percent to 100 percent.

The subsystem must also be able to withstand the elements such as snow and ice, high winds, rain, dust, salt, and other extreme weather conditions.

4.1.4.3.4 Field of View

A CCTV subsystem must be designed such that each field of view conveys the maximum information content possible. The field of view is a function of camera type, lens type, pan/tilt/zoom, and camera placement.

To define the field of view, the desired scene must be determined (i.e., what do you want to see?).

Typically, the operator should be able to view a minimum of four lanes of traffic (48 feet) in both the wide-angle shots and the telephoto shots. The actual field of view is dependent upon the actual camera type and placement.

The camera should be located with optimal height, offset, and viewing angle for maximum information content per image.

Once the location and spacing of the CCTV cameras is determined, the subsystem requirements such as coverage, lighting, and maintenance can be matched with the component requirements. As noted, typical camera spacing is 0.5 to 1.0 miles, and camera height is 25 to 45 feet, with a desired field of view of four lanes of traffic (48 feet). For a sample condition, the following are required focal length, assuming a 2/3" format camera to view a 48 foot width:

	25'	45'	0.25 mi	0.5 mi
Focal Length (mm)	4.5	8	210	400

Under this condition, to view a scene at the base of the camera pole would require a wide-angle focal length of 4.5 mm for a 25 foot pole mount, and 8 mm for a 45 foot pole mount. A telephoto focal length of 210 mm would be required for a camera spacing of one-half mile, while a 400 mm focal length would be required for one mile spacing. Therefore, the focal length ranges would equate to 4.5 - 210 mm (46:1 zoom) or 4.5 - 400 mm (88:1 zoom) for a 25 foot mount; and 8 - 210 mm (26:1 zoom) or 8 - 400 mm (50:1 zoom) for a 45 foot mount. It may be possible to get a fixed focal length lens of any of the above mentioned focal lengths; however, it is unlikely that there is a zoom lens package available that would meet both ends of these ranges. Any lenses close to this range are typically used in the television broadcast industry and are priced at least ten times the cost of a high quality camera. However, by matching available components to the field conditions, a satisfactory compromise is almost always possible.

The cameras should be located on a common side of the roadway to provide consistent view for the operator.

The cameras should be located such that viewing obstructions from trees, lighting, etc. should be minimized.

By optimizing camera placement, the camera should be able to view operation of ramp metering and variable message signing.

4.1.4.3.5 Maintenance Requirements

It is important to design the CCTV subsystem for ease of maintenance. Camera locations should have adequate space for trucks to park safely off the travelled way, in all weather conditions. This would include provisions for maintenance bays, guard rail, etc. to protect maintenance personnel. The availability and capability of bucket trucks should be considered in selecting pole heights.

4.1.4.4 Technologies

The functional requirements for each component listed below identify the baseline characteristics required to meet the facility objectives. Alternative technologies are presented for each component to provide the framework for assembling a CCTV subsystem. Detailed specifications would be determined from the requirements listed herein in addition to the system requirements and available technology.

4.1.4.4.1 Camera

The CCTV camera requirements are:

- color video
- low light-level sensitivity to achieve desired level of viewing at night
- minimal blooming and streaking
- appropriate resolution to achieve desired image content
- National Television Standard Committee (NTSC) video standard.

There are a number of technologies for closed circuit television systems. The two categories for the camera imaging device are optical tube technology and solid state technology. The two image types are described below.

Tubes - This type of camera was used in early freeway traffic management systems. Experience has shown that the optical tubes are susceptible to significant image degradation over time, and have a limited life (approximately two years). As the image degrades, blooming effects from headlights become more pronounced. These cameras are also very prone to image "burn" where spots are burned into the tube if left viewing a static illumination source. The types of optical tubes are listed below:

- Vidicon
- Newvicon
- Ultricon
- SIT - Silicon Intensified Target
- ISIT - 2x Silicon Intensified Target.

Due to the high maintenance cost and poor performance in the freeway environment, optical tube cameras are not recommended and will not be considered further.

Solid State - Solid state cameras use a semiconductor image device in place of the optical pickup tube. This technology is virtually maintenance-free, is considerably less expensive than other technologies, and is shock and vibration proof.

Early versions of the solid state camera could not provide the low light-level performance required for freeway surveillance. However, recent advances in solid state imagers have dramatically improved the low light-level sensitivity.

Imagers are available in 2/3", 1/2", 1/3", and most recently 1/4" formats. The resolution of the imager will increase as the imager size decreases; however, the angle of view will decrease also.

The types of solid state imager cameras are listed below:

- CCD: Charge Coupled Device (Frame Transfer)

- Charge Coupled Device (Interline Transfer)
- CID: Charge Injection Device
- MOS: Metal Oxide Semiconductor.

The solid state imager is actually an array of thousands of tiny pixels which generate charges to create an image. The method of transferring these charges determines the type of technology used in the imager.

Frame Transfer CCD - A frame transfer CCD imager moves generated charge patterns from an imaging section to a storage section on the chip, read in a serial fashion by a shift register.

The frame transfer CCD provides good horizontal resolution and low-light sensitivity; however, it is highly sensitive to bright light sources which can cause severe blooming and streaking.

Interline Transfer CCD - An interline transfer CCD imager moves generated charge patterns from vertical image sensors in a parallel fashion to storage columns on the chip.

The interline transfer CCD has similar resolution and sensitivity characteristics to the frame transfer CCD, however it provides better performance for anti-blooming and anti-streaking.

CID - The CID is similar to the CCD regarding charge generation; however, the image is read directly from the imager rather than from a storage register.

The CID camera has excellent anti-blooming and anti-streaking performance, but provides only moderate sensitivity and resolution. This camera is typically used for machine vision.

MOS - The MOS chip differs from the CCD chip in that every other row of pixels is offset by the half-width of a pixel to make up the array. Thus, the MOS pixels are less likely to overload and cause leakage to surrounding pixels, which results in less blooming and streaking. However, the light sensitivity is lower compared to CCD because of the MOS material.

The MOS camera has excellent anti-blooming and anti-streaking performance. Although the resolution and sensitivity are moderate, a number of agencies have installed MOS cameras in the past because of the anti-bloom and anti-streak characteristics. The popularity of the CCD technology today is making the MOS technology less competitive and thus less available.

The latest advancement in solid state camera technology is Digital Signal Processing (DSP). The camera has added circuitry to optimize operation of the camera, such as higher resolution and higher sensitivity. The camera imager incorporates an on-chip micro-lens which allows the camera to zoom in on a scene digitally, where no moving parts are involved. This allows the user to have zoom capabilities even with a fixed lens. The DSP camera also introduces a digital image stabilizer to compensate for vertical jitter, especially effective when the camera follows a moving subject. In addition, a DSP camera has the capability for RS-232 control, such as from a computer, for maintenance functions that would normally be performed at the camera site, thus reducing the frequency of bucket truck field visits. Note that the output of a DSP camera is still analog. The analog signal is digitally processed to enhance the video signal.

The future generations of cameras will introduce "true" digital cameras, where the output is not the conventional analog signal, but a digital data stream of video information that can be read directly into a computer or other digital coder/decoder device. Formats will be based upon industry standards for digital video compression, such as MPEG-I, MPEG-II, J-PEG, etc.

At this time, it is envisioned the DSP camera will most likely become the standard for ITS applications. The camera technology includes increased nighttime viewability with the color CCD imager. Coupled with the built-in features for digital zooming and camera setup, this technology should be considered for ITS applications in the Buffalo region. These cameras range in price from approximately $750-1500.

4.1.4.4.2 Lens

The lens requirements are:

- motorized zoom lens
- appropriate f-stop range to maximize light entry
- appropriate focal range to achieve desired field of view
- auto-iris with manual override capability
- spot filter to minimize glare and blooming.

Current lens technology offers motorized zoom lenses with zoom ratios that surpass 500:1. Recent studies have shown that a zoom lens with a minimum of 10:1 and a maximum of 14:1 will provide the objective level scenes with satisfactory performance.

Higher zoom ratios have a negative effect on system performance. The available light that passes through the lens is greatly reduced as the zoom ratio increases. In addition, the scene becomes difficult to view and manage with higher focal lengths (telephoto) due to the high magnification of even the tiniest movement of the camera.

The focal length range should be selected to provide the desired objective level scene. The field of view is determined by this focal length in conjunction with the imager format. It should be noted that a smaller imager format camera can utilize an equal or larger lens format; however, the converse is not true. For instance, a 1/2" camera can use a 1" lens, but a 1/2" lens on a 1" camera would result in a porthole effect around the image.

