FINAL REPORT

Early Deployment of ATMS/ATIS For Metropolitan Detroit

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1.0 Background

The Michigan Department of Transportation (MDOT') is currently planning for the expansion of their current Advanced Traffic Management and Advanced Traveler Information Systems (ATMS and ATIS, respectively). Current ATMS and ATIS coverage include 32.5 freeway miles surrounding Metropolitan Detroit and an additional 212 freeway miles of coverage is in the planning stages.

In order to aid MDOT in assessing deployment strategies for the expansion of freeway coverage, MDOT contracted Rockwell International to conduct a 9 month engineering study and to provide guidance in the Early Deployment of ATMS/ATIS Technologies within Metropolitan Detroit. Studies have been conducted by Rockwell International to assess appropriate technologies, architectures, and deployment strategies for the expanded area of coverage.

Established and promising new technologies were assessed in order to maximize system efficiency and minimize costs (installation, operating, and maintenance). System components such as controllers, sensors, communications, and information dissemination systems were evaluated to determine compatibility with the overall system architecture. The system architecture, which was developed and finalized during this project, follows an open architecture model that provides MDOT the capability to use standard commercial-off-the-shelf (COTS) system components.

In addition to technology assessments, the Early Deployment project analyzed area traffic congestion to determine corridor priorities. This assessment was used to aid in the development of implementation plans and to identify which freeway corridors or segments warrant immediate ATMS/ATIS deployment to reduce congestion and improve traveler safety.

1.1 Introduction

Technology, architecture, contracting, and deployment recommendations resulting from the study enable MDOT to begin system design and construction. However, in order to demonstrate the implementation methods of new ATMS/ATIS components and system architecture quickly, an initial deployment phase has been initiated. The initial deployment activity uses an architecture that is a subset of the overall and final system architecture. Components that satisfy system functional requirements are recommended and deployed in a manner which will demonstrate capabilities and functionality of the new system architecture.

The goal of the initial deployment activity is to provide MDOT with an interim system in an area which needs immediate assistance in reducing congestion, increasing traveler safety, and enhancing incident management activities. Additionally, specific emphasis was placed in deploying IVHS technologies where particular user services are mostly needed in metropolitan Detroit. Existing infrastructure and components are used to reduce initial costs and minimize system deployment time. A unique deployment strategy is recommended to allow the initial deployment solution to be incrementally integrated into the final architectural solution. Although the initial deployment solution may not be physically equivalent to the final solution, the functionality of the system will be retained due to the modular and open architecture techniques used. The distributed processing architecture also allows deployment in a non-linear manner. Linear implementation, usually attributed to laying conduit and cable, cannot provide the mixed deployment functionality required by the initial deployment physical architecture.

In this report, the ultimate system architecture covering over 240 miles of freeway and trunkline is provided. Additionally, the application of existing and newly promising technology is assessed.

This document provides specific engineering analysis details and is segmented into the following sections:

Section 1 - Background
Section 2 - Technological Analysis
Section 3 - Priority Corridor Analysis
Section 4 - System Description
Section 5 - Engineering Design for Deployment

2.0 Technological Analysis

Technology assessments are conducted for major Advanced Traffic Management System (ATMS) and Advanced Traveler Information System (ATIS) components. These assessments evaluate key functional and non-functional (i.e. installation cost, aesthetics, operating and maintenance cost) characteristics which effect deployment strategies. Weight factors are applied to each key requirement and the components are analyzed based on their capability to satisfy the requirements. System components evaluated are:

- Traffic sensors
- Environmental sensors
- Video surveillance
- Control and data processors
- Traveler information dissemination
- Communication systems

Each assessment steps through an evaluation process that identifies alternate technologies, identifies trade matrix/selection criteria, performs analyses, and derives results/recommendations.

2.1 Traffic Sensors

One of the key characteristics of any ATMS is its capability to sense and monitor traffic conditions accurately. Various traffic sensing techniques have been developed in recent years and other innovative techniques are in development.

Traffic sensors are used to determine specific measures of effectiveness (MOEs). These parameters are communicated back to the traffic operations center (TOC) to aid in determining traffic conditions relating to the various sensing locations. Measures of effectiveness parameters that are widely used are:

- vehicle velocity
- lane flow rate
- lane occupancy
- vehicle classification
- vehicle counts
- travel time
- roadway density
- traffic headway

All of the MOEs listed above depend on the precision and accuracy of vehicle presence detection. These MOEs can be directly measured by traffic sensors or can be derived from basic presence and non-presence signals.

In the following sections, various vehicle sensing technologies are evaluated to determine the most viable and cost effective technology to be implemented during the anticipated deployment time frame. The sensor technology assessment is segregated into three categories; active and passive sensor technology and probes. Active sensors require a source signal to be emitted onto the roadway and a receiver circuit measures the change in the source signal reflection as vehicles pass over or through the sensing area. Passive sensors on the other hand, do not require an emitter signal. These sensors monitor the natural environment and detect vehicles by slight changes in the surrounding environment. Probes use actual vehicle positioning to determine traffic conditions. Such use of vehicles as probes in the near term is not foreseeable because the deployment of such in-vehicle positioning systems in the quantities required for probe use are not expected to happen immediately. However, as automobile manufacturers and private enterprises develop low cost vehicle positioning devices, the use of probes for calculating traffic congestion can be implemented. The system architecture provides the means to accept additional inputs to enhance system accuracy and performance.

2.1.1 Identification of Alternate Vehicle Detection Technologies

Active Sensors

Inductive Loops

The predominant sensor technology currently used is the inductive loop detector. A loop of wire is buried under the roadway nominally four inches below the surface. The wire is excited with a 10 KHz to 200 KHz signal generating an inductive field which is altered by the passage of a metallic object such as a vehicle. As a vehicle stops or passes over the inductive loop, the inductance is decreased. This change in inductance is detected by the associated driver/monitor electronics as a detection. This on/off (presence/non-presence) indication is normally processed by a separate processor to provide measurements of effectiveness parameters.

Inductive loops can be installed in two configurations, a single loop and by pairs. In a single loop configuration, presence and non-presence of vehicles can be detected. Lane occupancy, lane flow rate, and any other MOE which does not require vehicle velocity can be calculated accurately from a single loop configuration. Single loop velocity calculations can be accomplished in two separate ways. First, a statistical average vehicle length can be used to calculate velocity. However, the variance in actual vehicle lengths can contribute to over + 10% velocity errors just in the pure calculation (ignoring any detection fluctuations due to analog rise time variations). Second, an advanced detector amplifier circuit is being developed which measures the rate of change in inductance. This rate can be used to calculate vehicle velocities. Velocity values vary depending upon vehicle height and structure of the vehicle undercarriage.

The two loop configuration provides a more precise means of calculating velocities. The two loops are used as "speed traps" (also known as timing gates) to measure the time a vehicle takes to travel the distance between two loops. This time measurement, in addition to the fixed distance between the two detectors, can be used to determine vehicle velocities. The two detector configuration can also provide vehicle acceleration and deceleration information by comparing the two loop's presence pulse widths.

A concern with inductive loops is that failures are typically attributed to how well the loops are initially installed. Additionally, the associated maintenance effort and disruption of traffic flow during repairs require careful scheduling of these efforts. Other failures and reliability concerns can be attributed to poor loop detector design, poor implementation of maintenance practices, or some combination. Newer installation techniques that use better sealants and loop wire in PVC or polyethylene conduits have greatly improved loop reliability.

Inductive loop detector technology has been proven to operate very well for the past few years. Installation and maintenance problems are primary causes for failures and are not an inherent deficiency of the technology itself.

Microwave

Microwave detectors operate in a similar manner to radar detectors. Microwaves are transmitted toward an area of detection from an overhead mount. These microwaves are pulsed toward the roadway at a sampling rate of approximately four times a second. The reflected pulse to the roadway surface is measured as a function of time and as a vehicle passes through the detection zone, this interval is reduced due to the profile of the vehicle. Lane specific volume and occupancy data can be calculated if two detection zones are configured to measure vehicle speed. With slow sampling rates, these detectors do not provide accurate presence data at freeway speeds.

Newer microwave detectors operate at a sampling rate of up to one hundred times a second and are capable of providing multiple lane detection or presence data. However, data from the New Jersey Turnpike RTMS show significant variances in volume, occupancy and speed data as compared to inductive loop detectors. These variances can be attributed to improper or difficult setup procedures. Since microwaves are not visible to the human eye, exact detection zone setup information cannot be verified. Corresponding setup information can be misaligned with actual locations of detection zones which provides misregistered timing traps to the system software. This misalignment results in variances in calculated speed, occupancy, and vehicle classifications. Additionally, the system software must be able to accommodate different sized detection zones in order to assure accurate presence and timing registration.

Microwave detectors can be mounted in two fashions, 1) Side-fire or 2) Forward-looking. Sidefire mounting can be configured to provide lane specific volume and occupancy data. Vehicle speed and lane occupancy can be provided if two sensors are mounted adjacent to each other emulating a loop speed trap configuration. The side fire mounting technique (see Figure 2-l) allows maintenance activities to occur without lane closures and is virtually unaffected by construction activities. However, side-fire mounting techniques induce occlusion problems where high profile vehicles in the lanes nearest to the sensor block the microwave paths to other lanes. For example, if a smaller vehicle is traveling next to a tractor trailer truck, the sensor cannot detect the smaller vehicle. The truck height profile will most likely trigger the detector providing a false reading. This false reading can be negated by the processing controller by bounding reflected signal intervals to be limited to the lane width under surveillance. This phenomenon can be avoided by placing the microwave detector at a higher position, However, this mounting adjustment may be limited. Moreover, errors tend to increase as detection distances and traffic flow increases.

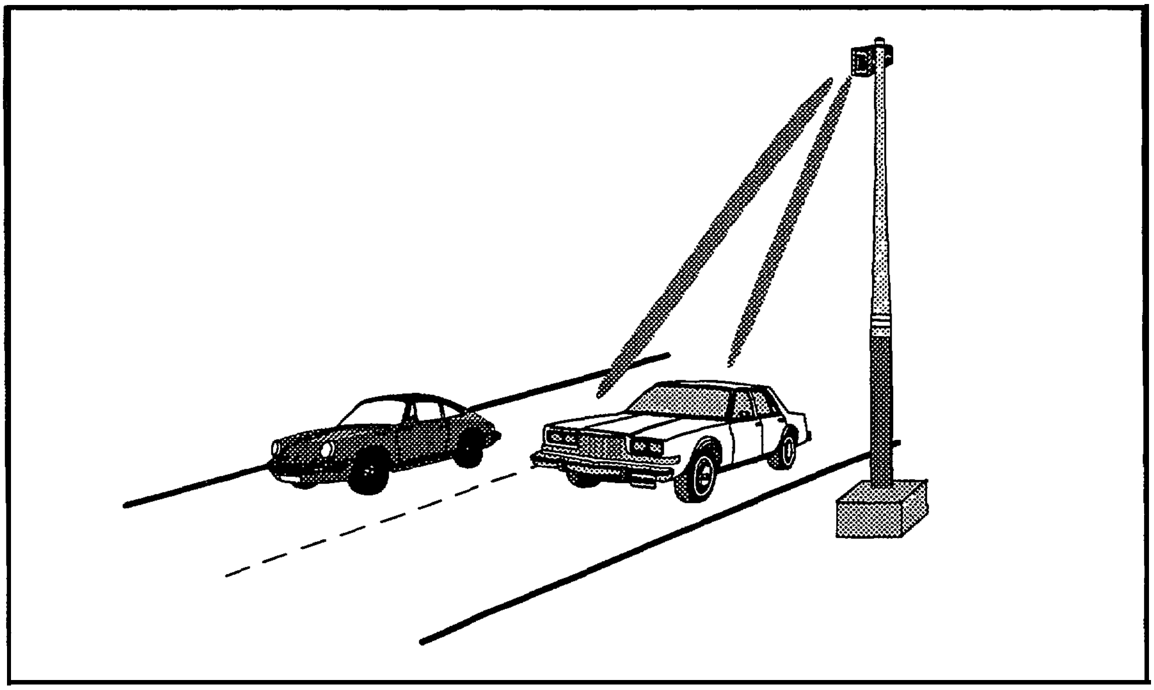

Figure 2-1. Side Fire Sensor Mounting Configuration

Occlusion or similar type of interference from large vehicles can be virtually eliminated by mounting detector units in an overhead fashion (see Figure 2-2) facing on-coming traffic. Two detection zones can be configured in the newer type microwave sensors to measure velocity, occupancy, volume and vehicle classification. To obtain lane-specific information, a detector unit must be placed directly over each monitored lane which in turn increases initial capital costs.

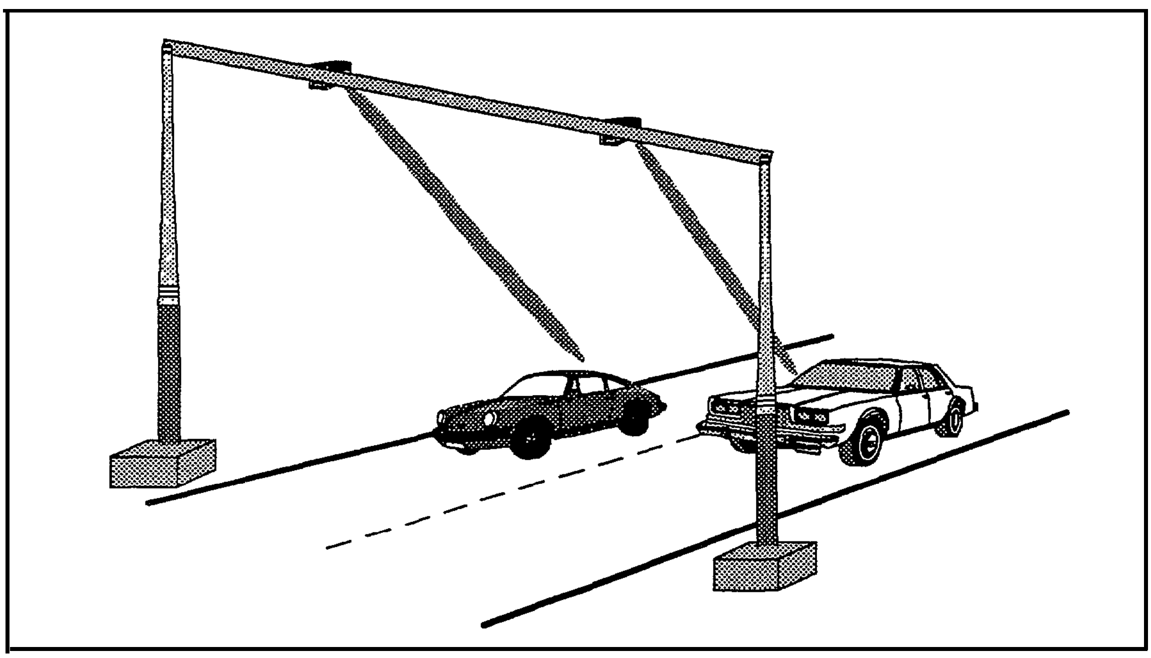

Figure 2-2. Overhead Sensor Mounting Configuration

As with radar detectors, the perceived health effects with microwave based detection units may cause the deployment of this technology to be limited.

Laser/Infrared

Laser detector systems require a laser emitter and receiver pair. These sensors generally use a diode laser operating in the 1.5 - 1.9 micrometer wavelength. The sensor is mounted directly over the lane and emits a laser beam onto the roadway surface. The detection system uses pulsed time-of-flight, laser range finding techniques to measure vehicle presence. As passing vehicles pass through the detection zone, the change in the laser reflection is detected by the receiver. On-board processing allows the system to detect vehicles with 10 inches of separation at 25 miles per hour when the laser beam is pointed vertically downward. The output of the laser sensor system is similar to inductive loop detectors. However, the detection signal represents the physical length of the vehicle rather than the structure of the vehicle undercarriage.

Two laser emitter and receiver pairs are necessary to acquire sufficient presence data to calculate the MOEs listed above. The beam spacing and receiver sensitivity must be aligned accurately to avoid reflection interference from each of the two laser beams. Two different wavelengths are utilized in conjunction with appropriate receiver filters to discriminate between the two detection zones. At times, different modulation frequencies are used for each laser beam, thus providing the means to discriminate between detection zones. Laser sensors can be mounted either over the lane or sidefire.

The laser system typically has a range of over 150 feet, however the potential and perceived health hazard realized from this technology makes this sensor system somewhat unattractive. Also, laser systems are currently in the experimental phase and are not likely to become a deployable product in the early deployment time frame.

Sonic

There are two dominant active sonic sensor operating schemes. The sonic emitter generates source waves at frequencies between 20 KHz and 70 KHz in a pulsed or continuous manner. The pulsed system emits bursts of energy at rates of 50 to 100 times per second. Measurements are taken to determine the time it takes to receive the reflected sonic wave. As a vehicle passes through the detection zone, the difference in the reflected signal time measurements determine the presence of a vehicle. Reflected sonic waves from overhead mounted sensors are used to determine the height and profile of the passing vehicle, thus providing classification data in addition to volume and occupancy. Since sound waves are carried through the air, this scheme of sonic detectors is susceptible to air turbulence and acoustic interference.

Continuous wave sonic method is based on the Doppler shift principle and is accurate for vehicle speeds from 5 to 80 miles per hour. The Doppler shift technique, however, is not able of detecting motionless vehicles. Therefore, occupancy and queue lengths cannot be provided. The sensor can be mounted either directly over the lane or sidefire.

Radar

Radar technology-based sensors operate on a Doppler effect principle. Low power microwaves operating in the range of 10 GHz are directed toward the area of the roadway from units which are usually pole mounted. As vehicles pass through the beam, the energy is reflected back to the sensing element at a different frequency. The receiver senses the change in frequency and denotes it as a passage of a vehicle.

Radar detectors are available in two configurations, 1) wide beam and 2) narrow beam. Wide beam units are installed either above the roadway or to the side. These units are used only to gather general freeway flow and speed information. Whenever a vehicle enters the detection zone, its velocity is measured using the Doppler principle. If multiple vehicles enter the zone simultaneously, usually the largest vehicle's speed is recorded.

Narrow beam units are used whenever lane-specific speeds and volumes are required. One detector is required for each lane in this configuration. The sensor can be mounted either over the lane or sidefire.

The majority of the radar based sensors use the Doppler effect principle to record vehicle speed and flow rate. However, with this technology, slow moving or stopped vehicles cannot be detected. Thus, these sensors are not able to provide occupancy and queue information. Additionally, a Federal Communications Commission (FCC) license is required to operate such detectors.

Radar detectors are currently being installed and field tested in Connecticut, Missouri, New Jersey, Texas, California, Florida and Toronto, Canada. Operational field test results from these deployments are not yet available.

Passive Sensors

Sonic

Passive sonic detectors use sonic technology derived from previous U.S. Navy projects. An array of microphones gathers acoustic data and by using digital signal processing techniques, determine vehicle presence. The microphone array can be mounted directly overhead or on existing roadside structures and various detection zones can be configured and used to calculate velocity, occupancy, and flow rate. The microphones monitor a wide range of frequencies providing capability to detect slow and fast moving vehicles. However, the system cannot detect stalled vehicles, thus making incident detection slightly difficult.

Operational characteristics and accuracy of data from passive sonic detectors are currently not available due to the lack of system deployment. The use and recommendation of this technology for vehicle detection will not be able to be determined until actual field data is collected and results published.

Infrared

Passive infrared detection technology has been deployed in several military applications. Thermal signatures of objects are used to detect presence and motion. Traditional far infrared detectors which discriminate objects from thermal signatures require that the detector array be cooled to 77 degrees Kelvin (-196 degrees Celsius). This is accomplished by using dewars fiied with liquid nitrogen or by thermal electric coolers. Objects can be detected through fog, rain, haze, snow, etc. The image acquired by the infrared focal plane array is further processed by an on-board processor. Image processing techniques are then applied to determine object presence. Additional processing is then performed to determine object position and motion characteristics. Accuracy of the processed data depends upon the robustness of the image recognition algorithm and image scan rates. Accuracies of up to ± 0.5% can be realistically achieved.

Currently, there are no known operating area passive infrared traffic detection systems. However, with activities associated with "defense conversion" projects, it is inevitable that passive infrared traffic detectors will emerge. It is anticipated that detectors which use this technology will be mounted directly above traffic lanes or on road side structures. Data should be able to be obtained for each lane and provide lane specific MOEs. Recurring activities associated with maintaining liquid nitrogen dewars increase operation and maintenance costs significantly.

Recently, passive lane infrared detectors which do not require cooling have been developed. This particular application of infrared technology uses a near infrared point detector and can provide presence, count, speed, occupancy and queue length data. However, this technology is typically used where background infrared signatures remain constant. Varying thermal signatures which occur during the day and changes in the seasons could result in erroneous vehicle detection. Additionally, the thermal resolution of the sensor may not provide reliable detection. Further field testing of such devices needs to be performed in order to determine applicability of this particular infrared technology.

Magnetic

Magnetic detectors (magnetometers) were one of the earliest forms of vehicle detection systems. Magnetometers operate by sensing changes of the vertical component of the earth's magnetic field. Magnetometer probes, which are typically cylindrical (2 inches in diameter, 4 to 5 inches in length) are buried approximately 12 inches below the road surface and provide a point detection zone. Sensor probes are connected to an electronic circuit board which converts the analog signal into a discrete digital pulse. A series of probes must be buried to provide area coverage. Accuracy of data is similar to inductive loop detectors.

As metallic objects travel over the magnetometer, the earth's magnetic field changes depending upon the metallic content of the object. Resulting magnetic field signatures are generally unique to the type of vehicle. With sufficient digital signal processing, vehicles can be characterized by make and model. By tracing the movement of the magnetic field signature, velocities, vehicle counts, and flow rates can be obtained.

Installation of these types of sensors requires road closures and generally does not provide any more information than inductive loop detectors. However, in applications where drilling or cutting of the road surface is prohibited (bridges, overpasses, etc.), magnetometers can be mounted underneath such structures to provide traffic characteristics.

Machine Vision

Machine vision is one of the latest technologies to be applied to traffic detection. Images are typically acquired through the use of closed-circuit television (CCTV) cameras and processed via image processing circuit boards. CCTV cameras are mounted either overhead or on road side structures. The cameras are connected to a processor unit (which is located at ground level) for image processing. Vehicle presence, speed, lane occupancy, lane flow rate, and classification information can be extracted. Discrete outputs similar to inductive loops are typically provided to enable the system to be integrated with existing traffic controllers.

Multiple detection zones can be defined within the field of view of the CCTV camera, thus providing multiple lane coverage. Multiple cameras can be connected to one processor unit providing wide area coverage.

Accuracies of machine vision detector systems heavily depend upon system setup and camera mounting location. The optimum camera position is typically located as high as possible and centered over the roadway with the viewing angle as perpendicular to the road surface as possible. If these camera mounting criteria are not available, the cameras must be mounted from road side structures. In such cases, as with any line-of-sight sensors, visual occlusion reduces calculated MOE accuracies.

Additionally, in low-light or night conditions, headlights are generally used to detect vehicles. In such cases, the rear end of vehicles cannot be distinctively detected, thus effecting the accuracy of vehicle lengths and classifications. Low light CCTV cameras can somewhat alleviate this problem if ambient light conditions provide sufficient illumination of the detection zones.

Machine vision sensors are currently operating in Oakland County, Michigan, Minnesota, Fontana, California, and Long Beach, California. Initial results from the implementation of machine vision sensors are favorable. With additional software algorithms, incident detection may be accommodated. Although current systems require heavy up front investments, lower cost machine vision systems are emerging and may be more cost effective within the next few years.

Probes

The use of vehicles as probes in determining traffic conditions have been studied in recent years. Vehicles transmit their current positional data acquired from in-vehicle navigation systems. Such navigation technologies include Global Positioning System (GPS), differential GPS, dead reckoning, and systems which rely upon established navigation supporting infrastructure such as beacons.

Vehicle probes provide an accurate depiction of travel and delay times on particular corridor segments. As vehicles travel on a certain corridor segment, positional data which are time-stamped are stored. Incremental changes in position and time are used to calculate actual travel times and thus delay times are derived.

Additional information can also be acquired with the use of vehicle probes. In times of recurring and non-recurring congestion, probes can be polled for their current position to identify traveled alternate routes. The collection of this type of information can be used in enhancing incident management plans and identifying alternate route patterns selected by traveling motorists.

Vehicle probe information can only be beneficial when a sufficient sample of the traveling motorist can be taken. Some commercial trucking and package delivery firms have started outfitting their vehicles with automatic vehicle location (AVL) systems. Most of these systems are used to enhance dispatching and delivery functions. However, due to the low number of such systems within the metropolitan Detroit area, positional sample data collected from such instrumented vehicles do not accurately reflect traffic patterns of the traveling majority. Until a higher sampling of the traveling vehicles can be acquired, the use of vehicle probes for traffic monitoring should not be relied upon. Therefore, vehicle probes will not be considered as a sole supplier of traffic data. The use of probe data from experimental or existing probes is recommended to supplement the recommended traffic sensor system.

Traffic Sensor Technology Summary

Table 2-l summarize the characteristics of the discussed sensor technologies. System capabilities are listed in addition to generalized advantages and disadvantages. A representative freeway installation scenario was used to determine initial installation costs and to estimate operational and maintenance (O&M) costs for 20 years. O&M includes costs associated with operation, maintenance, and more importantly, preventative maintenance. A four lane freeway section with an adjacent two lane on-ramp configuration was used as shown in Figure 2-3. Each lane is also configured to collect speed, occupancy, presence, count, and queue length data. Figure 2-4 shows estimated life cycle costs (LCC) over 20 years. Subsurface sensors show higher annual O&M costs due to failures contributed by mechanical stress induced by thermal expansion and road surface deflections. Above ground sensors require less maintenance and require substantially less labor for annual maintenance and repair.

Figure 2-3 depicts an inductive loop detector configuration. However, configurations for the cost summary vary depending upon the sensor type and its lane coverage capability.

Table 2-1. Traffic Sensor Technology Characteristics

Technology	Measuring Capabilities	Advantages	Disadvantages	System Cost (Install +20 yrs O&M)
Inductive Loop	Presence Count Speed Occupancy Queue Length	• Proven technology • All weather, day/night operation • Size & shape of detection zone shaped by loop geometry • Capable of measuring all traffic parameters	• Lane closure required for installation and maintenance • Susceptible to damage due to thermal coefficient of expansion (TCE) mismatch • Cutting of pavement reduces life span of road	$194,856
Microwave	Count Speed	• Above ground mounting • Only a single head needed to measure velocity	• Unable to detect motionless vehicles • Precision setup required • Potential health hazard • Deployment numbers limited	$110,928
Laser/ Infrared (Active)	Presence Count Speed Occupancy Queue Length	• Above ground mounting • Accurate vehicle length measurement	• Susceptible to spectral interference • Potential health hazard • Not proven technology in traffic applications	$148,740
Pulsed Sonic (Active)	Presence Count Speed Occupancy Queue Length	• Above ground mounting • Can be used at locations with irregular surfaces • Can provide height profile	• Non-directional • Conical beam pattern provides inaccurate measurements • Accuracies degrade under congested traffic	$108,240
Continuous Sonic (Active)	Count Speed	• Above ground mounting • Can be used at locations with irregular surfaces • Slightly improved speed measurements than pulsed sonic	• Sensitive to environmental conditions • Cannot detect motionless vehicles	$132,432
Radar	Count Speed	• Above ground mounting • Not effected by electromagnetic interference	• Requires FCC license to operate • Does not measure presence/occupancy • Precision setup required • Potential health hazard • Currently in field test	$116,304
Passive Sonic	Presence Count Speed Occupancy Queue Length	• Above ground mounting • Potentially accurate vehicle classification	• Cannot detect stalled vehicles • Not a proven technology • Susceptible to environmental interference	$105,552
Passive Infrared Lane Coverage	Presence Count Speed Occupancy Queue Length	• Above ground mounting • Operates in snow, rain, fog • Can provide all traffic parameters	• Currently under test • Potential high O&M cost • Detailed setup required	$135,300
Passive Infrared Area Coverage	Presence Count Speed Occupancy Queue Length	• Above ground mounting • Operates in snow, rain, fog • Can provide all traffic parameters	• No current traffic applications • Potential high O&M cost • Detailed setup required	$143,940
Magnetic	Presence Count Speed Occupancy Queue Length	• Proven technology • Not effected by noise from direct current power lines • Can be mounted under bridges without cutting pavement	• Requires lane closure during installation and maintenance • Multiple units needed to measure velocity • Potential multiple triggers on single vehicle due to magnetic material distribution	$209,760
Machine Vision	Presence Count Speed Occupancy Queue Length	• Above ground mounting • Proven technology • Does not depend upon pavement condition	• Detailed setup required • Units currently being field tested • Long term operation unknown	$177,393