The F-stop of the lens is important in determining how much light will pass through the iris of the lens. As the F-stop number decreases, more light is passed through the lens, critical for low light-level performance. Typical minimum F-stops for zoom lenses range from 1.2 to 1.9, usually measured in the wide-angle position. An increase of magnification will increase the F-stop number also. For instance, it may be desirable to double the magnification of a lens by adding a 2x extender.

However, by doubling the focal range, the light available to the camera has now been reduced by half.

Many motorized zoom lenses have a built in extender which can be implemented at any time from the control center. The disadvantage is that the increase in moving parts adds to maintenance.

A new lens technology has emerged that offers improved light performance, called Aspherical Lens Technology. Standard lenses are ground to a spherical surface, which results in blurring of the optical rays at the lens focal point. This has prevented manufacturers from developing high speed lenses (low F-stop). The new technology grinds the lens to an aspherical surface, allowing more optical rays to converge on the focal point, thus increasing the light available to the camera.

Cameras rated for a light-level of 3 lux at F1.4 can now produce usable scenes at a light-level of 0.9 lux using an aspherical high speed lens at F0.75.

Due to the variable lighting conditions, the selected lens should have an automatic iris and a neutral density spot filter to compensate for overloads of light.

All lens have standard "C" or "CS" mounts for connection to cameras.

Camera height and spacing need to be identified before a focal length can be selected to achieve the desired objective level scene.

4.1.4.4.3 Enclosure

The enclosure requirements are:

- adequate size to house camera/lens combination
- connector/wiring provisions for video, control, and power signals
- protection of the camera/lens from the environment
- provisions for heating, cooling and ventilation
- provisions to keep viewing window area clean
- vandal resistant, tamper-proof locks
- aesthetics, minimal visual impact to public.

There are various types of enclosures for camera/lens combinations. The three most common types are:

- Standard aluminum, steel, or plastic enclosure with removable top. This enclosure has a viewing window in the front of the unit, with a capability for windshield wiper/washer. Heating, cooling, and ventilation is provided through heaters, fans and louvered openings. Cabling is accommodated through protected openings. The flip-top allows for easy maintenance or removal of the camera; tamper-proof locks prevent unauthorized entry.

- Nitrogen-filled pressurized enclosures. The pressurized enclosure, typically a cylinder shape with a front viewing window, is used in harsh or corrosive environments. The camera/lens is environmentally protected by pressurized nitrogen, accompanied by internal heaters. The unit is completely airtight. Camera/lens functions are provided through a connector port on the back of the unit. The entire unit must be removed for maintenance since the unit is sealed. This makes maintenance more difficult.

- Domed enclosures. Domed enclosures are typically used indoors for security applications. However, a few systems have proved that the same dome can be applied outdoors. The dome houses the camera/lens as well as a pan and tilt unit. The viewing window is actually the lower half of the dome sphere. Present technology has incorporated a high speed pan/tilt with lightweight camera/lens to give the operator the flexibility to follow rapidly moving objects in a complete 360 degree radius. This is accomplished by the use of slip ring contacts so the cables will not tangle as the unit rotates. However, the slip rings may corrode in an outdoor environment, resulting in unsatisfactory performance and increased maintenance. Maintenance of the unit would require the replacement of the entire camera/lens/pan-tilt combination in most instances.

4.1.4.4.4 Pan/Tilt

The pan/tilt unit requirements are:

- provisions to support camera/lens/enclosure combination, in addition to snow and ice accumulation;
- provisions to achieve desired fields of view in the pan (horizontal) plane and 360° continuous rotation;
- provisions to achieve desired fields of view in the tilt (vertical) plane;
- capability for positional feedback and preset positioning;
- provisions for internal heater to prevent damage from frozen condensation.

Present pan/tilt technology incorporates increased speed and performance in controlling the unit. Dynamic braking prevents the unit from drifting beyond the desired stopping point. Pan and tilt speeds of 90 degrees per second are now attainable. Positional feedback allows the system to use preset positions or to control movement of the unit by computer to an exact position.

4.1.4.4.5 Camera Controller

Each camera location should have a camera control receiver connected by modem to a central control processor. The camera control system as a whole should be capable of:

- control of camera functions such as lens focus, lens zoom, lens iris, auxiliary, etc. (some systems may include controls for wiper/washer, heater, blower, etc); (provisions now for controls not currently used will protect the City against costly upgrades in the future).
- control of camera movement (pan left/right, tilt up/down, preset positioning)

- alarm indication and status feedback including loss of video alarm
- capability for camera identification titling
- capability of host computer control via RS-232 and the selected communications system
- capability for remote control of any camera from more than one location, with appropriate hierarchial override with the operations center having highest priority.

The camera controller is used to send operator-generated commands from central to the CCTV field sites to control camera functions. Present technology allows the camera controller to be connected to a computer for control purposes. The computer may be programmed with a response plan, in which case select cameras might be called up and directed toward an incident upon an alarm indication.

Camera controllers are commonly integrated with personal computers (PCs). This integration frees up console space by using the computer and mouse as a substitute to the joystick camera control keypad. Graphical software to control camera functions is available from most CCTV manufacturers to operate from standard PCs. A graphic layout of the camera coverage area, possibly a GIS for the freeway system, is displayed on a screen. The user clicks on an area of interest with the mouse which, in turn, brings up a graphical screen of camera control functions, such as pan, tilt, zoom.

4.1.4.4.6 Video Matrix Switch

The size and method of video switching is a function of the number of monitors, the number of viewing sites, communications system, and the number of cameras. The video switch unit requirements are:

- NTSC video standard
- appropriate number of inputs (= number of field cameras)
- appropriate number of outputs (= number of monitors, VCRs, video workstations, remote site users, quad or split screen units, etc.)
- capability to switch any camera input to any video output
- capability of host computer control via RS-232 and selected communications system.

Video matrix switches allow a user to switch any video input to one or more video outputs. This differs from a conventional video switch such that a conventional switch can only switch a single video input to a single output. The matrix switcher can take a single input and switch it to multiple outputs. This type of switch is useful for multiple users who need to view the same video image on separate monitors.

The video matrix switch also can be controlled by a host computer or integrated with a PC much like the camera controller.

Another device used for video matrix switching is a digital access and crossconnect switch (DACS) or other similar digital matrix. A DACS is a switch that takes standard digital signals in formats of DS-1, DS-3, among others, and switches that particular input to any number of digital outputs.

Typically used for telecommunications, the DACS has been used for video switching in several systems that transport video as a digitally coded signal as part of an integrated voice, data, and video SONET fiber optic backbone.

4.1.4.4.7 Video Monitor

The number of video monitors selected is a function of available control room space, number of operators, and camera/monitor ratio. Video monitor requirements are:

- color video (usually matches camera type)
- NTSC video standard
- appropriate screen size for optimal viewing by operator
- appropriate resolution to achieve desired image content, dependent upon camera resolution and communication system performance.

Operations centers have typically used a variety of video monitors to view respective CCTV images, the majority being cathode ray tube (CRT) monitors.

CRT monitors have advanced over the years with higher resolution and larger screens. However, the common element has been the tube. CRT monitors generate considerable heat. Equipping a control center with banks of monitors creates the problem of dissipating the heat so the monitors (and operators) do not overheat.

With the advances in multi-media technology, video and graphics are now being integrated on the same screen. In the past, NTSC video could not be displayed on a computer graphics monitor, or vice versa. This was due to the different scanning frequencies of the signal formats.

Computer manufacturers have off-the-shelf products to display full motion NTSC video on a computer screen. As described in previous sections, integration of CCTV control/viewing with Freeway Traffic Management Systems (FTMS) computer functions can benefit the operator by having better access to information.

Video display manufacturers have also integrated video with graphics to optimize the space along the display wall. Older systems typically had a bank of CRT monitors for video and either a lamp board or graphics display for data information. By overcoming the same scanning frequency problem, video projection display systems now offer the flexibility of using the same wall display for multiple functions.

A projection video wall does not use any tubes. Therefore, less heat is generated and subsequently, a quieter environment persists (no cooling fans). A video wall can be partitioned electronically such that a portion is used for full motion video while the rest could be used for high quality graphics. At the click of a mouse, the entire wall could switch to all video, all graphics, or a suitable mix. This flexibility is software driven, and most likely will be a custom system.

4.1.4.4.8 Video Recorder

Time-lapse video cassette recorders should be used for long-term video record keeping of all cameras. Requirements are:

- S-VHS/VHS compatible
- appropriate resolution
- capability for host computer control via RS-232
- time-lapse recording mode
- alarm inputs/outputs
- NTSC video standard.

Standard video cassette recorders should be used for specific video record keeping during incidents, traffic flow, etc. Requirements are:

- S-VHS/VHS compatible
- appropriate resolution
- NTSC video standard.