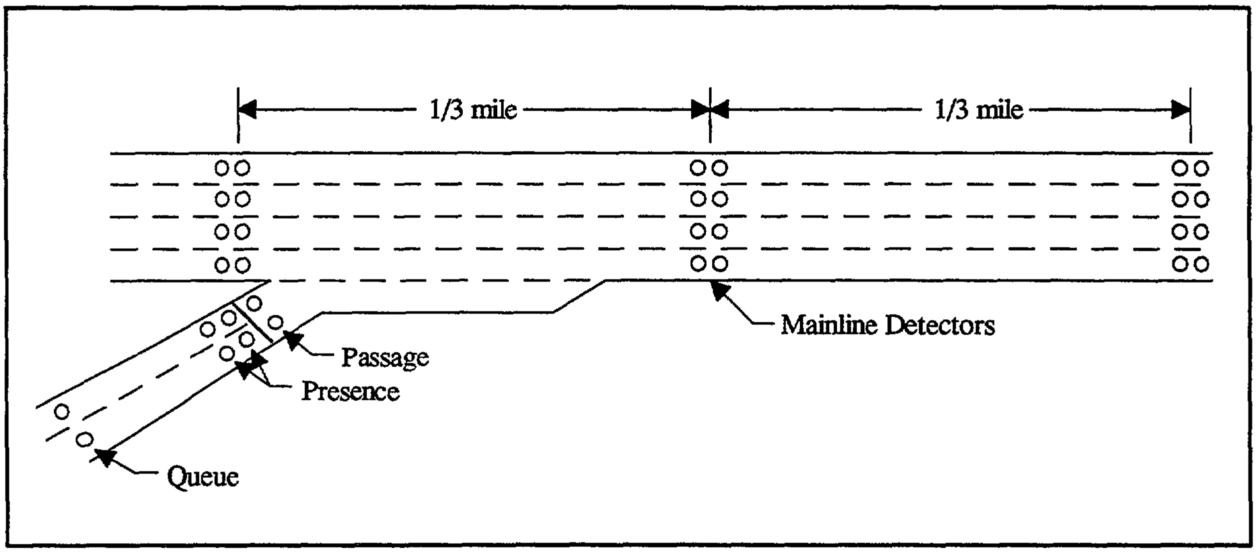

Figure 2-3. Representative Freeway Sensor Layout

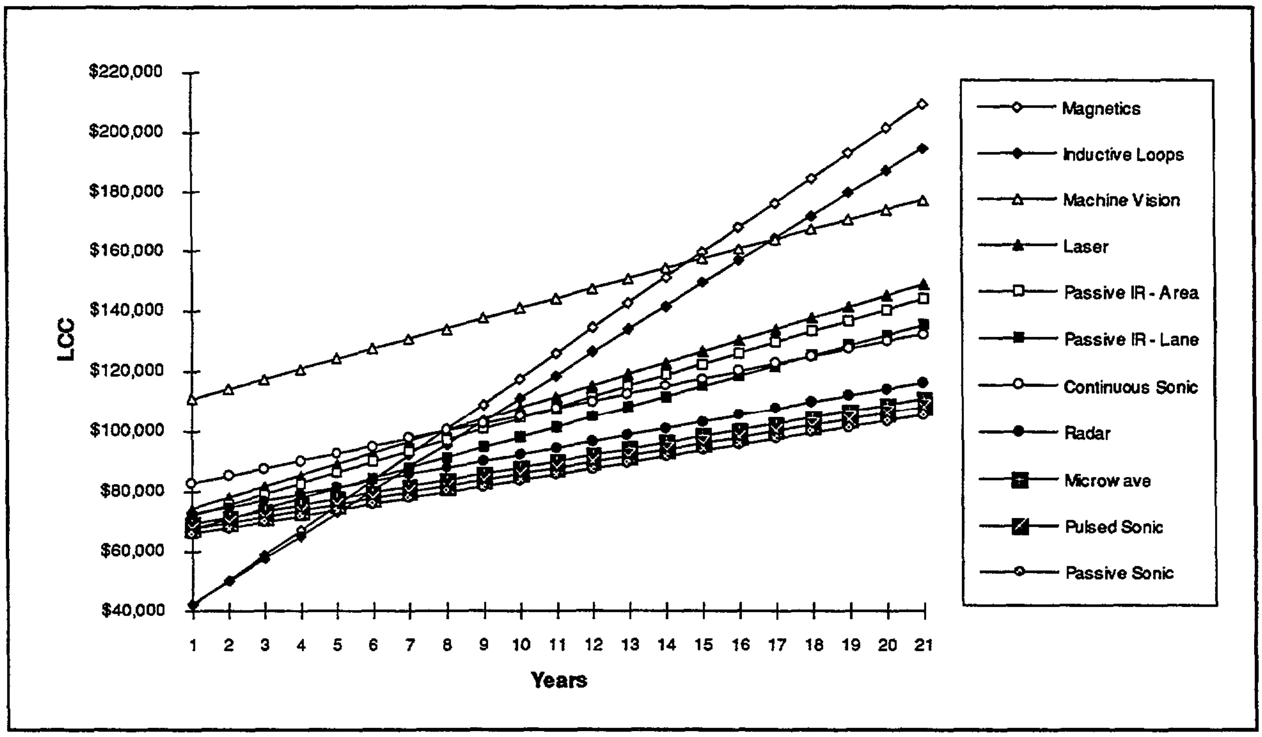

Figure 2-4. Traffic Sensor Technology Life Cycle Cost Comparison

2.1.2 Trade Matrix and Selection Criteria

The criteria used for this evaluation consist of the parameters listed in Table 2-2 and their relative importance to the implementation of the specific detector technology. The list represents criteria categories to achieve desired goals. These criteria are used to evaluate technologies applied in various vehicle detection technologies.

Table 2-2. Traffic Sensor Evaluation Criteria and Weight Factors

Evaluation Criteria	Weight Value	Comments
Feasibility/Ease of Implementation	10	Assessment of technical risk.
Implementation and O&M Cost	10	Assessment of required budgetary funds.
Upgradeable	8	Assessment of openness options.
Environmental Durability	8	Assessment of tolerance to the surrounding environment.
Satisfaction of Required MOEs	7	Assessment of traffic monitoring
Accuracy	6	Assessment of sensing repeatability and precision
Proven Technology	6	Assessment of technology field readiness

Each sensor technology is evaluated based upon the satisfaction of evaluation criteria. Raw scores are tabulated and an overall ranking is established using weight factors and assessment guidelines in Table 2-2 and 2-3.

Table 2-3. Traffic Sensor Evaluation Assessment Guidelines

Level of Compliance	Score
Exceeds Compliance	10
Fully Compliant	9
Good Compliance	8
Above Average Compliance	7
Average Compliance	6
Minimum Compliance	5
Marginal Compliance	4
Partial Compliance	3
Poor Compliance	2
Does Not Comply	1

2.1.3 Analysis

Raw scores presented in Table 2-4 are translated into composite scores (see Table 2-5) using the evaluation criteria weighting factors. Relative ranking of each technology was then determined, with results provided in Table 2-5.

Table 2-4. Traffic Sensor Technology Comparison Raw Scores

Technology	Ease of Implement.	Implement./ O&M Cost	Upgradeable	Durability	MOE Satisfaction	Accuracy	Proven Technology
Inductive Loop	10	6	5	5	6	8	10
Microwave	8	10	6	6	6	5	4
Laser/Infrared (Active)	8	8	6	5	6	7	4
Pulsed Sonic	6	10	5	5	6	5	4
Continuous Sonic	6	9	5	5	5	5	4
Radar	7	10	6	6	5	5	4
Passive Sonic	6	10	7	5	7	5	4
Passive IR - Lane	8	8	6	6	10	6	4
Passive IR- Area	7	8	7	7	10	6	3
Magnetic	8	6	4	5	5	7	10
Machine Vision	8	8	8	7	10	7	7

Table 2-5. Traffic Sensor Technology Composite Scores And Ranking

Technology	Composite Score	Relative Ranking
Inductive Loop	390	2
Microwave	372	5
Laser/Infrared (Active)	356	7
Pulsed sonic	336	10
Continuous Sonic	319	11
Radar	355	8
Passive Sonic	359	6
Passive IR - Lane	386	4
Passive IR - Area	386	3
Magnetic	349	9
Machine Vision	434	1

2.1.4 Traffic Sensor Technology Results and Recommendation

The resulting technology trade analysis identifies machine vision sensors to be favored over other sensor technologies. The margins between composite scores of various technologies are not wide spread. This indicates that there is no one technology which is far superior than others. However, the machine vision technology shows high potential in future expansion and enhancements to current capabilities without changing the basic sensor implementation.

The technology uses “image processing” techniques to determine the measures of effectiveness locally to the sensor unit, thus, distributing data processing and reducing communications requirements. Additionally, the technology provides an attractive life cycle cost figure and tends to require less operational maintenance due to above ground mounting methods. Machine vision application in traffic management will increase in the next several years. It is inevitable that hardware costs will significantly decrease as the technology matures. The use of machine vision technologies has been prevalent in manufacturing applications for several years and is migrating into traffic applications. Software algorithms used in such detection technologies are inherently upgradeable as detection techniques mature (i.e. fuzzy logic, neural networks, artificial intelligence, etc.). Additionally, lower cost machine vision sensors are appearing in the transportation market and it is foreseeable that the initial hardware and installation cost will dramatically be reduced in the near future.

However, the inductive loop technology has been a proven technology in traffic detection. Loop detector electronics are very inexpensive and widely available. The technology cannot cost effectively be improved upon. This technology has matured to the point that costs associated with deployment and O&M costs will not decrease. Changing pavement conditions reduce the reliability of loops and tend to have a high life cycle cost. If properly installed and preventative measures are taken to maintain the road surface, inductive loops have the potential to be cost effective. Extreme adverse weather conditions in Michigan, however, reduce the reliability.

It is recommended that machine vision sensors be used to maximize the benefits from long term life cycle costs. Inductive loop detectors should remain as an option for areas where machine vision technologies cannot be deployed due to visual obstruction, height restrictions or cost effectiveness (i.e. ramp metering or off ramps). Furthermore, areas which previously could not be instrumented (i.e. bridges) can now be monitored with machine vision sensors.

2.2 Environmental Sensors

Environmental sensors provide MDOT with the capability to monitor road and driving conditions. Various sensors can be used to monitor road surface temperature, humidity, wind speed, etc. Correlating various inputs from these sensors will allow MDOT to close a freeway segment if unsafe conditions arise.

It is anticipated that the excess computing capacity at remote controllers will be used to process raw inputs from environmental sensor systems which do not have an on-board processor. Since these types of sensors do not require fast conversion times (time to convert analog data into a digital format), the processing burden on remote controllers is almost negligible.

Two different configurations of environmental sensor systems were investigated. The two configurations are 1) separate environmental sensors controlled by the field controllers; 2) a self contained integrated environmental sensor system.

Separate Environmental Sensor Components

In this configuration, individual sensors which can monitor temperature, humidity, wind speed, and road surface temperature can be individually attached to a field controller to collect environmental data. This configuration requires a separate controller interface for each sensor component. Software to acquire and convert raw analog or discrete data from individual sensors must be written unless supplied by individual sensor vendors. Environmental sensor parameters must then be stored in the field controller's memory to be further placed into the data stream which is to be transmitted back to the operations center. Integration of environmental sensor components requires relatively moderate efforts to deploy and overall costs can add up to over $400.

Self Contained And Integrated Environmental Sensor

The advancement in micro-electronics production enables various environmental sensors to be integrated into a self contained electronics package. These sensor systems have their own on-board processors which provide raw data conversion internally. The output from these systems typically uses the industry standard EIA-232 serial interface. Further processing in field controllers is only limited to receiving the processed information and placing the data into its appropriate position in the controller data stream. Software development and hardware integration require relatively low efforts to deploy and the associated cost for such sensors is around $200 - $300.

Environmental Sensor Components

The number of environmental sensor components (temperature, humidity, etc.) depend widely upon options provided by vendors. Area temperature and humidity are two environmental parameters which can be mostly used in the metropolitan Detroit freeway traffic management system. The ability to sense potential hazardous road conditions allow MDOT to take preventative measures.

There are two predominant temperature sensor types which are available today. The first is the contact type sensor which depends upon direct contact with surfaces. These sensors typically use either resistive temperature devices (RTD) or thermal couple technologies. These sensor technologies provide the advantage of acquiring direct road surface temperatures. However, these sensors must be in contact with the road surface in order to measure the temperature.

The second method uses infrared technology to measure the road surface temperature. Typical infrared measuring devices can only measure surfaces which are a maximum of 1 0-15 feet away. There are some devices which can measure surface temperatures at larger distances, however, the cost of such devices is extremely high. This method significantly limits available mounting positions.

Low cost passive element humidity sensors which can be electronically monitored by computer processors are widely available. Wind speed measuring devices are available, however, placement of sensors are critical in providing accurate wind speed measurements. Sensors which are typically used at airports can also provide visibility measurements. Table 2-6 show a compilation of environmental sensor techniques and methodologies.

Table 2-6. Environmental Sensor Components

Sensor Type	Technology	Ease of Deployment	cost of Deployment	Accuracy	Comments
Ambient Temperature	RTD Thermal couple Diode	LOW	Low	+ 2 degrees F	• Canbeusedin combination with humidity sensor to predict icing . Surface temp. can be projected
Surface Temperature	RTD Thermal couple Diode Infrared	Moderate	Moderate	+ 1 degrees F	• Must be mounted in close proximity of road surface
Humidity	Passive element	Low	LOW	+ 2%	• Must be used to predict icing
Wind Speed	Mechanical Pitot tube	Moderate	Moderate	+ 3 mph	• Susceptible to damage
Visibility	Optical Reflective IR	Moderate	High	+ 50 feet	. Low benefits

Environmental sensors provide additional information to aid in regional traffic management. Basic temperature and humidity sensors can provide sufficient information in determining hazardous conditions, especially during the winter seasons. Areas within Michigan, specifically the greater Detroit area, encounters such harsh conditions as snow and ice. The ability to predict these hazardous conditions will enable MDOT to take preventative measures to ensure driver safety.

It is recommended that the use of an integrated environmental sensor system be deployed at predefined intervals. A one mile increment is recommended since sufficient data can be collected to model representative road conditions. This type of sensor system requires only a small amount of software development and very low integration efforts.

Ambient temperature sensors are recommended for temperature measurements due to the lower deployment cost and lower susceptibility to damage. Humidity sensors should be used in conjunction with the temperature sensor since the combination of the two sensors can provide sufficient information to predict icing conditions. Other environmental sensors such as wind speed and visibility sensors should only be deployed in areas where recurring wind and visibility problems arise.

2.3 Video Surveillance

Video surveillance provides the MTC with a visual means to determine the nature of traffic congestion. Images provided by the video technology are transmitted to the MTC for viewing and incident assessment. Resolution of the image must have the granularity whereby the MTC Detroit Freeway Operations Unit (DFOU) operator can determine the nature of the incident or other roadway impairment. Surveillance coverage locations will be strategically selected through an analytical analysis of metropolitan Detroit incident data obtained from the Michigan State Police (MSP) and the Michigan Emergency Patrol (MEP). This data will be normalized to identify incident problem areas.

The video surveillance technology must be versatile to provide video images in bright light (day), flat light (overcast/low contrast), adverse weather (rain, snow), and low light (night) conditions. Color images tend to provide maximum resolution for daylight conditions, while black and white images provide the best contrast for low light conditions.

In general, the camera, mounting, and communications interface equipment/enclosures must be designed to function year-round (i.e., rain, ice, snow, etc.) in the local metropolitan Detroit urban environment. These equipment/enclosures include integrated environmental conditioning features (i.e., defogger, cooling, etc.), be modular in design, and promote ease of maintenance.

The following paragraphs list video surveillance requirements of which the early deployment video surveillance technology shall satisfy.