There are two methods of video recording: real-time and time-lapse. Real-time recording takes a single video input, recording 100% of events. Time-lapse recording accepts multiple video inputs, recording each video input in a sequential manner. Each input is assigned a time interval for recording length, thereby recording segments of each input.

Current VHS technology offers a maximum recording cassette length of 8 hours for full motion real-time recording. Time-lapse recording can range from 12 hours to 480 hours per recording cassette, dependant upon desired recording quality and selected time modes. Time-lapse recorders also include multiple alarm inputs; when activated, the VCR switches to real-time mode to record the programmed alarm area. In addition, an RS-232 port is included to allow computer control of the time-lapse VCR.

Full-motion real-time, and time-lapse VCRs offer VHS and Super-VHS formats. Standard VHS format yields approximately 300 lines of resolution, whereas the S-VHS format exceeds 400 lines of resolution. The average CCTV camera ranges from 330-460 lines of resolution. The S-VHS format has become very popular in the CCTV industry for this reason.

A drawback of the timelapse VCR is that events may be missed if the event occurs between the selected frame recording intervals. A solution to this is a unit called a digital field switcher or multiplexer. Each video input is recorded simultaneously in a multiplexed manner such that the risk of missing an event is reduced or eliminated. At time of playback, the unit decodes the video signals and plays back a single uninterrupted scene, or displays multiple signals on a split screen for uninterrupted viewing.

Split screen or quad units are useful for viewing multiple cameras on a single screen. Quad units come in various forms, such as a stand-alone box or as an optional feature on a video matrix switch.

Quad units take four video inputs and display each signal on a quarter of the video screen. As part of a well-designed operations center, the use of quad units could reduce the required monitors by a factor of 4, keeping in mind that each image is now 1/4 the size. Some quad units can display a full screen image for more detail when needed, for instance upon an alarm activation.

4.1.4.5 Recommendations

This section has presented factors to be considered in implementing a CCTV subsystem along with the available technologies. With proper design, the CCTV subsystem can achieve all of the facility objectives outlined in the above sections.

The functional requirements of the CCTV subsystem are highly dependent upon the detailed design of the system. Equipment specifications can be "mixed and matched" to meet most of the functional requirements for the Buffalo region. However, none of the CCTV technologies alone can meet 100% of the requirements prior to the detailed design. It is necessary to prioritize the requirements, and address the variables in the detailed design to maximize the overall performance of the system.

Of critical importance is the placement of the cameras. Once the location and spacing of the CCTV cameras is determined, the system requirements such as coverage, lighting, and maintenance can be matched with the component requirements.

It was stated previously that typical camera spacing was 0.5 to 1.0 mile, and camera height was 25 to 45 feet, with a desired field of view of 4 lanes of traffic (48 feet). The following table lists the required focal length for a sample condition.

Assuming a 2/3" format camera to view a 48 foot width:

	25'	45'	.25 mi.	.5 mi.
Focal Length (mm)	4.5	8	210	400

Under this condition, to view a scene at the base of the camera pole would require a wide-angle focal length of 4.5 mm for a 25 foot pole mount, and 8 mm for a 45 foot pole mount. A telephoto focal length of 210 mm would be required for camera spacing of one half mile, while a 400 mm focal length would be required for one mile spacing. Getting specific focal length lenses is difficult. Therefore, the solution is either to decrease camera intervals or adjust the desired field of view requirement to fit within available technology. This is one aspect of the detailed design.

Another problem is night-time viewing. Theoretically, present camera technology can view scenes in complete darkness. However, the lens, an important component to achieving that goal, must be a fast lens with a very low F-stop. Motorized zoom lenses typically do not boast a considerably low

F-stop. The high contrast from headlights also compounds the problem with blooming and streaking.

A well-specified camera/lens combination as well as proper placement of the camera to avoid viewing directly into the headlights can alleviate this problem.

The CCTV industry is constantly changing, with new technologies or advancements as often as every six months. Any new camera, lens, pan/tilt, enclosure technology will most likely be compatible with the existing system, as will some central components such as video monitors/displays and VCRs. The area that typically is proprietary is camera control and switching, but CCTV manufacturers are increasingly providing protocol and other software information to allow control to be integrated into other ITS control interfaces.

The final selection of appropriate CCTV technology should be based upon detailed design with further analysis supplemented by product demonstrations.

4.2 COMMUNICATIONS

The selection and evaluation of communications technologies for ITS applications is an integral part of the successful implementation of ITS.

Communications alternatives need to address not only the communications medium, but also the options for transport and institutional issues related to the various technologies. This section will attempt to present suitable communications technologies for potential use within the Buffalo/Niagara Falls Regional ITS.

4.2.1 Communications Media

4.2.1.1 Copper Twisted Pair

Copper twisted pair has been used for many communications systems, from telephone companies to freeway management systems. The bandwidth limitations of twisted pair (TWP) has since made it obsolete for long distance transmissions. However, it is still very useful and cost-effective to use it for distribution of low-speed circuits, as is evident in residential housing.

Recent advances in technology have pushed the envelope of TWP transmission to the point where a T-1 (1.544 Mbps) signal can be transmitted over standard copper pairs for several miles.

Primary use of TWP in ITS is for voice and low-speed data service; video transmission is not at an acceptable level for consideration over twisted pair.

4.2.1.2 Coaxial Cable

Coaxial cable has been in use for many years in the cable television (CATV) industry. The method of transmission is typically Radio Frequency (RF) amplitude modulation. It is practical for a multi-drop environment because a single cable can service many users by tapping into that cable as necessary.

Some disadvantages of coaxial systems are:

- high signal attenuation, high cable loss
- the need for amplifiers every 2,000 feet
- susceptibility to electromagnetic interference and noise.

Coaxial cable is commonly used for local video distribution from a camera to a point of access for optical transmission (node or hub) over fiber optics.

4.2.1.3 Fiber-optic

Fiber-optic cable is currently being deployed at a rapid rate for communications worldwide. The advantages of fiber-optics are:

- virtually unlimited bandwidth (only limited by equipment)
- long-distance transmission with no need for frequent amplification
- cost comparable to copper
- robust, allows ease of redundancy
- impervious to electromagnetic and radio frequency interference.

Fiber-optic transmission functions on a point-to-point basis. A light-emitting device feeds into one end of a fiber, and a light sensing device is attached to the other end of the fiber. This provides unidirectional operation. Two fibers are employed for a bi-directional communications link.

4.2.1.4 Microwave Radio

The use of microwave radio to provide communications links in a system is useful where a hard-wired link is not possible or desirable. Microwave systems are able to transport voice, data, and video information to remote sites via point-to-point communications networks.

Some of the microwave disadvantages are:

- Microwave is point-to-point line of sight radio. This means that for each field device, it is necessary to deploy at least one pair of radio transmitters/receivers. When the radio line of sight is obstructed by any physical object, an additional radio link pair is necessary. Future tree growth or building construction could obstruct or degrade an operating microwave radio link.

- Microwave radio links are expensive. With literally hundreds of possible ITS devices in a system, this means a substantial up-front cost.

- Each microwave radio link must be licensed with the Federal Communications Commission (FCC) before putting it into operation. Each license petition requires: a site survey, a detailed path analysis, frequency coordination with other local area users, and the petition must be certified by a licensed radio engineer. This is time consuming and costly, and not always successful.

- In metropolitan areas, such as Buffalo, radio microwave activity is very common and active. Radio frequency coordination for microwave might prove a very difficult task. This is so because the existing microwave users have probably been licensed to the lower (and better) frequency bands. Although the higher microwave bands (18 GHz and 23 GHz) could be available in this area, these bands are typically limited to short ranges. The microwave signal is attenuated not only by distance, but also is susceptible to heavy rain, snow, or fog; under such conditions, ITS is needed most.

4.2.1.5 Spread Spectrum

The use of spread spectrum radio (SSR) as a medium for traffic control systems is gaining popularity across the nation for limited implementations. This is particularly true where communications infrastructure, cable and conduit, is non-existent.

Some advantages of spread spectrum radio include:

- license free operation
- low construction cost
- secure communications.

Disadvantages include the following:

- no protection under Part XV FCC licensing
- requires line-of-sight antenna propagation
- unproven in high density areas for wide scale implementation.

SSR can be used for point-to-point or point-to-multipoint communication lines. Radio signals are transmitted on individual channels equally spaced across the operating frequency range of the radio. This frequency spacing limits the number of channels to a maximum of 29. This limitation can easily preclude the use of SSR in areas with large numbers of controllers or cameras in a geographically condensed area.

4.2.1.6 Packet Data Radio

There are various versions of packet data radio services available today. The two major options are private packet switched networks, such as RAM Mobile Data and ARDIS, and public switched networks built around the Cellular Digital Packet Data (CDPD) standard.

The theory behind the options are the same however. The data is transmitted as discrete "chunks", or packets, of data rather than a continuous stream of data.

RAM Mobile Data is a joint venture between RAM Broadcasting and BellSouth. The RAM Mobile Data network is designed around the Mobitex wireless technology. Mobitex is an international standard based upon open, non-proprietary protocols for two-way, wireless data communications.

Mobitex is continuously enhanced under direction from the Mobitex Operators Association (MOA), an international group that manages the Mobitex specifications. Mobitex is a proven system, having been in operation for 10 years. The RAM network provides service to over 90% of the US metropolitan areas, while Mobitex networks are running in Canada, the United Kingdom, Sweden, Finland, Norway, Australia, the Netherlands, Belgium, and France, among others.

The Mobitex open standard approach ensures compatibility among devices produced by different manufacturers. Mobitex-compatible communication devices that operate over the RAM network include Ericsson GE, Fujitsu (Poqet), Grid, Hewlett-Packard, IBM, Motorola, and NCR.

The capacity of RAM's networks is virtually unlimited. Two-way data transmission is accomplished via multi-channel radio base stations, which can simultaneously operate up to 16 channels. RAM has as many as 30 channels available in each of the larger metropolitan areas. RAM can expand network capacity transparently to the subscriber by adding channels to existing base stations or by deploying additional base stations. The system makes use of frequency agile modems to maximize channel utilization by allowing transparent selection of the most favorable channel at a given subscriber location.

Data is sent over the RAM networks in short bursts of information packets. Each packet contains up to 512 bytes of information, the equivalent of 3/4 of a page of text. Longer transmissions are transparently broken into packets of 512 bytes and seamlessly reassembled at the receiving end.

RAM's technology ensures seamless, accurate transmission with an undetected bit error rate equivalent to that achieved with today's landline modems. Numerous fault-tolerant systems are employed, including link-level data checking and forward error-correction. Because of the unique error checking, only blocks of data with errors need to be re-transmitted.

Current ITS applications utilizing the RAM/Mobitex standard include the Ministry of Transportation of Ontario where RF detectors by EIS (RTMS) were interfaced to RF modems that sent the data packets to the operations center. This was a test installation, recently concluded, however it is expected the Mobitex wireless packet data transmission option will find increased usage in future

ITS applications for small scale installations. This technology is still too cost prohibitive for larger scale installations, but service costs may decrease over time as competition increases.

4.2.1.7 Cellular

The public packet data network is the Cellular Digital Packet Data (CDPD) system. CDPD is a fast and efficient digital system that overlays the existing analog cellular network. The CDPD standard is also an open standard protocol. The method of transporting data is the same as within the RAM or ARDIS network. The data is separated into small packets, sent to the desired destination, and then reconstructed back to the original message. Each communication device has an Internet Protocol address, much like a phone number. This allows the data to transport directly to a computer with an internet address, if the computer is connected to the network. The size of the packet can be up to 2000 characters in length.

CDPD is slowly evolving across the U.S. since existing cellular networks need to be upgraded to handle the packet data. There is no FCC licensing required. Costs are contained to the provision of cellular data transmission equipment and the cost of packet data transmission. Since CDPD will directly compete with RAM, it is expected that the costs for data transactions will range from 3 to 20 cents for nominal size messages.

Both cellular providers in the Buffalo area have no immediate plans to upgrade their infrastructure to accommodate CDPD. Communications via cellular will be limited to voice calls and low speed data over conventional cellular circuit switched modems.

4.2.2 Communications Transport Methodologies

There are basically two methods for transporting information along a communications medium. The first method would be analog transmission, which is information derived from measurable quantities from electrical or optical signals (i.e., amplitude or frequency). The second method would be digital transmission, which is information derived from a binary-based electrical or optical signal (i.e., 1's and 0's).

4.2.2.1 Analog

Analog communications can transport voice, data, and video information over all media, although analog is quickly being replaced with digital communications.

Examples of analog communications include:

- telephone service from phone company to home
- AM and FM radio
- cable TV service from CATV company to home
- cellular phone service.

Analog communication is traditionally less expensive than digital, however analog introduces a higher level of noise and/or distortion to the resultant signal.

Areas where analog proves beneficial are for short haul distances, since the signal tends to degrade over distance.

Copper twisted pair cable can support analog voice and low speed data up to bandwidths of approximately 8 kHz. Telephone service from the phone company is limited to 3 kHz, which is why conventional modems are typically limited to speeds of 28.8 kbps, the maximum for any dial-up service considered for ITS.

Private copper systems can use wider bandwidth equipment since the phone company band-limited equipment would not be present.

Coaxial systems use analog transmission with either AM or FM for high bandwidth applications. AM transmission for video, used for CATV, allows the transport of multiple video signals simultaneously on the order of 60 or more channels.

Fiber optic systems also utilize analog transmission for the same applications as copper twisted pair and coaxial systems. The use of fiber optics increases the distance that the analog signal can travel before degradation. The conversion of AM coax to AM fiber for CATV companies is rapidly being deployed.

4.2.2.2 Digital

Voice and data systems very rarely use analog transmission currently. The trend in the telephone industry is to use digital transmission as much as possible. The telephone industry has used digital techniques for decades, creating the National Digital Hierarchy. The NDH is the North American standard to package and transmit information in a digital format. The advantage is that the information that comes out is exactly the same as it was going in, no information is lost. This results in higher quality and more reliable service.

The transmission rates employed by standard telephone equipment have, as their basis, a 64 kbps unit, commonly referred to as a channel unit, which is designated as a DS-0. A DS-1 unit is a multiplexed serial stream of 24 DS-0s. Higher order multiplexed serial streams are: DS-2, comprised of 4 DS-1s; and DS-3, comprised of 28 DS-1s.

A recent standard of high transmission rates has been adopted for optical transmission of a variety of signals, including telephony. These rates are based on a DS-3 unit. An OC-1 signal at 50 Mbps, can carry 1 DS-3 signal; an OC-3 signal, comprised of 3 OC-1s, can carry 3 DS-3s. Up to 48 OC-1 units can be multiplexed under this standard to create an OC-48 signal at 2.4 Gbps. Future standards will allow OC-96 and OC-128 signals. Present standard units are summarized in the following table.

SUMMARY OF STANDARD TRANSMISSION RATES

DESIGNATIONS			CHANNELS	RATES
T-0	DS-0		1	64kbps
T-1	DS-1		24	1.5 Mbps
T-2	DS-2		96	6.3 Mbps
T-3	DS-3	OC-1/STS-1 *	672	45 Mbps
3 T-3		OC-3/STS-3	2,016	155 Mbps
		OC-12/STS-12	8,064	620 Mbps
		OC-48/STS-48	32,256	2.4 Gbps

* A true OC-1 signal is 51 Mbps including overhead bits. It can accept a DS-3 45 Mbps signal.

Video systems have primarily used analog transmission due to the high level of information to be transported. Full-motion color video requires a nominal bandwidth of 6.0 MHz. Direct conversion to digital for a single full-motion image, without advanced compression techniques, would be approximately 90 Mbps. Present day technology can compress video signals for transmission over standard telephone using a codec (coder/decoder). However, once a signal is compressed, it is no longer full-motion video. The more compressed the signal, the higher the loss in signal quality and perceived motion.

The advantage of a digital video signal is that there is no information lost or distorted during the transmission or reception process. This allows the signal to travel longer distances at a higher quality level, an ever-increasing goal of CATV companies.

The cost to transmit digital video has historically been quite high. The push for digital video over standard phone lines has introduced codecs (< 1.544 Mbps) which cost approximately $20,000 per end for a single video channel. However, as the transmission rate increases, the cost decreases.

Non-standard digital systems (non-NDH) are transmitting video at 192 Mbps for approximately $3000 per channel. The equipment cost is obviously less expensive, but is dependent on a medium that can handle the bandwidth, (e.g., a fiber-optic or microwave system).

4.2.3 Communications Transport Technologies

4.2.3.1 Voice/Data

The previous generation of equipment mentioned above is described today as asynchronous equipment. All DS-0, DS-1, DS-2 and DS-3 equipment available today is of the asynchronous type.

Though the multiplexing of digital data by this equipment must be "synchronized" to form the exact composition of the 1.544 Mbps data stream of a DS-1, or the 45 Mbps stream of a DS-3, the start of transmission by a piece of equipment in one fiber node to the corresponding equipment in the next node is not synchronized to a "master" clock, therefore the term asynchronous.

The main disadvantage to this type of equipment is that there is no standard for the units other than the transmission rates, (i.e., 1.544 Mbps, etc.) The formatting of the data blocks differs from one manufacturer to another, hence, one DS-3 unit may not be able to communicate with another DS-3 unit if they are not from the same manufacturer.