<u>Environmental Conditions</u>

Video surveillance technologies must operate and endure many years in the adverse metropolitan Detroit environment. They must be robust and operate in temperatures ranging from sub-zero with snow and ice, high heat (cabinet) with high humidity, to corrosive elements and electromagnetic interference.

All fielded components shall provide features to protect the components from the local metropolitan Detroit urban environment. In addition to weather effects, consideration must be given for equipment vandalism and theft. Features such as low value materials, camouflage (or neutral colors), or low-profile equipment mounting (or locations) should be considered to aid against damage.

To minimize excessive development costs, field components should capitalize on readily available, commercial-off-the-shelf (COTS) equipment which has been designed for operation in adverse weather.

Table 2-7 summarizes environmental conditions for video surveillance field components.

Table 2-7. Video Surveillance Environmental Conditions

Parameter	Requirement
Temperature	-50 degrees F to +140 degrees F
Humidity	100 percent relative.
Lightning/Electrostatic discharge	All equipment shall incorporate features to prevent damage from transient electrical discharges in the fielded configuration.
Radio Frequency Interference (RFI)/Electromagnetic Interference (EMI)	All CCTV subsystem electronic equipment shall not be affected by normal RFI/ENl conditions emanating from the surrounding MTC office and Metropolitan Detroit urban environments. Correspondingly, all video equipment shall not emanate RFI/EMI which will interfere with other MTC and localized fielded equipment.
Wind/salt/sand/dust/contaminants	Protection from the effects of wind, salt, sand, dust, and other organic and inorganic contaminants emanating from roadway vehicles and the surrounding environment for a period no less than 10 years from field deployment..
Other environmental-related effects	Insulation from other (direct or induced) environmental effects. Other effects include acceleration/shock, vibration, acoustics, heating due to solar radiation, vandalism and theft, etc.

Performance Requirements

Specifications for the video surveillance equipment shall satisfy the requirements listed in Table 2-8.

Table 2-8. Video Surveillance Performance Requirements

Camera Feature	Minimum Requirement
Full color (daylight)/low light black and white (dawn/dusk/night) capability:	Adjustable aperture, 0.1 lux (0.01 FC)
Bright/low light compensation/transition	Automatic/Manual (selectable)
Image resolution (min.):	500 lines horizontal, 400 lines vertical; NTSC compatible.
Image zoom/telephoto:	Effective zoom/telephoto of the video image shall be 25-180 mm @ f1.2, with manual focus, remotely controlled.
Frame speed:	Full motion video (real-time).
Display text:	Programmable (operator-entered (i.e., "I-94 Ford Freeway @ I-75 Chrysler Freeway")
Power Compatibility	115 VAC +/- 15% VAC; 60 Hz +/- 5%; min. 20A
Power surge protection:	Circuits shall be protected from current surges and voltage transients up to 1000 Volts

2.3.1 Identification of Alternate Video Surveillance Technologies

Video camera technologies which have been examined include day light color, low light black/white, machine vision (high and low resolution), visually-enhanced infrared, and low-light intensified systems. A summary of these technologies is listed in Table 2-9.

Table 2-9. Video Surveillance Technology Characteristics

Video Technology	Advantages	Disadvantages
Daylight Color Video	• High bright light contrast resolution (colors) • Maximum resolution determination • Good viewing aesthetics • Commercially available • Proven technology	• Degraded low light capability • Low light versions costly • Colors cannot be easily seen in low light conditions
Low light Black/White Video	• High low light contrast resolution • Average viewing aesthetics • Commercially available • Proven technology • Lower communications bandwidth requirements than color	• Degraded viewing resolution in bright light
High Resolution Machine Vision	• Comparable to NTSC video * Digital format for communications compatibility	• Higher cost than NTSC video • Specialized digital signal processing adaptation (programming required) • Specialized support base
Low Resolution Machine Vision	• Low cost • Digital format for communications compatibility	• Impaired visual resolution capability • Specialized digital signal processing adaptation (programming required) • Specialized support base
Video-Enhanced Infrared	• Not dependent on optical vision	• Impaired visual resolution capability • Specialized support base • Requires special visual training • Low visual aesthetics
Low Light Intensified	• High performance in extreme low light conditions	• Low performance in bright (daylight) environment • Potential to burn out intensifier during daylight hours • High cost

2.3.2 Trade Matrix and Selection Criteria

Criteria used for the evaluation of video surveillance equipment consists of the parameters listed in Table 2-10. The criteria weight values are also listed in the table. The list represents categories to achieve the desired performance goals of video surveillance.

Table 2-11 details the evaluation guidelines used in evaluating each video surveillance technology.

Table 2-10. Video Surveillance Evaluation Criteria and Weight Factors

Evaluation Criteria	Weight Value	Comments
cost	10	Installation and O&M costs
Color Discrimination	7	Aid in vehicle determination
Low-light Capability	7	Low light & night operation
Image Resolution	7	Provides detail for incident response
Image Zoom/Telephoto	7	Added area coverage
Frame Speed	7	Motion clarity
Text Display	7	Location and positioning information
Durability	7	Operation under harsh environments
Input Power Compatibility	7	Power availability
Power Surge Protection	7	Lightning and power distribution protection

Table 2-11. Video Surveillance Evaluation Assessment Guidelines

Level of Compliance	Score
Exceeds Compliance	10
Fully Compliant	9
Good Compliance	8
Above Average Compliance	7
Average Compliance	6
Minimum Compliance	5
Marginal Compliance	4
Partial Compliance	3
Poor Compliance	2
Does Not Comply	1

2.3.3 Analysis

Raw scores presented in Table 2-12 are translated into composite scores (Table 2-13) using the evaluation criteria weighting factors. Relative ranking of each technology was then determined, with results provided in Table 2-13.

Table 2-12. Video Surveillance Technology Comparison Raw Scores

Technology	cost	Discern Colors	Low-light Capability	Image Resolution	Zoom/Tele photo	Frame Speed	Text Display	Durability	Compatible Input Pwr	Surge Protection
Daylight Color Video	8	10	6	8	9	8	8	9	8	8
Low light Black/White Video	10	1	9	8	9	8	8	9	8	8
High Resolution Machine Vision	6	10	6	8	9	8	8	8	8	8
Low Resolution Machine Vision	4	4	6	2	9	8	8	9	8	8
Video-Enhanced Infrared	3	1	10	8	9	8	8	8	8	8
Intensified Black/White	5	1	10	8	9	8	8	6	8	8

Table 2-13. Video Surveillance Technology Composite Scores And Ranking

Technology	Composite Score	Relative Ranking
Daylight Color Video	598	1
Low light Black/White Video	576	2
High Resolution Machine Vision	571	3
Low Resolution Machine Vision	474	6
Video Enhanced Infrared	506	5
Intensified Black/White	512	4

2.3.4 Video Surveillance Results and Recommendations

Video surveillance technologies reviewed included traditional video, non-traditional devices and visual image processing. Advanced video technologies were assessed for incident verification and response resolution; however, these technologies tend to fall short of satisfying day and night viewing and visual resolution. The recommended video surveillance technology is a combination of color and black/white video, color for bright light conditions, and black/white for low light/night viewing. This combination is currently deployed for this application and offers the most cost-effective solution for day and night traffic surveillance.

The recommended configuration should also use commercial-off-the-shelf components. Additionally, the dual camera configuration is also compatible with video surveillance equipment currently installed in Oakland County.

2.4 Control and Data Processors

Distributed processing techniques to reduce communications bandwidth require raw data to be processed at remote locations. These processors will not only process traditional traffic MOEs or parameters, but will also be used (depending upon site locations) **to** process data and control other system components such as:

- Video Surveillance Controls
- Changeable Message Signs (CMSs)
- Highway Advisory Radios (HARs)
- Environmental Sensors

In addition to the processing of raw data, remote controllers must be able to manage the communication protocol. To maximize data through-put and minimize the number of communication channels, a more robust Carrier-Sense-Multiple-Access/Collision Detection (CSMA/CD) communications scheme must be used. CSMA/CD does not operate in a traditional master-slave poll-response method. All node participants have equal access to the communication network and "talk" whenever required provided that the node participant follow the rules of the protocol. Therefore, higher than traditional local communication processing capability is required.

Requirements for the remote controller and data processing component of the ATMS/ATIS are established to describe the requirements which must be satisfied by the "node." The node supports multiple functions and are:

- Calculate mainline MOEs
- Process ramp data and control ramp meters
- Provide control of CCTV, CMS, HAR (where required)
- Acquire and process environmental data
- Conduct Built-In-Test (BIT) (power up and background)
- Handle communication to and from host system (host-to-peer)
- Handle communication between controllers (peer-to-peer)

It is not a requirement that a single piece of hardware perform all the functions listed above. However, node components, which may contain multiple functions, must be able to process the required data.

Processing Requirements

In order to establish the required processing capacity for remote controller and data processing nodes, the functions listed above are tabulated and estimates of the number of lines of code (LOC) were generated. LOC estimates are based upon standard mathematical equations used to determine MOEs, control algorithms (CCTV, CMS, and HAR), standard BIT processing, and communication protocol processing. Table 2-14 lists the LOC estimates and conversion to processor instruction counts. Eight (8) processor instructions per LOC are used based upon non-optimized, commercially available "C" compilers. Execution optimization may be realized if optimizing compilers are used

Node processing capacity of 0.33 million instructions per second (MIPS) is required to perform functions which are currently required (based on 10 ms polling resolution), Additional capacity will be required if other IVHS functionality is imposed on the system such as Weigh-In-Motion (WIM), Advanced Vehicle Control System (AVCS), moveable barriers (lane control), automated toll collection, Automated Vehicle Identification (AVI), etc.

Table 2-14. Node Processing Estimates

Function	Lines of Code (LOC)	Total LOCs	Total Instructions
Calculate MOEs - Mainline		25	200
Speed	5		
Vehicle Length	5		
cum. speed	2		
Cum. Length	2		
Cum. Presence Time	2		
Increment Count	1		
Time Stamps	3		
Create MOE Message	5		
Ramp Control		25	200
Get Ramp Data	2		
Rate Calculation	10		
Time Stamp	3		
Output Control	5		
Create Status Message	5		
CCTV Control		23	184
PTZ Control	10		
Focus	4		
Iris Control	4		
Create Status Message	5		
CMS Control		14	112
Setup	3		
Message Parsing	3		
Message Transmit	3		
Create Status Message	5		
HAR Control		14	112
Setup	3		
Message Parsing	3		
Message Transmit	3		
Create-Status Message			
Built-In-Test (BIT)		215	1720
CPU	50		
Memory	50		
I/O	50		
Communications	50		
software checksum	10		
Combine Status w/MOE	5		
Communications		82	656
Interrupt Service Routine	7		
Retrieve Message	30		
Validate Message	30		
Post Message	5		
Send Message	10		
Environment Sensing		20	160
Acquire Data	5		
Calculate Results	5		
Compare To Thresholds	5		
Create Message	5		
TOTAL		418	3.344
Worst Case Processing Requirements (If all instructions must be executed at 10 ms intervals)			0.33 MIPS

2.4.1 Identification Of Alternate Node Configurations

Various configurations can be used to support the required functions. It is only required that the collection of hardware within a node support required processing, input/output, and data handling tasks. Various architectures within a node can be used to perform such tasks. Table 2-15 summarizes the various computational and data handling characteristics.

2.4.2 Trade Matrix and Selection Criteria

The criteria used for this evaluation consists of parameters listed in Table 2-16 and their relative importance to the implementation of the specific control and data processing technology. The list represents criteria categories to achieve desired functional and performance goals.

Each control and data processor configuration are evaluated based upon the satisfaction of evaluation criteria. Raw scores are tabulated and an overall ranking is established using weight factors and evaluation guidelines in Tables 2-16 and 2-17.

Table 2- 5. Alternate Node Configurations

Configuration	Description	Advantages	Disadvantages
170 Controller	• Traditional Traffic Controller • 768 KHz Clock Frequency • Approx. 0.10 MIPS • Integrated l/O • 6800 CPU	• Standard traffic controller	• Limited functionality • Serial port limitation • Cannot support additional IVHS functionality
179 Controller	• Traditional Traffic Controller • 1.5 MHz Clock Frequency • Approx. 0.25 MIPS • Integrated l/O • 6809 CPU	9 Standard traffic controller	• Limited functionality • Serial port limitations • Cannot support additional IVHS functionality • Limited Availability
NEMA Controller	• Traditional Traffic Controller • Integrated l/O • Functionally Defined By NEMA Specs.	• Standard traffic controller	• Limited functionality • Serial port limitations • Cannot support additional IVHS functionality
Integrated Single Board System w/CPU, I/O, Comm, and Standard Backplane	• Standard Industrial Computer • Clock Frequencies Up to 50 MHz • 1 to 40 MIPS • Integrated Serial and Discrete I/O • 8, 16,32 bit CPUs - 8086,8088,80x86 - 68xx, 680x0 - 320x0	• Daughter board can be installed - RAM (8 MBytes) - ROM - Up 4 serial ports . Many vendors • High level programming language supported - Many programming languages - Source level debuggers - Larger software support	• Not a standard traffic controller
Modular System w/Standard Backplaue	• Standard Industrial Computer • Clock Frequencies Up to 50 MHz • 1 to4oMlps • Modular Components • 8, 16.32 bit CPUs - 8086,8088,80x86 -68xX,680x0 -320x0	• Modular design • Additional components can be added when required - RAM (> 256 Mbytes) - ROM - Serial I/O - Discrete I/O - Image processing • Many vendors • High level programming language supported - Many programming languages - Source level debuggers - Larger software support	• Not a standard traffic controller
Industrial Programmable Controllers	• Standard Process Control Platform • Clock Frequencies Up to 33 MHz • 1 to1oMIps	• Potentially lower cost . Expandable l/O	· Not a standard traffic controller · Typically requires ladder logic software

Table 2-16. Control and Data Processor Evaluation Criteria and Weight Factors

Criteria	Weight Value	Comments
Installation / O&M Cost	10	Effects on Cost / Funding Availability
Excess Processing Capacity	8	Support For Full Deployment Applications
I/O Capabilities	8	Support For Future IVHS Applications
Expansion Capabilities	8	Capability of Adding CPUs, Memory, I/O Resources
Software Development Environment	6	Ease of Software Maintenance
Upgradeability	6	Migration Path for Next Generation Applications
Multiple Vendors / Suppliers	6	Component Availability

Table 2-17. Control and Data Processor Evaluation Assessment Guidelines

Level of Compliance	Score
Exceeds Compliance	10
Fullv Compliant	9
Good Compliance	8
Above Average Compliance	7
Average Compliance	6
Minimum Compliance	5
Martial Compliance	4
Partial Compliance	3
Poor Compliance	2
Does Not Comply	1

2.4.3 **Analysis**

Raw scores presented in Table 2-18 are translated into composite scores (see Table 2-19) using the evaluation criteria weight factors. The relative ranking of each technology is then determined, with results provided in Table 2- 19.

Table 2-18. Control and Data Processor Comparison Raw Scores

Method	Install. / O&M Costs	Proc. Capacity	I/O Capacity	Expansion Capability	S/W Dev. Environ.	Ability to Upgrade	Multiple Sources
170 Controller	10	3	3	3	3	4	4
179 Controller	9	3	3	3	3	4	3
NEMA Controller	7	3	3	3	3	4	4
Modular System	8	10	10	9	10	10	7
Integrated CPU, I/O, Comm.	6	10	7	7	10	7	7
Industrial Programm-able Controller	9	7	8	7	6	8	5

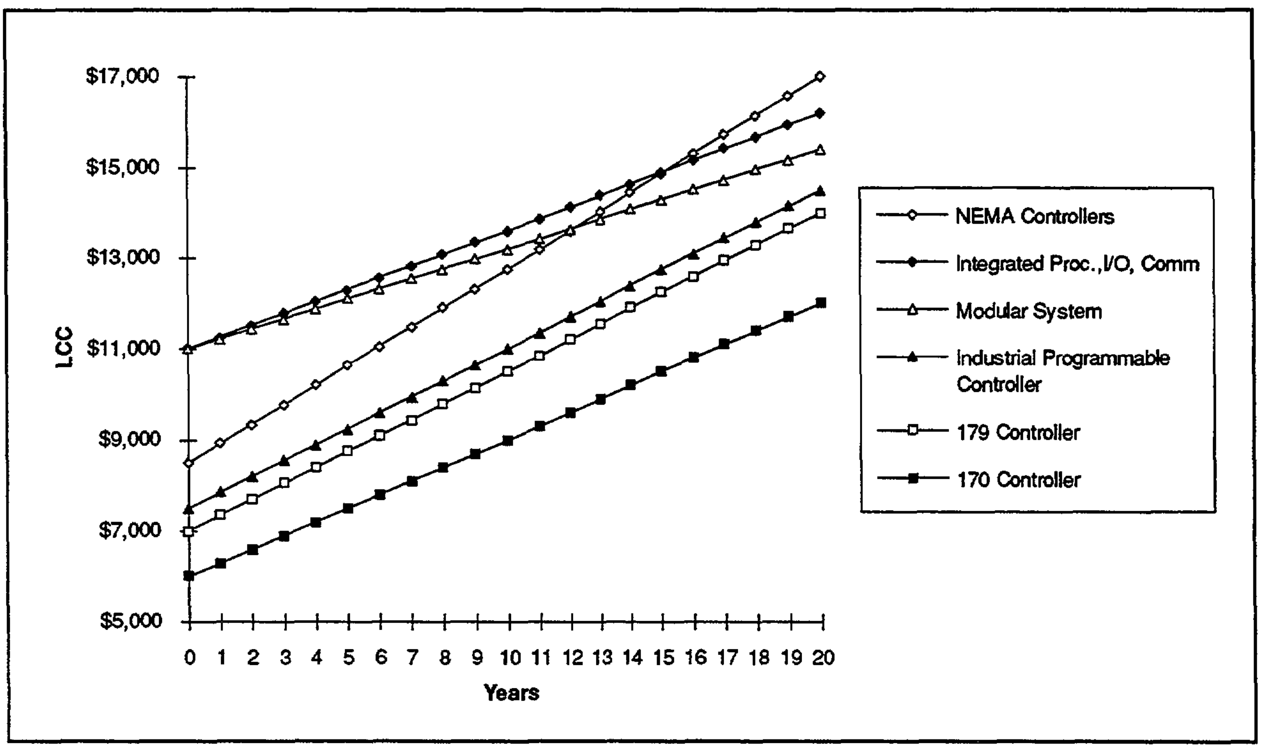

Figure 2-5. Control and Data Processor Life Cycle Cost Comparison

Life cycle cost analysis was performed for each control and data processor configuration. A single node configuration was used as a model in determining installation, operational and maintenance costs. The following lists the minimum configuration requirements used for the analysis:

- Minimum 3 MIPS processing capability
- 4 Mbytes of RAM
- **4** serial I/O ports
- 16 discrete parallel lines

Modular node configurations show higher initial costs as compared to traditional traffic controllers. However, further investigation identified deficiencies in traditional traffic controllers which do not satisfy expansion capabilities, CPU capacity, I/O and availability requirements.

Table 2-19. Control and Data Processor Composite Scores and Relative Ranking

Processor Configuration	Composite Score	Relative Ranking
170 Controller	238	4
179 Controller	222	5
NEMA Controller	208	6
Modular System	474	1
Integrated CPU, I/O, Comm.	396	2
Industrial Programmable Controller	380	3

2.4.4 Control and Data Processor Recommendation

The use of modular components is recommended for early deployment implementations. The modular aspect enables controllers to be configured in a manner that will support incremental upgrades as the early deployment migrates into other configurations supporting additional IVHS functionality. With this particular control and data processor configuration, memory and computational capacities can be sized to accommodate the early deployment requirements and be upgraded by means of memory and I/O expansion as required. Additionally, with the modular architecture, the communication interface can be easily exchanged as the communications media is upgraded (i.e. wireless to fiber optic). Several communications plug-in boards have resident processors and handle all necessary communications protocol processing. This feature reduces the processing requirements for the master processor. A standard backplane or bus structure is recommended (i.e. VME) in order to accept multi-vendor board products. The industry is leaning toward the VME bus configuration. The new 2070 controller specification, which is currently being developed by Caltrans, uses a 3U VME configuration. Since the specification is not complete, it is recommended that industry standard VME components be used. The 2070 architectural functionality will be maintained and can be demonstrated before the release of the 2070 specification.. The following modular configuration is recommended:

- **80x86** or 680x0 CPU board with general purpose serial and parallel I/O
- Serial I/O (38.4 Kbps x 2)
- Communications specific interface module (fiber optics, coax, radio modem, etc. if required)

It is also recommended that the CPU module be programmable in a higher level language such as FORTRAN or 'C'. Various software development environments and compilers are available for various CPU types. The use of higher level programming languages also makes the software easier to maintain and upgrade.

Node processors shall also have the capacity to accept a minimum of 2 additional multifunction boards to support future IVHS applications. This expansion capability will allow other features to be added without replacing the backplane.

2.5 Traveler Information Dissemination

Advanced Traveler Information Subsystems (ATIS), in conjunction with Advanced Traffic Management Subsystems (ATMS), will provide a variety of information services to assist travelers in arriving at their destinations whether the mode is via private vehicles, law enforcement, commercial dispatchers, public transportation, and intermodal travel systems.

Disseminated information includes congested and incident locations, alternate routing, roadway/freeway network status, weather and road conditions, roadway limitations and closures, and speed recommendations. Dissemination of traffic information will evolve over several phases, beginning with currently available communications media (i.e., AM/FM radio, variable message signing, printed material, etc.), then to more specialized telecommunications devices (i.e., personal communication devices, intelligent terminals and kiosks, roadway infrastructure devices, full featured call-up services, and other interactive information services), and finally to autonomous, in-vehicle navigation systems, pre-trip planning services from homes, offices, and roadside kiosks, and portable personal data assistants which interact with the infrastructure for real-time traffic and traveler information.

This evaluation examines the performance required to manage and disseminate traveler and traffic information from within the ATIS. Performance for information delivery to users will vary depending upon the telecommunications device and the service used, and is considered beyond the scope of this evaluation.

The scope of this evaluation encompasses traffic and roadway information management and transport between the system and the driver/traveler or third-party user. This function is anticipated to be performed by integrated subsystems which form an ATMS/ATIS.

Traffic and roadway information have the potential to be collected from a variety of sources. These include the ATMS, MDOT highway maintenance/construction crews, weather service bureaus, other TMCs, local and state government agencies (i.e., MSP, Detroit Police, Sheriff departments), courtesy patrols, public volunteer services, and local businesses. The following list represents a candidate list of the sources and users that may provide or receive traffic, weather, and roadway status information.

- Traffic surveillance and control subsystems
- Michigan Emergency Patrol
- Michigan Department of Transportation (MDOT) divisions / districts
- Michigan State Police (MSP)
- Metropolitan Detroit cities and counties public works (i.e., city/county road departments, Edison electric, Ameritech/Michigan Bell, water departments, etc.)
- Local weather bureaus/reports
- Roadway commuters and travelers (i.e., cellular call-ins)
- Commercial traffic reporting agencies

2.5.1 Technique/Technology Identification

Traffic and road condition information/status management and delivery methods and techniques are evaluated according to the stated evaluation criteria. The methods and techniques identified for this evaluation were selected from information systems architectures and dissemination methods currently used today, but not necessarily used for traffic reports. Technologies anticipated to be used in this capacity are available or currently under operational test, and are being specifically developed from new technologies which have shown promise for ATIS applications.

2.5.1.1 MTC Information Management.

Before any information can be effectively disseminated, it has to be collected, validated, and organized into a form that can be identified, processed (if necessary), and logged. Management of this information needs to occur in an efficient manner in order for effective operations and to provide timely, valid traffic information and status to outside users. In addition, the operators must be able to easily manage the information and system functions from an integrated work station which minimizes excessive operator actions. This information subsystem interfaces with the various subsystems (i.e., traffic surveillance and control subsystem [ATMS], Changeable Message Sign System (CMSS), etc.). Figure 2-6 illustrates a candidate information systems architecture which manages traffic information flow into and from the system.

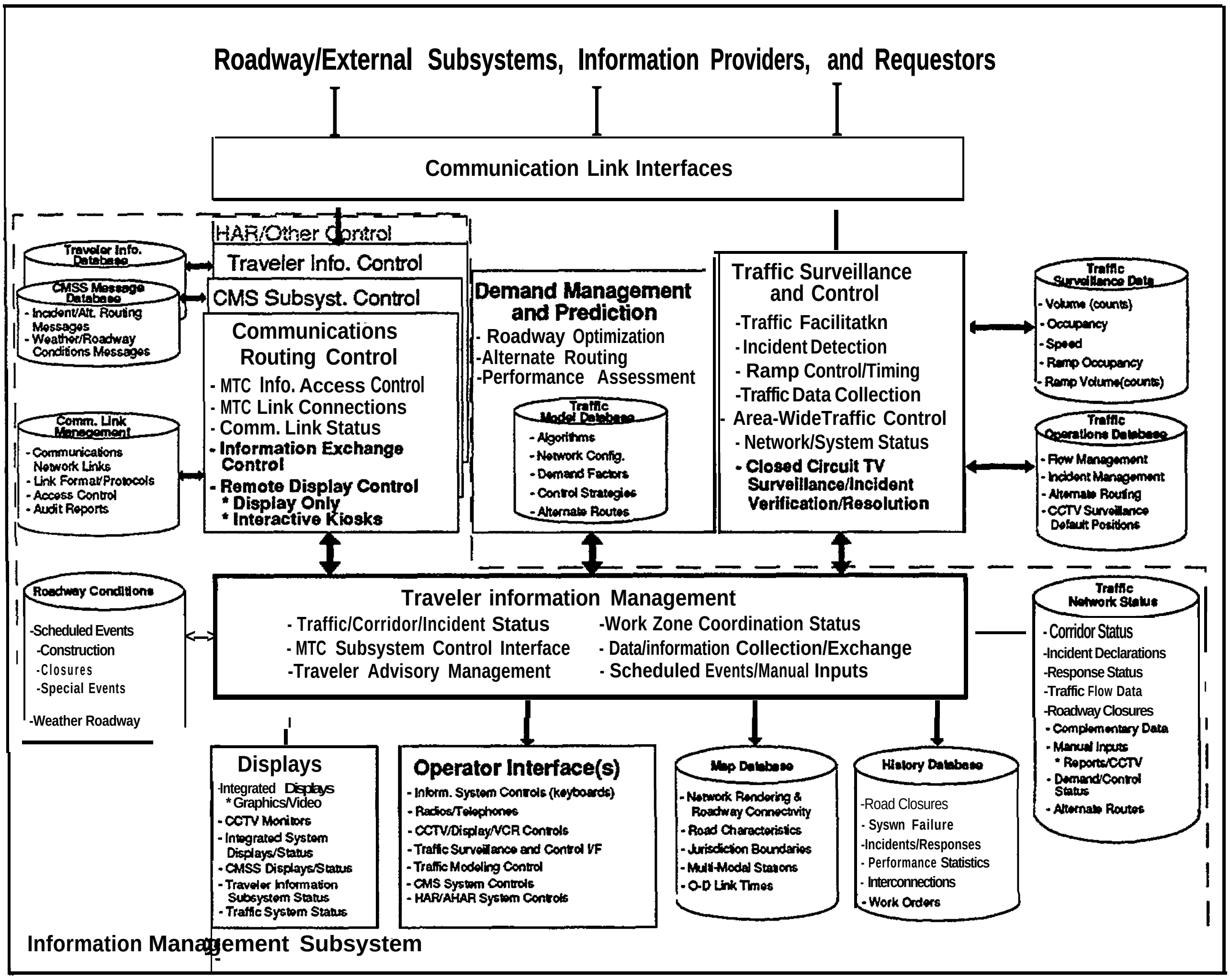

Figure 2-6. Candidate ATMS/ATIS Information Management Architecture

2.5.1.1.1 Information Subsystem Inputs

The traffic and roadway information collected by the system comes from many sources. The ATMS will provide traffic flow statistics, potential incident displays/alarms, system status (i.e., Failure Status, Controller Status, Traffic Page, and Incident Page), and CCTV video signals. The Detroit Freeway Operations Center (DFOC) operators monitor the ATMS displays/status, MSP dispatcher radio frequencies, Michigan Emergency Patrol (MEP) printouts, DFOU field unit radio calls, weather reports, and perform other DFOC duties (i.e., secretarial) to input and log incidents, system failures, repair work orders, weather and road conditions, and daily summaries. Local and state government agencies, public services, sporting and special event organizers, and businesses may provide schedules for events which could impact traffic flow. Information regarding these pre-planned events may be input (by DFOC operators) into the information management subsystem to provide traffic advisories through advanced equipment (i.e., CMS displays, HAR/AHAR announcements, etc.) and to further assist in implementing traffic control strategies (i.e., ramp control timing). Table 2-20 provides a summary of the inputs into the Information Management Subsystem.