The latest generation of equipment, the "add-drop" variety, is the synchronous type. It allows circuits to be added to, or dropped from a stream of data. Its transmissions are coordinated to a master clock. Synchronous equipment is only available in the OC-1 and higher transmission rates (OC-3, OC-12 and OC-48), and these levels are not all available from any one manufacturer. All synchronous equipment, however, is built to the "Synchronous Optical NETwork" (SONET) standard, therefore, one manufacturer's OC-3 unit should communicate with any other OC-3 unit on the market.

This equipment compatibility guarantee and the "add-drop" capability of the SONET equipment make it the recommended choice for optical transmission at these data bit rates.

4.2.3.2 Video

Two of the more common methods of transmitting video are analog FM and AM transmission.

FM transmission is the most widely used technology for video. Distances of up to 12km are attainable for FM video over multi-mode fiber and equipment. Single-mode fiber and equipment will yield an even higher range (> 50km). Multi-mode FM video is typically used for single channel short-haul transmission. Single-mode FM video is used commonly for multi-channel video for short to medium haul transmission.

AM transmission on coaxial cable has been widely used by the cable TV industry for years. It allowed large numbers of channels to be transmitted over a single coaxial cable. AM transmission on fiber is relatively new to the industry, but it strives for the same benefits as AM coax. It also allows for a large number of channels, however it is limited by distance. Current technology can carry up to 100 channels per fiber, but only for a limited range before the signals degrade to an unsatisfactory level.

A third method of transmission of video is digital transmission over fiber. As discussed earlier in Section 5.1, digital systems are available using standard telephony and proprietary systems. A single fiber can carry up to 24 full-motion digital video signals.

By using digital transmission for video, it allows the possibility of integrating the video with voice/data applications under a common network. However, integrating video with voice/data could increase the cost of the network terminal equipment by as much as tenfold. The reason for this is that each network node would have to be sized for much higher bandwidths than with strictly a voice/data network. The higher bandwidth equipment becomes progressively more expensive as the bandwidth increases.

Another form of transmission over fiber is wave division multiplexing (WDM). This can be used in conjunction with either AM, FM, or digital video, since it is the lightwave that is being manipulated. Different wavelengths of light are multiplexed onto a single fiber. At the receiving end, the light signals are reconstructed to be sent to the corresponding receivers. This technology will allow the capacity of a fiber to expand approximately twofold (i.e., the 24 video signals on a single fiber could be expanded to 48 per fiber).

Due to the large bandwidth required for video, architectures are somewhat limited. Three possible architectures are:

- Single Channel Point-to-Point - This is an extreme case where every video signal would be transmitted over separate fibers back to central. With an estimated 100 cameras in a system, this would require 100 fibers.

- Multiplexed Point-to-Point - This is similar to the single channel point-to-point scenario, where every video signal is accessible simultaneously at central. However, the benefits of multiplexing reduce the fiber count by more than tenfold. Assuming 100 cameras and 10 channels/fiber, 10 fibers are required as opposed to 100 fibers.

- Switched Multiplexed - This scenario takes the switching out of central and distributes it to the field. The single point of failure of a central switch is now transferred to multiple switch points. The disadvantage to this scenario is that blocking is introduced, where a particular camera may not be accessible if the other channels are being utilized by other viewers. This becomes more critical when the number of monitors approaches the number of available video signals.

4.2.4 Institutional Issues

With most communications systems come a range of institutional issues that need to be addressed. Factors such as public/private partnerships, leased versus owned facilities, and inter-agency resource sharing are some items that can speed the deployment of ITS communications or bring it to a halt depending upon the level of importance that these issues are defined.

4.2.4.1 Leased vs. Owned

The primary question when considering a communications system is whether to own the system or lease service from a communications provider. The question is most often answered when the communications requirements are heavy, usually resulting in high recurring costs if leased services are selected.

Most utilization of leased services proves to be cost effective only for temporary or small scale installations. Large installations for cable based systems almost always have a positive cost-benefit ratio compared to leased services over a 10-20 year life cycle.

NYNEX is the local telephone utility in the Buffalo metropolitan area. The communications services that are offered by NYNEX start with plain old telephone service, otherwise known as POTS, that is equivalent to typical residential service. This service will allow voice or low speed data up to 28.8 kbps to nearly any location in the metropolitan area. Higher speed services are not available everywhere, and are dependent upon the particular location to be served. These services may include:

- DDS (56 kbps)
- ISDN (64 to 128 kbps)
- T-1 (1.544 Mbps)
- T-3 (45 Mbps)
- SONET OC-3 (51 Mbps).

Costs are difficult to obtain without presenting detailed information. The first question always asked by the telephone utility is "What is the address for the desired service?" Without this address, it is nearly impossible to obtain a quote. However, rule of thumb estimates range from approximately $50 per month for POTS, DDS, and ISDN, to upwards of $1000 per month for T-1 rates and above.

Cellular telephone service in the Buffalo area is provided by CellularOne and Frontier Cellular. As presented earlier, digital service is not available. Only circuit switched analog service is available, allowing 4.8 to 9.6 kbps effective throughput over conventional cellular modems. CDPD will not be available for the foreseeable future. Cellular modems cost approximately $400-500, while the service costs approximately $29 per month plus $0.10 per minute for standard service. Special data rates are available at approximately $5 per month plus $0.15 per minute peak and $0.05 per minute off-peak.

Private data radio leased services, such as RAM Mobile Data, provide packet data at rates around 8 kbps with an effective data throughput of 4.8 kbps. Costs would include the provision of radio equipment and the cost for data packet transmission. Radio/modem costs are approximately $200-$1000 each, with data transmission costs ranging from 3 cents for a 20 byte packet to 12 cents for a 512 byte packet. The one time activation charge per terminal is $50, while the monthly subscription fee is $25 per terminal.

The decision to go with leased services needs to be made on a case by case basis. Leased services are very useful for bridging gaps in cable based systems or for providing remote links between operations centers where agency right-of-way may not exist for private communications, provided the required bandwidth exists with the utility company.

4.2.4.2 Public/Private Partnerships

One option for gaining communications without building a private system is to partner with private enterprise. The first experience with partnering was with local CATV operators. Whether required through franchise agreements or through good-will, CATV operators commonly offered bandwidth space within their coax cable plant.

This has expanded greatly in recent years with increased interest generated by the Telecommunications Act of 1996. Many agencies are considering partnerships with telecommunications providers in an effort to get all or parts of a system implemented with minimal cost. In return, the provider receives benefits in the form of right-of-way access, duct access, revenue generation, etc.

The media typically considered for partnering is fiber optics. It has the greatest capacity and expansion potential, and is the media for choice for future communications installations. Wireless bandwidth is typically at a premium, therefore few options exist for resource sharing.

Agencies that have already established partnering agreements are as follows:

- New York State Thruway - The NYSTA has contracted with MFS to install fiber along all Thruways in return for a certain number of stands.

- State of Missouri - The Missouri Highway Administration has contracted with Digital Teleport Incorporated (DTI) to have installed over 1300 miles of fiber along state freeways. MHA receives six fibers within the cable, with associated telecommunications equipment and maintenance, dedicated to MHA use. In return, DTI receives exclusive access to the same ROW for its own fiber-optic system.

- State of Maryland - The Maryland Department of General Services has contracted with MCI and Teleport Communications Group for shared resources. This agreement includes over 75 miles of fiber optics along I-95. Maryland will receive 48 fibers, equipment to utilize 24 of the 48 fibers, and maintenance services. Each partner will own its own fibers, but only MCI will physically access the system.

- Ohio Turnpike - The Ohio Turnpike Commission has several non-exclusive licensing agreements with private firms for the installation of telecommunications infrastructure along the right-of-way. Projects and locations vary, however each case receives a fixed annual license fee of $1600 per mile and rights to use the fiber optics for Turnpike purposes at low or no cost.

- Bay Area Rapid Transit - In a unique agreement, MFS Network Technologies has contracted with the Bay Area Rapid Transit (BART) in the San Francisco area for procurement of a fiber optic system supporting rail operations from MFS and for MFS to invest funds to install additional conduit throughout the system to lease to carriers willing to pull their own fiber. Caltrans is a silent partner because some of BART's right-of-way is leased from the State of

California. BART receives 91% of lease revenues from MFS owned conduit, MFS retains 9%, and Caltrans receives part of BART's revenues as well as the use of four fibers.

- Additional investigations are underway with the Illinois Tollway to install empty duct for carriers to lease, with the Chicago Transit Authority to partner with a CATV company in exchange for fibers, among various other agencies across the country.

It may be too early in all of these agreements to determine whether any have been truly successful for both parties involved. Two obvious problems are immediately addressed in that the carrier gets access to valuable right-of-way and the agency gets badly needed fiber optic communications with minimal cost. However, there are many institutional issues that need to be addressed with each case to be considered. For instance, is there any legislation that prohibits public/private partnerships, as is the case in Colorado? Can the ROW be accessed for non-highway and non-transportation functions? Will the allowed access by one provider be considered exclusive and therefore unfair competition to other providers? If a system goes into failure, who gets top priority for restoration of service? If service is interrupted, is the agency liable for lost revenues by the provider? If the provider is performing maintenance on the system within agency ROW, is the agency liable for accidents involving the maintenance personnel with other motorists, including fatalities?

These are just some of many issues that need thorough investigation before partnering can be accomplished.

4.2.4.3 Inter-Agency Resource Sharing

Resource sharing between agencies is similar to public/private partnerships, however there are fewer institutional issues to contend with. The popularity of fiber optics and the dire need for advanced communications is causing many agencies to consider private communications systems. With some foresight, agencies can achieve their systems with less cost and in less time by combining resources and avoiding duplication.

For instance, the school system decides to implement a fiber optic based distance learning network, the department of transportation decides to implement a fiber optic based ITS network, and the transit agency decides to implement a fiber optic based communications network to handle all voice, data, and video requirements for rail operations. Since all three of these would cover a great distance, full implementation may take many years. By combining resources, the infrastructure can be built to service all three networks with an accelerated schedule.

4.2.4.4 Recommendations

The field of communications is constantly changing, with new technologies being introduced as often as every six months. The primary focus should be for a state owned fiber optic SONET backbone for the Buffalo region, however the industry needs to be monitored as design and implementation stages approach. Decisions such as whether video should be transported over the

SONET backbone or transported over a separate parallel video backbone will be impacted by the latest technologies.

The evolution of SONET technology has introduced a new standard for communications called Asynchronous Transfer Mode (ATM). ATM was developed to provide a common ground for networking data, voice, and video communications. ATM is an application layer that is transported over a SONET communication system, however some ATM is being implemented over copper systems, using SONET transmission rates. ATM is rapidly being deployed in many industries to migrate voice, data, and video communications, allowing dynamic allocation of bandwidth to user needs. For example, in addition to standard bandwidth allocated to network users, the spare bandwidth can be used as needed to transport larger applications such as a CCTV video signal, graphic images, or video conferencing. Use of ATM in ITS has been limited, with one of the first applications being used for the ETTM on Highway 407 in Ontario, Canada. ATM should be investigated for possible applications within the Buffalo regional FTMS, as part of the proposed SONET fiber optic backbone communications system.

Wireless technologies should be considered mainly for remote installations where a backbone cable link is impossible. Spread spectrum holds the most promise for these applications since no FCC licensing is required, also the radio system would be state owned.

4.3 PROCESSING

A description of the computer information processing requirements for the Buffalo/Niagara Falls ITS system involves defining the processing requirements and identifying the associated technologies currently being deployed or being designed for similar ITS systems, nationwide.

The processing requirements specifically address computer/communications hardware and associated operating systems which are critical to satisfying the functional requirements of ITS. Custom application software programs which are implemented on these systems are not addressed in this section.

A large number of widely varying hardware configurations are currently in existence in ATMS/ATIS and other ITS subsystems deployments. Arriving at the best choice for Buffalo ITS requires establishing a set of selection criteria which can be used to identify the various important advantages and disadvantages.

Computer hardware/software technology is rapidly advancing. This section provides an assessment of the current technologies and, by extrapolation from existing trends, attempts to predict what will be available in the near future. the performance and useability requirements are key to assessing the computer hardware/software technology that would be suitable for ITS deployment in the Buffalo/Niagara Falls region.

The primary criteria are as follows:

Functional Processing Requirements. The basic functional hardware requirements are:

- capability to acquire real time traffic data from field devices;
- process large amounts of real time data;
- perform traffic analyses;
- perform traffic control functions;
- consolidate data for use by various software processes;
- control field devices;
- disseminate information to the public through various information dissemination technologies;
- perform database administration.

Each of these functional processing requirements requires extensive central processing unit (CPU) performance capabilities as well as high speed data communications capabilities.

The center computing hardware must enable all real time processing tasks which run on ATMS systems to be within acceptable performance tolerances, particularly during peak operating periods. Execution of non real time (background) tasks such as database administration must not adversely affect real time ATMS/ATIS and CVO system performance. This hardware selection criterion affects the choice of CPU and input/output (I/O) subsystem configurations. The current trend towards distributed computing environments maximizes performance by minimizing processor load.

Capital Costs

Over the past several years the cost of powerful RISC-based mini computers has come down dramatically, approaching the cost of high end fully distributed PC architecture systems. This leveling of computing power costs has increased the number of suitable hardware platforms available for central ITS computing functions.

Maintenance Costs

In addition to the basic hardware costs, the price of both hardware maintenance and operating systems support must be considered carefully. In some cases, the cost of RISC-mini computers may be very attractive, but the associated maintenance and support costs may be extensive.

Reliability

Reliability of advanced computer/communication systems is critical to the overall deployment and operation of these systems over an extended period of time. Robustness is a major factor that needs to be evaluated in selecting advanced hardware/computer systems for ITS applications.

Multi-vendor Integration

The proliferation of hardware and software components from different vendors which are currently in the market underlines the need for "programmable platforms" as opposed to platforms solely utilizing proprietary software. Open programmable systems are capable of allowing users to customize reports, screen displays, and other application functions such as data collection, to tailor to specific environments. This multi-vendor integration capability also facilitates multiple application support.

Affordable Redundancy

System down time can be reduced automatically by switching to hot standby computer systems during primary computer failure. This feature is currently available in advanced hardware/software systems.

Scaleability

The current computer hardware architecture (options) provides for expansion in terms of multiple processors and memory for central/distributed computer systems, which allows for future needs.

Open Architecture/Interoperability/COTS Support

The interoperability requirements and commercial off the shelf (COTS) software support capability are essential features that allow advance computer systems for ITS applications to be managed and maintained in a user friendly environment. These features support many different tools and third party applications.

Portability

This feature essentially allows for software that can easily be ported to more powerful platforms in the future.

4.3.1 Centralized Systems

For advanced traffic control and management systems (ATMS, ATC) the architecture of choice a few years ago was a centralized system environment. In order to obtain the central processing power and communications I/O functional capabilities the only efficient computer systems architecture platform was the mini computer system. The DEC VAX system, Concurrent mini computer system, IBM mini computer and HP mini computer are all examples of such systems. These multi-processing, multitasking mini computer environments were capable of managing the communications overhead required for real time data acquisition and control of ATMS/ATIS and CVO applications.

These architectures are still considered for some application environments within the ITS systems for metropolitan systems. The centralized concept has advantages in being tightly coupled with respect to hardware and software and highspeed internal bus architectures which allow for real time access to large amounts of data.

The physical appearance of the centralized mini computer environments have changed over the years but the functionality has remained somewhat constant.

4.3.2 RISC-Based Systems

These are hybrids of centralized/distributed architecture and reflect the state of the art with respect to computing power and communications capability. They also contain the advanced interfaces to peripherals that are used in ITS applications such as communications processing systems and networking capabilities.

The operating environments of these systems are typically UNIX based with the current crop of Windows NT based systems being more prevalent in this category. Most work stations are still based on the RISC architecture and have advanced functions such as 3-D graphics and networking environments.

Sun workstations, DEC Alpha systems and HP RISC systems with Windows NT and Sun OS are typical of this environment.

4.3.3 Advanced PC Architecture

This is the newest category of advanced computer hardware/software systems that are currently being deployed for ITS applications. These represent the fastest growing segment of the market with fully distributed advanced networking capabilities as well as redundancy and backup capabilities using commercial off the shelf software systems. The biggest advantage of these systems are the extensive user base which leads to low cost high function commercial off the shelf tools being available to manage most ITS functions. The distributed nature of this architecture represents the interoperability/flexibility. This type of computer system architecture may be most relevant to the Buffalo/Niagara Falls ITS.

4.3.4 Associated Peripherals

All of the above computer systems contain peripherals which are critical to the basic functionality of ITS systems. These peripherals include as a minimum the following:

- advanced laser printers (monochrome and color);
- high resolution graphical user interface monitors (minimum 1280 x 1024, 24-bit color);
- advanced pointing devices;
- high capacity disk drive;
- advanced communications processor subsystem (serial communications);
- high speed local area network interface system (100 BASET, UTP architecture);
- flat bed color scanner (24 bit, 600 dpi resolution);
- high resolution projection systems (7' x 9', 1280 x 1024, 15.75 kHz to 75 kHz bandwidth systems);
- advanced telephony systems which integrate voice data and video multimedia into console.