Table 2-20. Information Management Subsystem Inputs

Input Information	Source	Input Method	Destination/Database
Traffic Conditions Traffic Plow Data Corridor Status . Demand/Control Status TOC Data Exchanges	- Traffic surveillance subsystems (ATMS) - Michigan State Police (MSP) - Operator - Roadway commuters and travelers (i.e., cellular call-ins)	- Manual - Electronic	- Traffic Network Status Database - History Database - Roadway Conditions Database
Incident Declarations . CMS messages . Advisories . Alternate Routing	- Operator - MSP - MEP	- Manual	- Traffic Network Database - History Database
Incident Response Status	- Operator - MSP -MEP - Removal Service	- Manual	- Traffic Network Database - History Database
Maintenance Work Orders	- Operator	- Manual	- Traffic Network Database - History Database
Scheduled Events - sports - Conventions - Public Works	- Operator - Data Exchange Link - Metropolitan Detroit cities and counties public works (i.e., city/county highway departments, Edison electric, Ameritech/ Michigan Bell, water departments, etc.)	- Manual - Electronic	- Traffic Network Database - History Database - Roadway Conditions - Traffic Modeling Database - Traffic Operations Database
Weather Reports	- Operator - Local weather bureaus/ reports	- Manual	- Traffic Network Database - History Database - Roadway Conditions - Traffic Operations Database - CMSS Message Database - Traveler Info. Subsystem
Roadway Closures - Construction	- Operator - Data Exchange Link	- Manual - Electronic	- Traffic Network Database - History Database - Roadway Conditions - CMSS Message Database - Traveler Info. Subsystem
System Status - Performance Statistics - System Failures - Work Orders	- Operator - ATMS - MTC Subsystems	- Manual - Electronic	History Database Roadway Conditions
System Confignration - Comm. Network Links - Access Control	- Operator	- Manual	Comm. Link Management
Operator Control Commands - ATMS - Traffic Modeling - CMSS - Communications - Traveler Information - Information System Administration	- Operator	- Manual	- Traffic Operations Database - Traffic Modeling Database - CMSS Message Database - Comm. Link Management - Traveler Info. Subsystem - System Database

2.5.1.1.2 Management Processing

The Information Management Subsystem (IMS) will provide the “virtual” database for management of all system and subsystem data. The IMS will fuse data received from multiple sources, both internal and external to the system Operator commands and controls will be routed through the IMS to electronically interface to other subsystems.

2.5.1.1.3 Operator Interfaces

The information management subsystem must provide timely information upon operator request. System responses and requested information should be provided to the operator without disrupting the continuity of the task (e.g., respond within 10 seconds of the request). The DFOC operator interface must provide an integrated station where all freeway operations can be managed. Traffic information management and control displays will be integrated to handle [1] overall system status, [2] freeway network surveillance and control, [3] subsystem displays and controls, [4] administrative management (i.e., operator inputs, incident reports, system status reports, work orders, communications link access control. etc.), and [5] software and system updates.

2.5.1.1.4 Information Outputs and Routing

The IMS will provide DFOC personnel with an integrated station from which to monitor and control all subsystems (i.e., ATMS and ATIS). Outputs from the IMS consist of electronic data and information exchanges with subsystems, and also administrative reports for the purpose of record keeping, traffic studies, data reduction, and maintenance work orders. Table 2-21 identifies information and corresponding output methods used for dissemination to freeway network users.

Table 2-21. Information Management Subsystem Outputs

Output Information	Oupout Method	Destination
Traffi cConditions - Traffic Flow Data - Corridor Status - Incidents/Response Status	ATIS - CMSS - HAR/AHAR syst. - Traveler Info. Syst. - Electronic Dat Link	- Travelers - Public/Private Kiosks - MSP - Emergency Services - Commercial Business - Public Transit
Roadway Conditions - Weather - Closures	ATIS - CMSS - HAR/AHAR syst. - Traveler Info. Syst. - Electronic Dat Link	- Travelers - Public/Private Kiosks - MSP - Emergency Services - Commercial Business - Public Transit
Traffic Modeling and Prediction	ATMS - Electronic - Printouts	- Traffic Operation Database - History Database
Work Orders	- Bar copy Printouts - Electronic Storage	- DFOC Personnel - History Database
System Reports - Traffic Data - Weather Reports - System Performance Reports - Incident/Response Reports	- Hard copy Printouts - Electronic Storage	- DFOC Personnel - System Archives
Operato Control Commands - ATMS - Traffic Modeling - CMSS - HAR/AHAR Subsystem - Communications - Traveler Information - Syste Administration	- Electronic Storage	- Traffic Operations Database - Traffic Modeling Database - CMSS - HAR/AHAR Subsystem - Communications Routing - Traveler Informatio Subsystem - Information Managemen Subsystems

2.5.2 Trade Matrix and Evaluation Criteria

The criteria used for this evaluation consists of the parameters listed in Table 2-22 and their relative importance to providing benefits to the driver/traveler or third-party user. This list represents both mandatory and optional criteria categories to achieve the desired goals defined by MDOT. These criteria will be used to evaluate technologies applied in different information delivery techniques. Table 2-23 show guidelines used in the assessment.

Table 2-22. Traveler Information Dissemination Evaluation Criteria

Evaluatn Criteria	Weight Value	Nee d Category	Comments
Feasibility/Eas of Implementation	10	mandatory	Assessmen of technica risk.
Implementatio Cost	10	maudatory	Assessmen of require d budgetar funds.
Operations/Maintenanc Cost	10	mandatory	Assessmen of recurrin costs.
Disseminatio Effectivity	8	mandatory	Assessmen of deliver y effectiveness.
Expandability/Flexibility/ Growth	8	mandatory	Assessmen of opennes options.
Environmenta Durability	8	mandatory	Assessmen of toleranc to th esurrounding environment.
Eas eof Use	7	optional	Assessmen of practica use/application.
Potentia Marke Support/Cost Recovery	5	optional	Assessmen of servic eviabilit yto develo pa marke base.
Distributio of Benefits/Costs	5	optional	Assessmen of fai rdistributio of benefits and costs of service.

Table 2-23. Traveler Information Dissemination Evaluation Assessment Guidelines

Level of Compliance	Score
Exceeds Compliance	10
Full yCompliant	9
Good Compliance	8
Above Average Compliance	7
Average Compliance	6
Minimn mCompliance	5
Marginal Compliance	4
Partial Compliance	3
Poor Compliance	2
Does Not Comply	1

2.5.3 Analysis

Evaluation of candidate methods and associated technologies was conducted through assessments using the evaluation criteria listed in Table 2-22. The assumption is made that a traffic information management system provides the platform to control the collection, management, and dissemination to the subsystem technologies. Dissemination methods were identified (see Table 2-24) based upon general traffic information type, candidate technologies, and associated advantages and disadvantages as related to generally-accepte d information distribution techniques available today and in the near future (see Table 2-25) .A trade study of technologies, associated with each dissemination method and candidat e technology wa s conducted to evaluate the level to which each supported the criteria areas within the context of information delivered to the motorists or roadway users. The results of this evaluation are tabulated in Table 2-26.

Table 2-24. Traveler Information Dissemination Methods

Dissemination Method	Infonnation Type/Use	Candidate Technology	Advantages	Disadvantages
Radio Frequency Broadcast	• TravelerAdvisories • RoutingInformation • Roadway Network Status	• Highway Advisory Radio (HAR)/Automatic HAR • Public Radio (AM/FM) • FM Subcarrier Broadcast • CB Radio • Amateur Radio	Wide area dissemination Relative low implementation cost Little or no traveler costs Available to all travelers	One wa ycommunications Special access infonuation (tuning) No interaction/requests capability Reliant on broadcaster
Roadway Signin g	• TravelerAdvisories • DiversionAdvise	• Changeable Message Signs • Fixe dSigns • Portable Signs	Location specific Effective diversion capability No user costs Available to all travelers	Limited information Reliant on broadcaster
Passive Visual Aides	• Roadway Network Status • Education	• Printed Service Ads • Public TV Broadcast • 👍✌❄✞	Comprehensive information Graphics capable Wide area dissemination Little or no traveler cost Available to ail travelers	Not timely Questionable effectiveness Reliant on broadcaster
Passive Information Services	• TravelerAdvisories • RoutingInformation • Roadway Network Status	• Kiosks • Public TV Broadcast • Remote Traffic Status Displays • Public Radio (AM/FM) • Pagets • Dial-uptelephone • CATV	Wide area dissemination Relative low implementation cost Graphics capable Little or no traveler cost Available to all travelers	Reliant on broadcaster No interaction/request capability
Interactive Information Services	• TravelerAdvisories • RoutingInformation • Roadway Network Status	• Call-inTraffic Message Service (Cellular/Wireline) • Personal Communications Devices/System (PCS) • Public/Office Kiosks • In-VehicleGuidance . Computer Bulletin Board Service • CB Radio • Digital Data Link to MTC • Mobile Data Terminal • AmateurRadio	In-vehicle capabilities On-request/interactive Specific Information Convenient Real-time information capable	User equipment costs required Infrastructure system requited Not affordable to all users
Electronic Links	• TravelerAdvisories • RoutingInformation • Roadway Network Status	• Digital Data Link to MTC • Fax	Cln-request/interactive Specific Information Convenient Real-time information capable Large public support base	User equipment costs required Limited service request.9

Table 2-25. Traveler Information Dissemination Candidate Technology Descriptions

Index	Candidate Technology	Information Type/Use	Dissemination LinkType	Technology/ Equipment Required	Implementation cost
A	Highway Advisory Radio (HAR)/Automatic HAR	Local advisories Diversion advise	RF	Special vehicle AHAR equipment Special RF transmitters	Infra - Moderate User - Low
B	Changeable Message Signs	Local advisories Diversion advise	Electronic RF or wireline	Specialize sign equipment Control Terminal	Infra - Moderate User - None
C	Public Radio (AM/FM) Broadcast	Local/wide area advisories Diversion advise	RF	AM/FM radio Radio Transmitter	Infra - Low User - Low
D	Public TV Broadcast	Local/wide area advisories Diversion advise Graphical displays	RF	NTSC TV TV transmitter	Infra - Low User - Low
E	Personal Communications Devices/System (PCS)	Local/wide area advisories Interactive data	RF	Personal Communications Unit Infrastructure transmitter	Infra - High User - Moderate
F	Call-in Traffic Message Service (Cellular/Wireline)	Local/wide area advisories Interactive data	Telephone	Cellular telephone Wireline telephone	Infra - Moderate User - Moderate
G	Public/Of&e Kiosks	Local/area wide advisories Interactive data Graphics capable	Wireline/ wireless	Display terminal Control terminal	Infra- Moderate User - None
H	In-Vehicle Guidance	Local/area wide advisories Interactive data Graphics capable	Wireless	In-vehicle computer and display unit Control terminal	Infra - High User - High
I	Remote Traffic Status Displays	Local/area wide advisories Interactive data Graphics capable	Wireline/wireless	Display terminal Control terminal	Infra-Low User - Low
J	Printed Service Ads	Local/area wide advisories Interactive data Graphics capable	Manual/mailings	Printed matter	Infra - Moderate User - None

Table 2-25. Traveler Information Dissemination Candidate Technology Descriptions (continued)

Index	Candidate Technology	Information Type/Use	Dissemination Lii Type	Technology/ Equipment Required	Implementation cost
K	Computer Bulletin Board Service	Local/area wide advisories Interactive data Graphics capable	Wireline	PC	Infra - Low User - Low
L	CB Radio	Local/area wide advisories Interactive data Graphics capable	RF	CB radio unit	Infra - None User - Low
M	Digital Data Link to MTC	Local/area wide advisories Interactive data Graphics capable	Wireline/wireless	Interfacing computer system	Infra - Low User - Low
N	Mobile Data Terminal	Local/area wide advisories Interactive data Graphics capable	RF	Mobile Data Terminal Dispatcher station	Infra - Moderate User - Moderate
0	Display Only System (DOS)	Local/area wide advisories Interactive data Graphics capable	Wireline	NET DOS	Infra-Low User - Moderate
P	Pagers	Local/area wide advisories Interactive data Graphics capable	RF - satellite	Pager units Transmission station	Infra - High User - Low
Q	FM Subcarrier Broadcast/RDBS	Local/area wide advisories Interactive data Graphics capable	RF	Special radio unit	Infra - High User - Low
R	Fax service	Point-to-point information service Graphics capable Still-frame data	Telephone	Fax equipment	Infra - Low User - Low

Table 2-26. Traveler Information Dissemination Technology Assessment Raw Scores

	SCORES																	
Evaluation/Criteria	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**	**R**
Feasibility/Ease of Implementation	8	9	8	7	6	7	8	6	8	9	8	9	7	8	9	7	7	9
Implementation Cost	8	8	9	9	5	8	7	4	7	8	8	8	8	6	8	7	7	9
Operations/ Maintenance Cost	9	9	9	9	8	9	8	1	8	1	7	7	7	6	7	8	8	9
Dissemination Effectivity	8	8	9	6	9	5	8	9	8	6	5	5	8	7	9	6	8	7
Expandability/ Flexibility/Growth	8	8	6	6	8	6	8	9	8	6	8	5	9	8	8	6	7	7
Environmental Durability	7	8	7	7	7	7	8	8	8	5	7	7	7	7	7	8	8	8
Ease of Use	8	8	8	8	8	8	8	8	8	9	8	8	8	7	8	8	8	6
Potential Market Support/Cost Recovery	7	7	6	6	4	4	7	4	6	6	6	6	6	5	8	5	5	5
Distribution of Benefits/Costs	8	9	8	7	7	6	8	8	8	6	7	7	8	6	8	6	7	8
Total Scores	**565**	**588**	**557**	**523**	**493**	**490**	**553**	**494**	**548**	**499**	**531**	**517**	**558**	**500**	**588**	**491**	**520**	**559**

2.5.4 Information Dissemination Recommendations

Recommendations for implementing dissemination technologies (and supporting systems) are consistent with criteria defined through discussions with MDOT. The premise that an information management system supports the dissemination technologies is assumed This recommendation is divided into two steps: [l] initial deployment; and [2] follow-on strategies to expand the information dissemination capabilities of the system.

Due to the nature of coordination with other government agencies and effective public participation, traffic information dissemination to travelers and other users for initial deployment is recommended to be accomplished with CMS messages displayed on the roadway, data availability and electronic exchanges accomplished with the RCOC TOC, and composite traffic data (i.e., graphic traffic status, video, and fax information) provided to MSP, MEP, Metro Traffic Control, and other TOCs via direct data/electronic links. These data consist of CCTV images and passive graphical displays.

A printed material educational campaign via auto clubs or DMV should also be directed by MDOT to educate the general public about the new services being offered. To support commercial businesses, the current plans to provide UPS, Greyhound Bus, Smart Bus, Detroit Department of Transportation, and Commuter Transportation Service with NET-developed Display-Only Site (DOS) terminals should be carried out.

For future deployments, it is recommended to launch a marketing campaign to attract other potential users for the DOS terminal or similar method of dissemination. Because of the versatility of the DOS platform (PC-based), future ATIS applications could potentially use the same platform through software upgrades. Considerations for a DOS in the State Plaza Building, as a simple kiosk, should also be investigated. Information dissemination through the DIRECT program for the implementation of HAR/AHAR transmitters should be carried out; however, smooth integration of the AHAR operation into the DFOC should be studied. In addition, a marketing campaign should be launched to attract motorists to purchase HAR/AHAR vehicle radio units.

2.6 Communications

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

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

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

2.6.1 Identification of Alternate Technologies

Various established communications technologies are evaluated to determine the most cost effective and expandable system. Alternative communications analyses are conducted for the following technologies:

- Voice Grade Channel
- Twisted Pair Wire
- Coaxial Cable
- Fiber Optics
- Power Line Carrier
- Packet Radio
- Trunked Radio
- Microwave
- High speed digital line
- Spread spectrum radio

Voice Grade Channel

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

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

Twisted Pair Wire

Twisted pair wires can be used to provide serial connectivity in point-to-point or point-to-multipoint communications topologies. The pair of wires typically operate in a "balanced" mode such as RS-422 or RS-485. Both types of circuits provide digital communications with the pair of wires operating in opposing polarities. In other words, digital data is sensed by monitoring the voltage difference between the pair of wires. This method is highly immune to noise since the induced noise signal is seen on both wires simultaneously, however, the voltage difference between the two wires remains the same.

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

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

Coaxial Cable

Coaxial cable systems, commonly known as "coax", operate with a carrier frequency of 5-350 MHz. Data signals, either analog or digital, are modulated and transmitted along the length of the cable. Various carrier frequencies can be applied to one coax cable providing multiple channels on a single line. Typical channel bandwidths are 6 MHz and may be further subdivided for digital data transmission. Data rates of up to 7.5 MHz can be achieved based on channel subdivision. Frequency Division Multiplexing (FDM) techniques are used for channels and Time Division Multiplexing ('T'DM) is used for data on a channel. Various types of data can be accommodated by coax systems including digital data, voice, analog data, full motion video, and compressed video.

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

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

Fiber Optics

Fiber optics communications systems use a beam of light, which is generated by a laser diode or gas laser, transmitted through a glass fiber in a serial manner. The pulses of light with wave lengths between 850 and 1550 nanometers turn on or off depending upon the logic state of the transmitted data bits. Fiber optic cables are typically bundled with multiple fibers, providing several data channels. Data rates of up to 2.4 giga bits (2.4

billion bits) per second can be accommodated by using time division multiplexing. Multiple channels of digital data can be transmitted at high speeds providing extraordinary through-put capabilities. Data can be transmitted over several miles (25 to 30 miles) and the transmission range is rarely a limitation provided communications hubs or fiber optic repeaters are installed.

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

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

Power Line Carrier

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

Packet Radio (Area Wide Radio)

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

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

Trunked Radio

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

Microwave

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

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

High Speed Digital Line

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

a. Signals may be regularly reshaped or regenerated during transmission since information is no longer carried by continuously varying pulse amplitudes but by discrete symbols.

b. All-digital circuitry may be used throughout the system.
c. Signals may be digitally processed as desired.
d. Noise and interference may be minimized by appropriate coding of the signals.

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

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

Spread Spectrum Radio

Available spread spectrum radios which operate in the 902 MHz and 2.4 GHz range in an FCC unlicensed mode contain the logic needed to handle network protocol including relay among nodes (where required). These units are designed to work in “cells” where there is a “headend” radio connected to the central facility, one for each cell. Adjacent cells use different frequency channels and each remote controller requires a radio.

Frames are used for transmit / receive / network join functions, with a typical frame time of 1 second. During the top of frame time, the central site sends all polls, etc. to its headend radio for all controllers in the cell. The headend then initiates outbound transmission of all bundled traffic in a single packet. Each radio receives the transmission and removes the message for its controller (passing it to the controller over an RS-422 or RS-232 serial link of selected data rate). If the radio is also providing relay service for other nodes (who cannot receive the headend directly), it builds a new packet containing the messages for its “customers” and sends it. This process repeats until all radios have received outbound messages. When a response comes from a local controller, it is placed into a new packet by the radio and combined with responses from other “customers” of the radio before being sent in a burst back to the headend. The process repeats until the headend has collected all inbound messages, which are then forwarded to the central facility.

This system is similar in concept to packet radio. No additional infrastructure is required (beyond supplying power for the units). Approximately 30 nodes could be accommodated on a single frequency. Disadvantages include the cost of the units and the uncertainty of future use of the 902 MHz band (which could interfere with radio operation).

Cellular Telephone

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

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

Communications Technology Summary

Table 2-27 summarize characteristics and system capabilities of the discussed communication technologies.

Table 2-27. Summary of Communications Characteristics

Technology	Expansion Capability	Max. Data Rate per Channel	Information Types Supported	Transmission Range	Comments
Voice Grade Channel	Additional channels can be easily added	9600 bps	Data, voice, Slow Scan TV (SSTV)	Several miles (10-100 miles)	High recurring lease costs
Twisted Pair Wire	Additional construction required	9600 bps	Data, voice, SSTV	9-15 miles w/repeaters	Construction is key cost driver
Coaxial Cable	Bandwidth available, additional construction required	7.5 Mbps	Data, voice, live video	Several miles (10-12 miles)	Construction is key cost driver
Fiber Optics	Bandwidth available, additional construction required	2.4 Gbps	Data, voice, live video	Rarely a limitation with repeaters (20-30 miles without repeaters	Construction is key cost driver
Power Line Carrier	Expansion limited to single side of power transformer	100 Kbps	Data, voice, SSTV, compressed video	4,000 feet	Limited to single side of power transformer or 4000 ft. w/ bridge
Packet Radio	H/W expansion easily accommodated, frequencies can be added for data volume	9600 bps	Data, SSTV, voice	Several miles with repeaters (30 miles without repeaters)	FCC license required for each channel used
Trunked Radio	H/W expansion easily accommodated, frequencies can be added for data volume	9600 bps	Data, SSTV, voice	Several miles (25-50 miles)	Protocol used does not lend to fast response
Microwave	Extensive construction needed for additional sites	7.5 Mbps	Data, voice, live video	Several miles, range varies (up to 30 miles)	Line of sight availability, weather, multipath sensitivity
High Speed Digital	Additional channels can be easily added	DS0 64 Kbps	Data, voice, compressed video	Several miles (10 - 50 miles)	High recurring costs
Spread Spectrum Radio	H/W expansion easily accommodated	256+ Kbps	Data, voice, SSTV, compressed video, live video	Several miles (up to 50 miles)	No FCC license required
Cellular Phone	Infrastructure exists for expansion	9600 bps	Data, voice	Several miles Point-to-point	No FCC license required High recurring costs

2.6.2 Trade Matrix and Selection Criteria

The criteria used for this evaluation consists of the parameters listed in Table 2-28 and their relative importance to the implementation of the specific communication method. The list represents criteria categories necessary to support the required digital and video data types. Each communication method is evaluated based upon the satisfaction of the evaluation criteria. Raw scores are tabulated and an overall ranking is established using weight factors and evaluation guidelines in Table 2-28 and 2-29.

Table 2-28. Communications Evaluation Criteria and Weight Factors

Criteria	Weight Value	Comments
Implementation and O&M Cost	10	Assessment of Installation and operating costs
System Expandability	7	Infrastructure Capability for System Growth
Maximum Data Rate	7	Capability to Accommodate Reauired Data
Effective Range	7	Assessment of Area Coverage

Table 2-29. Communications Evaluation Assessment Guidelines

Level of Compliance	Score
Exceeds Compliance	10
Fully Compliant	9
Good Compliance	8
Above Average Compliance	7
Average Compliance	6
Minimum Compliance	5
Marginal Compliance	4
Partial Compliance	3
Poor Compliance	2
Does Not Comply	1
Not Feasible	0

2.6.3 **Analysis**

Separate analyses were conducted for each ATMS/ATIS system component in order to identify minimum acceptable communications techniques and to provide acceptable perfommnce in a cost effective manner. Additionally, analyses were based upon the capability to implement the specific communications technology in a timely manner to support the initial deployment implementation phase. Table 2-30, 2-31 and Figure 2-7 reflect analyses of digital data. Table 2-32, 2-33 and Figure 2-8 reflect analyses of video data. The life cycle cost analyses were based upon a 6.5 mile freeway segment with communications nodes to highway advisory radio, changeable message signs, detector stations, and ramp controllers.

Table 2-30. Digital Communications Technology Comparison Raw Scores

Technology	Impl. / O&M Cost	Expandability	Data Rate	Range
Voice Grade Channel	4	9	6	9
Twisted Pair	3	4	8	6
Coaxial Cable	3	4	10	9
Fiber Optics	3	10	10	9
Packet Radio (Area Wide)	10	9	6	9
Trunked SMR	8	8	6	8
Microwave	4	4	10	9
HS Digital DS0	4	10	8	9
Spread Spectrum Radio	8	9	9	8
Cellular Phone	0	10	6	10

Table 2-31. Digital Communications Technology Composite Scores and Relative Ranking

Technology	Composite Score	Relative Ranking
Voice Grade Channel	208	6
Twisted Pair	156	10
Coaxial Cable	191	8
Fiber Optics	233	4
Packet Radio (Area Wide)	268	1
Trunked SMR	234	3
Microwave	201	7
HS Digital DS0	229	5
Spread Spectrum Radio	262	2
Cellular Phone	182	9

Table 2-32. Video Communications Technology Comparison Raw Scores

Technology	Impl. / O&M Cost	Expandability	Data Rate	Range
Coaxial Cable	3	4	10	9
Fiber Optics	3	10	10	9
Microwave Only	4	5	10	9
HS Digital DS1 - Codec	0	7	6	9
Wideband wireless / Microwave link	10	5	10	9

Table 2-33. Video Communications Technology Composite Scores and Relative Ranking

Technology	Composite Score	Relative Ranking
Coaxial Cable	191	4
Fiber Optics	233	2
Microwave Only	208	3
HS Digital DS1-Codec	154	5
Wideband wireless / Microwave link	268	1

2.6.4 Results and Recommendations

Results from a similar communication study performed for the Road Commission for Oakland County (RCOC) indicate that owned cable (twisted pair, fiber or coax) was not a cost effective near term solution even though the media support required bandwidths for all system components, including live video for fiber and coax. However, fiber optic communications has been identified as the ultimate solution which has enormous expansion and bandwidth capacities. The recommendations provide a migration path to other communications means as the system expands and other IVHS functions are applied, With the modular and open architecture defined, each system component is not dependent upon a single communication solution. The following recommendations are based upon the immediate need to implement the early deployment system.

Power line carrier communications is not recommended due to its range limitations and the uncertainty of power distribution topologies in various areas. Leased media do have attractive characteristics. However, to support live video transmission, high leasing costs will be incurred.

Detector Stations /Ramp Controllers

It is recommended that communications to and from detector station / ramp controllers be accomplished by packet radio. The required bandwidth in communicating the digital data does not warrant higher capacity mediums. However, if an existing backbone (i.e. fiber optic or coax) is available for use, it is recommended that communications be done over the backbone. The cost of installing a backbone for the initial deployment prohibits its use in the near term. Currently, several community access TV (CATV) suppliers are identifying the need to install a backbone in metropolitan Detroit. Freeway right of ways are the most appropriate for their application. It is possible that MDOT could grant right of way access to CATV or fiber providers in exchange for communications bandwidth use. The timeliness of implementing such an agreement will dictate the final initial deployment solution. If the agreement cannot be achieved during the initial deployment phase, packet radios should be used on an interim basis. As the backbone is installed in the corridor, communications for the detector stations / ramp controllers can be converted over to the new medium. The packet radio equipment then can be used for the next corridor on a “leap frog” basis until total coverage is achieved by the backbone.

When a backbone type communication system is implemented, across-the-roadway communications can still be accommodated by wireless packet radio. This implementation method eliminates the need to trench under the freeway (jacking) or to route conduit on an overpass.

CMS/HAR

The current architecture, as described in Section 4 of this document, supports multiple means of controlling CMSs and HARs. If detector / ramp control nodes are used to control CMSs and HARs, the main communication medium will be the one identified for the detector / ramp control nodes. Communications between these controllers and the

CMS can be accomplished by wireless modems or dedicated cables depending upon the distance between the devices.

If the placement of the CMS or HAR device is not near a controller, it is recommended that the communications link be accomplished the same way as the detector / ramp control node (packet radio or backbone). Since the architecture identifies CMS/HAR nodes as independent functions with identical interfaces, the communications and control methods are the same for all system components. However, if CMS/HAR devices are remotely located, away from any infrastructure components (such as Detroit Metro Airport or Pontiac Silverdome) cellular phone modems could be used since CMSs and HARs do not require continuous communications to the traffic operations center.

Video

Similar to the other nodes, it is recommended that a wireless approach be used for video control and video return. Since the required bandwidth for the video returns far exceeds packet radio, other means of wireless communications are required. New techniques with wide band communications allow short distance live video transmission. Several live video channels (3 to 5) can be concentrated to one central point and then relayed back to the control center on a single microwave link or leased digital line.

As a more permanent and cost effective communications medium becomes available (i.e. CATV fiber optics access), the control and video return transmission can be migrated onto the new system. The existing RF equipment is then salvaged and used to expand the system further.

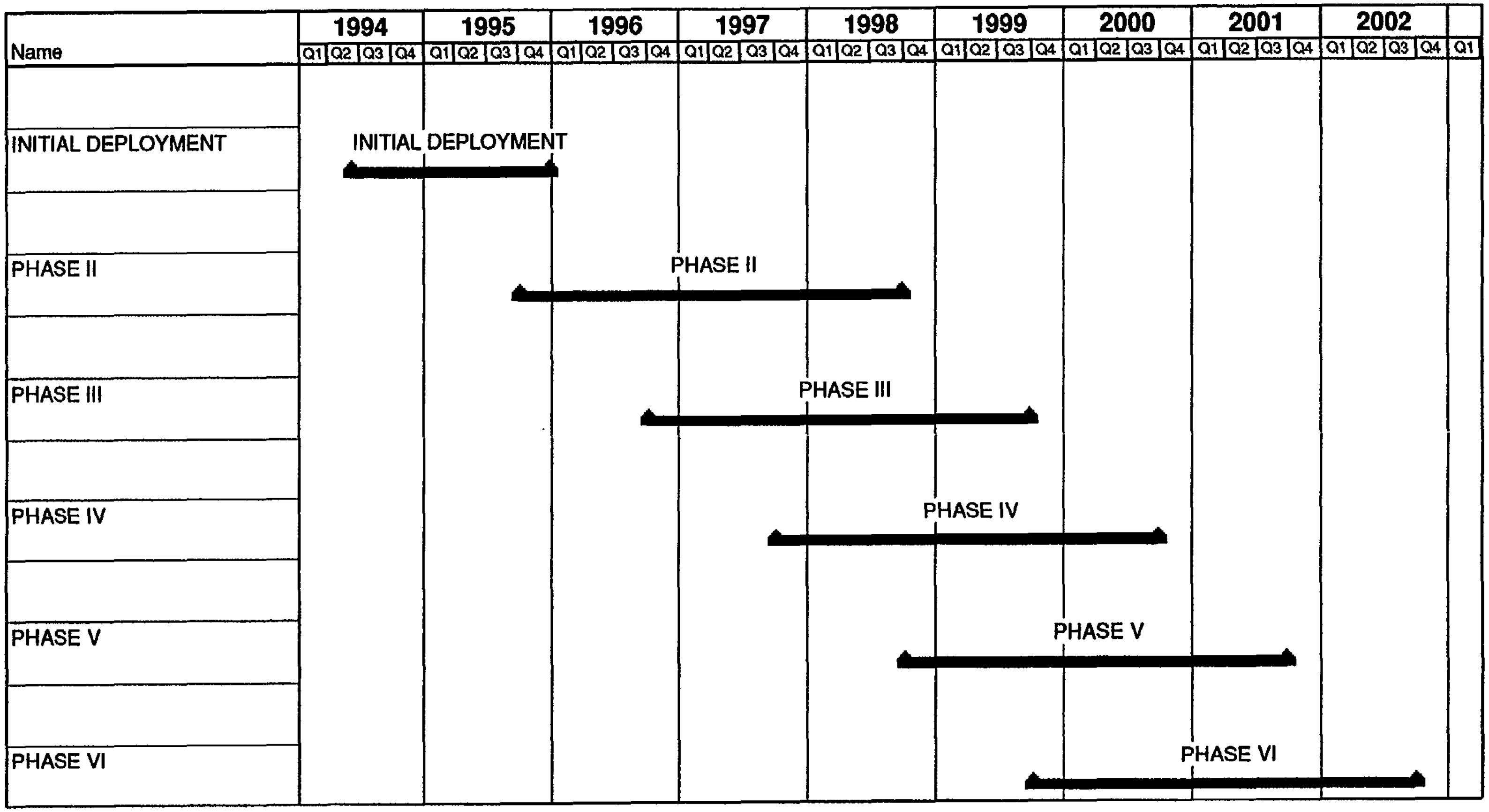

Figure 3-5. Phased Deployment of ATMS/ATIS Schedule

4.0 System Description

This section describes the system requirements and architecture for the Michigan Department of Transportation (MDOT) Michigan Intelligent Transportation System (MITS), hereinafter referred to as the system.