4.3.5 Review of Current Computer Hardware/Software Systems

The following table summarizes a selection of current ATMS/ATIS systems being deployed:

SYSTEMS	CENTRALIZED (MINIBASED)	DISTRIBUTED (RISC BASED)	DISTRIBUTED PC BASED
1. ATMIS (Allied Signals)	DEC VAX4000		
2. CALPOLY TMC		SUN ULTRA 1	
3. MIST PB FARRADYNE			NOVELL SERVER
4. GARDNER ROWE			WINDOWS NT
5. IBI ATMS SYSTEM		DEC ALPHA	
6. JHK SMART CORRIDOR		SUN SPARC	
7. LOCKHEED MARTIN INTEGRATED TMC		SUN SPARC	
8. NET - CALTRANS	HP9000-725		

The above table reflects the majority of these systems are moving to distributed RISC/PC based architecture with contempory operating environments such as NT and Sun OS. It is important to reflect the trend and implement a similar environment for the Buffalo ITS system.

4.4 INFORMATION DISSEMINATION

4.4.1 Variable Message Signing

Variable message signing (VMS) is used to disseminate traffic related information to motorists by means of strategically located signs along roadways. The signs are typically configured in a multi-line display (two to three lines) with a static or dynamic message to inform the motorist of downstream traffic conditions and to allow the motorist to change routes accordingly.

The benefit of using VMS for information dissemination is that the audience (motorists) receives consistent traffic information, as opposed to varying and even conflicting traffic reports from multiple sources such as radio stations. There is no need for specialized in-vehicle equipment. All motorists receive the same information, allowing the traffic management agency to have greater control over a strategic or incident plan.

However, the success of a VMS system is dependent upon not only the accuracy of the information being displayed, but also the ability of the sign to display the message in all conditions. VMS systems have been in use for over ten years, but because of display technology limitations, few systems can be regarded as completely successful.

This section will present the various technologies that have been used for VMS systems. Passive displays (reflective) and active displays (light emitting) will be addressed.

4.4.1.1 Reflective Flipped Disk VMS

Reflective flipped disk variable message signs are currently the most common VMS used in the ITS industry, including hybrid flipped disk signs which will be presented later. The flipped disk sign is a fully programmable dot matrix with alpha-numeric and graphics capability, each disk controlled by an electro-magnetic pulse. The disks are colored in a fluorescent yellow against a black background.

Power consumption is typically low for a flipped disk sign. Power is only applied when a pixel is activated. Visibility is excellent in direct bright sunlight, however it drops off considerably in normal atmospheric conditions. Nighttime visibility is poor, requiring external illumination thus increasing overall power consumption.

- Low luminance - nighttime visibility is lower than conventional freeway static signs
- Low contrast ratio - display is not clearly visible to motorists when backlit by sunlight
- External and internal illumination schemes are plagued by problems related to glare and/or uneven lighting levels
- Flip-disk mechanisms are prone to fading and ultraviolet damage and require routine maintenance activities.

While flip-disk technology compares favorably with other technologies from a cost perspective, the limitations noted above constitute serious shortcomings. The reflective flipped disk VMS no longer meets the optical performance demanded for traffic use. Many transportation agencies in North America either would not consider flip disk technology for future use or are in the process of retrofitting their existing flip disk VMS with light-emitting technology. It is therefore recommended that the flipped disk technology only be considered with light-emitting technologies for VMS applications in the Buffalo area.

4.4.1.2 Incandescent Bulb VMS

Incandescent bulbs were the first light emitting technology used for VMS applications. Used heavily in California and on the Illinois Tollway, this technology performs well in inclement weather. However, this technology is characterized by high power consumption and intensive routine maintenance requirements associated with bulb replacement. The inefficiency of the incandescent bulb, where only 2% of the energy is converted to light, has been a major drawback in the acceptance of this technology.

The California Department of Transportation (Caltrans) is not considering bulb matrix technology for future traffic management applications. For the reasons indicated, the bulb matrix technology is not recommended for implementation in the Buffalo area and will not be further evaluated in this report.

4.4.1.3 Fiber Optic VMS

Fiber-optic VMS have been installed recently by various agencies, many of whom have had previous experience with conventional flip disk displays. Typical applications of this technology for sign display systems incorporate a series of halogen light sources to illuminate an array of display pixels via bundled fiber strands. The fiber ends at the display face are electro-magnetically shuttered to control the display of the pixels. In large scale applications, displays are typically monochrome. Other colors can be used for message display, and control can be achieved either from the operations center or locally in the field. Multi-color fiber optic VMS displays are not an off-the-shelf product.

The fiber-optic bundles are illuminated by means of quartz halogen lamps. Two lamps are usually provided for each module. One of the lamps act as a backup which is automatically activated in the event of the primary lamp failure.

The electro-magnetic shutters block the passage of light in the closed position. The shutters are controlled by pulses and remain in their position with zero electrical consumption after the pulse has been applied.

A variety of manufacturers are currently marketing shuttered fiber-optic displays, and transportation agencies experienced with its application have expressed satisfaction.

This technology provides superior visibility under all lighting conditions with a 10 to 30-degree cone of vision which can be significantly enhanced by affixing reflective material to the shutters. The brightness does not deteriorate over the life of the product thus increasing life expectancy. This technology has excellent reliability and is not adversely affected by high/low ambient temperatures. It has low power consumption and maintenance requirements.

4.4.1.4 LED VMS

Light emitting diode VMS are rapidly gaining popularity in the ITS industry. The technology typically operates on the basis that each display pixel is comprised of a cluster of high intensity light emitting diodes. Each cluster is recessed in a black cylinder so as to minimize the effects of direct sunlight on the visibility of the display. As a result, the cone of vision of the display is typically directional (e.g., 14 degrees) but exceeds the minimum 10-degree cone of vision needed for freeway applications. This technology provides good visibility under most lighting conditions but the brightness deteriorates over time thus shortening the life expectancy of the product.

Early versions of the LED sign boasted of more efficient light transfer than incandescent signs. This is because LEDs transfer nearly 100% of the energy into light, thereby reducing the power consumption considerably compared to the incandescent sign. However, the available LEDs could not provide the necessary light output suitable for traffic use.

In addition, the effective color of the sign display was difficult to control. At the time, red LEDs had the best performance over time and temperature. But, a small percentage of the motorist public are dichromatic (color-blind) to colors in the red spectrum. Red LEDs were combined with green LEDs to produce an amber/orange color, the preferred color for VMS displays. Unfortunately, green LEDs degrade at a faster rate than red LEDs, thereby resulting in an uneven display over time.

The introduction of high intensity amber LEDs at a wavelength of 590nm have improved the performance of LED VMS considerably and is rapidly becoming more accepted for VMS systems.

LED variable message signs have a significant advantage over other comparable technologies in the sense that the display elements incorporate no moving parts. Conversely, this technology is characterized by high power consumption and related thermal considerations due to the heat sensitive nature of the LED. The life of this technology is adversely affected by the high ambient temperatures. The excessive thermal output should, however, be managed by proper ventilation. Power consumption is managed by duty-cycles, where the LED is switched on and off at a rate to conserve power, but at a frequency unnoticeable to the human eye.

The new amber AlInGaP LED technology was first introduced in 1992. According to researchers (Hewlett Packard Co.), the new technology is on the order of ten times the light output of older generation LEDs. The light output per pixel is now compatible with the fiber-optic signs. However, at the present time, the capital cost of these AlInGaP LED VMS is still higher than their fiber optic counterpart. The expected operating life of the older LED generation to 50% degradation in intensity is approximately 30,000 operating hours. The light output performance of the new generation of signs is still being collected but it is expected to perform better than the older generation.

4.4.1.5 Hybrid Fiber Optic/Flipped Disk VMS

A recent development in light-emitting variable message signing is the hybrid fiber/disk technology which incorporates light-emitting fiber light source with the reflective flip-disk technology. The display is essentially a standard reflective flip-disk unit with the exception that each disk has a small opening to expose the end of an illuminated fiber strand. The disk viewing face is formed by an array of magnetized, pivoted indicators on a black matte background surface, electro-magnetically rotating to reveal a reflectorized disk, usually yellow, with a hole in the center of the disk through which fiber-optic bundles emit light on user request. The back of the disk contains a semi-circular shroud to prevent light emission in the "Off" position. The disk rotates in a 90-degree motion, and is controlled by electrical pulses. The disk remains in its position after the pulse is removed with no power consumption.

The rationale for this configuration is that the reflective flip disk provides superior visibility under conditions where the sign display is exposed to direct sunlight. In night conditions or backlit sunlight conditions, the output of the fiber provides very good visibility. In overcast, foggy and inclement weather conditions, the two technologies combine to maximize visibility.

While the fiber/disk technology does have the disadvantage of electro-mechanical actuation, the fiber-optic cable is less sensitive to heat generated by the lighting source and therefore, does not require extra ventilation. Feedback from users has indicated that the fiber/disk technology provides excellent visibility under varying lighting conditions, and a number of users are presently retrofitting existing reflective disk signs to the fiber/disk technology, including INFORM in Long Island, Illinois Department of Transportation (IDOT), and the Ministry of Transportation, Ontario. It is noted that both IDOT and INFORM have very favorable comments on the reliability of the flip-disk signs.

4.4.1.6 Hybrid LED/Flipped Disk VMS

Matrix Media has recently supplied and installed a hybrid LED/Flip Disk VMS for the MONITOR system in Milwaukee, Wisconsin, and previously for the INFORM system in Long Island, New York. The comments have been very favorable. This technology incorporates light-emitting LED with the well-developed reflective flip-disk technology. The display is essentially a flip-disk unit with a small opening at the top of the disk to expose a cluster of high intensity light emitting diodes recessed in a black cylinder as the light source.

In comparison with fiber/disk technology, the LED/disk technology has lower maximum light output level but still provides adequate visibility under all lighting conditions. Also, the LED/disk technology has lower maintenance requirements due to its individual module arrangement as opposed to the grouping of a 3-module unit for fiber/disk. Also, no luminares are required as lighting source. The operating power consumption of the LED/disk is about the same as that of the fiber/disk.

4.4.1.7 Recommendations

At present, it is recommended that only light-emitting VMS technology be used for the ITS in Buffalo. Indications are that the hybrid fiber optic/flipped disk technology is the more common technology being implemented throughout North America and provides the best available option of variable message signing. Single sign test implementations of LED and/or hybrid LED/flipped disk are increasing in many cities due to the promising outlook for LED technology, and it is most likely that LED technology will be utilized for full system implementation in the future.

From experiments, indications that a Luminance Ratio on the order of 10:1 between the character and the background gives optimum visual acuity. This value can be attained with fiber optics and LED technology, as such these technologies seem to provide the best visibility under all lighting conditions especially when the sun is directly behind the sign. Combined with the reflective flipped disk, these sign technologies provide a luminous intensity that is greater than the required values.

Finally, as the technology for variable message signing advances, limitations on the existing technologies may be eliminated and new technologies may emerge. In this case, a new analysis may be required to determine the correct course for pursuing successful VMS systems.

4.4.2 Highway Advisory Radio

Highway Advisory Radio (HAR) is a cost effective means of conveying detailed traffic information to a broad audience. Most vehicles are equipped with the necessary on-board equipment (i.e., AM/FM receiver) and transmitter hardware is relatively inexpensive. A wide variety of agencies including state DOTs, Turnpike Authorities and airports have utilized HAR to varying degrees of success. The use of solar powered HAR has allowed installation of antennas where power sources are difficult to reach.

The operating authority must take into consideration some unique functional aspects of HAR applications. While there is a wide vehicle population capable of receiving HAR information, motorists must be prompted to actively access the information by tuning their in-vehicle radios. This is a distinct disadvantage compared to VMS, which is a more passive medium. The voice delivery characteristic of HAR can be considered an advantage as it is not distracting to the driver and can provide detailed traffic event information. However, the operating authority must consider the resources required to maintain up-to-date reports. Recent systems use speech conversion technologies from automated text as opposed to manual recording. Another consideration is the relevance of the information to the particular motorist at a given location. Unlike voice information delivery over cellular telephone, the motorist cannot interact with the system to request information specific to the current route.

HAR applications can be categorized according to their transmitting range, including:

- area-wide broadcast within an available portion of the radio spectrum;

- local broadcast using low power (ten watt) transmitters;
- stationary traveler information broadcast using microtransmitters.

Area-Wide Broadcast. In its traditional form, an HAR system utilizes a single transmitter/antenna site to broadcast to an urban area. The difficulties with this approach lie in the licensing, antenna facilities, and the nature of the information to be conveyed.

FCC licensing is required for an area-wide system. Typically systems have utilized the expanded AM range (e.g., 1610-1710 kHz). Even if licensing is established, the coverage area could be impacted in the future by new or modified licensing for higher powered commercial broadcasters.

Larger transmitter sites require an antenna tower and ground grid. The costs for implementation of such facilities in an urbanized area can be prohibitive. As an alternate, some agencies have utilized a continuous "leaky coax" cable antenna along the corridor. This method is particularly well suited to tunnel applications. The Illinois DOT utilized leaky coax for surface freeways but subsequently abandoned the program after performance and maintenance problems.

From a functional perspective, an area-wide system typically employs a message of one to two minutes in length for its entire broadcast range. This may not be adequate to provide an appropriate level of detail for scheduled and unscheduled traffic events in a particular area or corridor.

Ten Watt (Low) Traveler Information Stations. The FCC has designated the 530 kHz and 1610 kHz band for licensed low power traveler information which cannot incorporate advertising or entertainment. Manufacturers such as Digital Recorders and Information Station Specialists market fixed and trailer mounted 10 watt transmitter stations for this application. Sites have a broadcast range of up to 6 miles and can be powered by AC mains, diesel generator, or solar panel. DOTs with experience in applying this equipment include California, New Mexico and Florida. While the solar power option is attractive in the southern states, it is unlikely that this will be suitable for the Niagara region.

100 Milliwatt Microtransmitter. Unlicensed 100 milliwatt microtransmitters are also available as standard products. These devices do not provide sufficient broadcast range for mobile users, but can be considered for stationary applications such as parking facilities and tourist areas. Attempts at synchronizing a series of microtransmitters to provide a broader coverage area under the Smart Corridor Program in California were not successful.

Recommendations. The ITS deployment program for Buffalo/Niagara Region should consider the application of fixed 10W transmitter sites at key nodes in the transportation network, such as freeway interchanges. Portable 10W units can be used for traffic management during construction. The central system could automatically download synthesized, location-specific messages to the field transmitters using wireline or wireless links. One potential application is the use of VMS to prompt motorists to tune in local HAR during non-standard conditions.

4.4.3 Kiosk

Publicly accessible, interactive kiosks are being increasingly utilized for a variety of applications ranging from tourist information in hotel lobbies to consumer product information in retail stores. Kiosks provide an opportunity to present a variety of traveler information including live video, real-time congestion information, and text based event data. Logical kiosk sites include parking facilities, lobbies, stadiums and other tourist attractions. A primary consideration when undertaking a kiosk deployment is the cost associated with installing and maintaining the kiosks and associated communications infrastructure. Consideration should be directed at integrating traffic information with other relevant kiosk programs, such as tourist information at hotel sites.

The ITS deployment program for the Buffalo/Niagara Region should explore opportunities to integrate traffic and road event information into multi-function kiosks at sites such as special event generators, tourist areas and large commercial developments.

4.4.4 Internet/Bulletin Board

In recent years, ATMS programs in regions such as Seattle and Toronto have provided remote dial-in access to receive current event and congestion information. The Internet now provides a widely accessible conduit for public access to ITS central systems. Most DOTs with active ATMS/ATIS programs currently operate web sites with varying degrees of real-time information available. Some are configured to enable the user to download video images from select camera sites. The ITS Online web site provides tours of various state DOT web sites, complete with evaluations/rankings.

Minneapolis is providing a congestion map and CCTV feeds to “The Traffic Channel” for two hours in the mornings.

The ITS deployment program for the Buffalo/Niagara Region should coordinate with Internet developments for the NYSDOT as a whole, with a view to establishing a presence for real-time information as it becomes available in the study area. This could potentially be provided by an independent service provider (ISP).

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5.0 SUMMARY

This report presented an overview of technologies applicable to the Buffalo ITS. The following recommendations have been made:

- Non-intrusive vehicle detection system - EIS RTMS microwave radar unit. (Needs to be confirmed by field testing.)
- Video detection system (intersection) - Autoscope Video Imaging 2004.
- In pavement detection system - Inductive loop (near term).
- CCTV, as needed - base technology = color CCD; details to be determined in design. Digital cameras recommended for further evaluation during design.
- Communications - SONET fiber optic backbone; spread spectrum for remote locations.
- Processing - Distributed - RISC or advanced PC based.
- Variable Message Signs - LED.
- Highway Advisory Radio - 10 Watt Transmitter.

It must be recognized that virtually all of the technologies discussed are constantly evolving and improving. As a result, detailed reassessment and analysis of each must be made in the design stage.

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