System requirements were developed from current freeway operations and future capabilities identified by MDOT Detroit Freeway Operations Unit (DFOU) personnel based at the MITS Center (MITSC) in downtown Detroit. These requirements identify and define system interfaces, functional processes, operational performance, system characteristics, processing resources, and logistical support which will be used as a basis for system/subsystem design and implementation. Section 4.1 summarizes the current system and resources, Section 4.2 summarizes the identified system operations, Section 4.3 contains the system requirements, and Section 4.4 contains architecture approach evaluations, and Section 4.5 documents the Baseline System Architecture.

The architecture was developed from the requirements to support effective freeway operations and to provide technological compatibility, openness, and adaptability. Commonality between requirements (functions) have been grouped into subsystems to promote synergism among operational tasks.

For the Initial Deployment option, an expansion of the current traffic surveillance and control capabilities of the current system will be the primary focus. Enhanced capabilities to provide traveler information to roadway users and other traffic centers will also be included. The Initial Deployment approach is a subset of the overall architecture to define general component-level functions, and specifies the manner in which the new corridor instrumentation interfaces with the current system and accommodates future ATMS/ATIS deployments. Requirements specifically identified for the Initial Deployment option are identified in Section 4.6.

4.1 Current Resource Usage

The Early Deployment approach concentrates on an initial deployment to expand the surveillance and control capabilities of the current system. This extension uses all in-place equipment to the maximum extent possible, modified as appropriate and includes the following:

a. Concurrent 3280MPS processor system and existing algorithms,
b. Vicon VPS-1300 video switcher and associated controls,
c. Vultron CMS control console and software,
d. DOS and GDS graphic processor subsystem,
e. Existing cable resources.

Use of existing equipment and software does not preclude development of new interface software, addition of new features to existing software, or internal database changes needed to accommodate an extension to the existing system. Addition of the extension utilizes current system capacities to the maximum extent possible.

As future corridor deployments begin to exceed current capabilities and capacities (and operator workload capabilities), the MITS will be upgraded and enhanced to accommodate the expanded freeway network system and streamline operator tasks and workloads.

To support the Initial Deployment program expansion, the existing CCU/RCU communications system shall be augmented, but not replaced, to accommodate the additional surveillance and control coverage. Direct extension of the CCU and RCU channel implementation will not be a requirement, and is discouraged due to potential command/response delay problems that could result in propagation delays or other communications-related problems when the physical cable/ communications path is extended beyond the current system bounds.

4.2 System Operations

Detroit Freeway Operations are managed from the MITSC located in the Greyhound Bus Building at 1050 6th Street, 2nd Floor, Detroit, MI. All freeway operation system functions are managed from the operations center.

The following describes the freeway operations capabilities to be provided by the new system (MITS). The purpose of this identification is to define the corresponding system functions required to support freeway operations. In addition, distinction between those functions or tasks performed by MITS personnel and those performed by the system can be made. From this identification, these operations can be distilled into requirement components (i.e., interfaces, functional processes, operational performance, system characteristics, system processing resources, and logistical support), to form the basis on which system/subsystem designs and implementations take their operational form; i.e., hardware, software, and support components.

The system supports three major operations (with major subtasks). These include the following:

- Traffic Management Operations
  - Manage Recurrent Congestion
  - Facilitate Incident Management

- Traveler Information Management Operations
  - Collect Traveler Information
  - Manage Traveler Information
  - Disseminate Traveler Information

- System Performance Monitoring Operations

- Monitor System Performance
- Perform Malfunction Management

4.2.1. Perform Traffic Management Operations

Traffic management encompasses a spectrum of DFO activities to minimize traffic delays and congestion; while providing improved safety, and effective utilization of roadway capacity; thus, promoting economic productivity and growth, and operational efficiency of the freeway network. Traffic management is accomplished through surveillance of mainline and surface street vehicle flow and adjustment of traffic control parameters and sequences to balance, optimize, or reroute/divert traffic flow on the metropolitan Detroit freeway network. The system manages traffic flow for both recurrent (routine congestion) and non-recurrent (incident) traffic conditions.

4.2.1.1 Manage Recurrent Congestion

Routine, recurrent traffic congestion is managed through mainline and entrance/exit ramp surveillance, ramp meter control, changeable message signing and information delivery, and area-wide coordination. Surveillance sensors collect raw traffic flow data (i.e., vehicle counts {for volume} and timing gate time differentials {for speed)) for processing into operational MOE's (average occupancy {% time detector is actuated by a vehicle), total volume {vehicles for a given period of time}, and average speed (mph}). These MOE's are used by the system to adjust entrance ramp metering or other flow controls (e.g., moveable barriers), and display and report the freeway network status to MITS personnel through graphical displays and reports. The freeway network status is used in conjunction with information databases (i.e., CMS and HAR/AHAR) for message delivery to motorists, other TOCs, commercial dispatchers/fleets, and other roadway users via CMS, HAR/AHAR, and electronic data links. Freeway network status is overlaid, in graphical form, **on** an enhanced version of the current GDS map display for the entire metropolitan Detroit freeway network. These enhanced map displays include advanced graphical user interfaces (GUIs) which integrate system/subsystem-operator interfaces, and capabilities to predict traffic flow patterns (based on road closures and construction, scheduled events and activities); and calculate appropriate traffic control strategies.

a. The current GDS platform could potentially serve as an intermediate host in parallel with an advanced GUI host for the expanded system. The advanced GUI will ergonomically integrate system displays and operator control interfaces for most system functions (traffic management operations, traveler information management operations, and system performance monitoring operations) into single operator work areas. Some tasks may still require manual attention. Operators will have the capability to cancel or override any operator-initiated commands at any time before system execution.

b. For recurrent congestion, the system will provide the capability to "smooth" traffic flow through ramp metering, variable speed recommendations, information to motorists (i.e., congestion forewarning, approximate delay time, etc.). The system will use these management controls in response to the recurrent excessive volume demands on the roadway's capacity.

c. For corridor traffic volume demands resulting from scheduled events and diversions due to planned work zones, the system will provide the capability to predict flow patterns and calculate traffic control strategies and tactics in anticipation to the increased demand or the presence of work/construction zones. These strategies and tactics include alternate routing, speed recommendations, lane control, roadway signing and ramp metering.

d. The system will also coordinate traffic flow throughout the geographic Metropolitan Detroit area (areawide). This coordination consists of integrated traffic information exchanges to manage traffic flow between surface arterials and the freeways and trunklines. This operation is envisioned to be accomplished between surface arterial TOCs and the MITS.

4.2.1.2 Facilitate Incident Management

Incident Management consists of a series of coordinated activities performed by various freeway operations, law enforcement, emergency service, public, private, and government agencies. Incident Management involves location detection, verification, response, removal, traffic management, and dissemination of incident information to the general public. The system provides the technological infrastructure on which DFOU personnel can effectively detect, verify, determine, respond and coordinate clearing activities, provide quick and accurate roadway incident information to motorists, and provide incident record keeping on a 24-hour, 7-day/week basis. Features to automate operator activities and tasks are facilitated by advanced GUTS. Common operator tasks are organized in a manner to minimize physical operator movement throughout the MITSC.

Application of the MDOT Incident Management Plan for Metropolitan Detroit will be supported by the system to the maximum extent possible to promote incident management coordination, reduce travel delays and potentials for secondary incidents, and improve travel safety and air quality (through minimized delays and reduced emissions). Principal incident management activities include the following:

- Incident Detection
- Incident Verification
- Response Formulation and Coordination
- Removal Coordination
- Incident Traffic Management
- Incident Information Dissemination (to motorists and others)

<u>Incident Defection</u>

The system facilitates detection of incidents through monitoring and processing of traffic flow MOEs (i.e., occupancy, volume, speed) along mainline corridors and interchanges.

That is, while the system calculates, monitors, and displays the different levels of traffic flow on the freeway network, an MDOT-approved incident detection algorithm measures the flow data against pre-determined thresholds and compares them to incident condition parameters. If traffic flow conditions indicate that there is an incident, the system identifies the suspected incident location (to the nearest l/3 mile) on status display(s) and issues an alarm to the operator. The status display(s) identifies l/3 mile segments for each instrumented mainline corridor.

Incident Verification

The system supports facilitation of incident verification tasks by providing the operator with multiple incident-reporting sources. These sources include:

a. Identification and control of appropriate CCTV camera(s) (if available).

b. Verification by facilitating incident correlation from multiple sources via the traffic surveillance subsystem, electronic links, or manual reports (i.e., MSP dispatcher, city police, MEP data, Metro Traffic Control, MDOT field/road crews, courtesy or service patrols, and other sources).

c. Once the operator verifies that there is an incident (via CCTV, MSP) and declares the incident (through procedures), an electronic form is displayed and used for entries into an incident log. If correlation data is available (i.e., MEP, Metro Traffic, etc.), correlation entries will also be made available.

Response Formulation and Coordination

The system supports facilitation of incident response tasks in accordance with the approved Incident Management Plan for Metropolitan Detroit. These tasks include:

a. If the MSP is not aware of the incident, the system offers notification assistance. If a video image is also available, the system configures appropriate video links for the MSP (or Metro Traffic Control, or other incident reporting services).

b. If the cause of the incident can be determined, additional information is offered to the MSP (or appropriate removal agencies {i.e., courtesy patrols, towing companies, etc.} so that appropriate removal efforts can be identified.

Removal Coordination

The system also supports coordination and execution of incident removal tasks based upon the incident cause. These tasks potentially include:

a. Coordination with the MSP, or appropriate removal agencies, for any additional support to on-site authorities.

b. If the cause of the incident consists of roadway debris, the system provides for notification and dispatch of MDOT agency field/road crews for removal.

c. Provisions to coordinate and report the clearance of an incident.

Incident Traffic Management

The system provides for traffic management around incident locations by facilitating deployment of incident information to upstream motorists and activation and metering of local upstream ramps, if necessary. In addition, the system also performs the following tasks:

a. Identification of the appropriate Incident Management Plan alternate routes (based upon the local area corridor status). Alternate routes are identified through the following priority identification criteria in accordance with MDOT criteria, AASHTO and MMUTCD engineering requirements, standards, and guidelines. Principal priority criteria (in descending order) include:

- Freeways without service drives.
- Freeways with service drives.
- Selected arterial surface streets.

b. Information exchanges with arterial TOCs to adjust alternate route signal timing plans for selected arterial alternate routes.

c. Identification of the appropriate upstream CMS locations and corridor HAR/AHAR transmitters, and selects and displays candidate CMS and/or HAR/AHAR message options to the operator. Once the operator selects and commands message deployment, the system configures the appropriate message packets, and issues the appropriate commands to the target CMS(s) or HAR/AHAR, or other ATIS functions.

Incident Information Dissemination

The system facilitates compilation of more detailed incident data, records the deployed information (i.e., CMS, HAR/AHAR, etc.) into an incident log, and provides other operator-selectable information dissemination options (i.e., fax, inter-TOC electronic links, freeway network status displays/kiosks, call-in traffic messaging systems, MEP and Metro Traffic Control communications links, etc.). Sources of incident data include:

- MDOT traffic surveillance and control system
- Michigan State Police/local city police
- MDOT field/road crews
- MEP reports
- Metro Traffic Control reports
- Manual observations from CCTV surveillance
- CB channel monitoring (i.e., CB channel 9)

Throughout activities surrounding the management of incidents, the system provides a graphical user interface (GUI) which controls and interfaces nearly all operator functions into single-operator position(s). These functions potentially include “hands-free”, wireless telephone, radio communications, and other features to minimize operator transit within the MITSC.

4.2.2 Perform Traveler Information Management Operations

To better serve travelers using the metropolitan Detroit freeway network, traffic status and road condition information provides the motoring public informative benefits for travel decision making and route selection. Information availability leads to a more informed roadway user and potentially improves travel safety, economic productivity and efficiency, and improved environmental air quality. This service is provided in the form of travel-related information collection, management, and dissemination to freeway network users. The system supports this service through traffic surveillance and information management with technologies and techniques which provide timely and accurate information delivery to freeway users and interfacing agencies (public, commercial and private).

The system collects travel-related information from traffic surveillance capabilities and external providers (i.e., MSP dispatcher, MEP printouts, MDOT field units, other TOCs and other interfacing entities). This information includes freeway network status, roadway conditions and closures, weather conditions, and other relevant travel or traffic-related information. Relevant information is integrated, or fused, into an organized information database for monitoring, display and dissemination to roadway users and requesting entities. Dynamic traveler information dissemination techniques and technologies include roadway CMS, HAR/AHAR, video images, graphic displays, TV and AM/FM radio broadcasts, facsimile and other messages, dial-up telephone service and information delivery through third-party providers. The system provides the capabilities to collect, manage, and disseminate all relevant traffic-related information to users of the metropolitan Detroit freeway network.

4.2.2.1 Collect Traveler Information

The system collects accurate information on traffic conditions, freeway network status, roadway conditions and closures, weather conditions, work zone/construction conditions, and other relevant travel or traffic-related information for database management. The system collects this information from both infrastructure and non-infrastructure-based sources. For the metropolitan Detroit area, traffic information is generally collected from (but not limited to) the following sources:

- MDOT traffic surveillance and control subsystem
- Michigan State Police
- Local Police (cellular calls)
- Metro Traffic Control (cellular calls)
- Michigan Emergency Patrol (CB and cellular calls)
- MDOT field/road crews
- Other TOCs

- Roadway travelers/general public (cellular call-ins)
- State and local public works agencies
- Visual sighting by traffic reporting aircraft
- CB radio monitoring

4.2.2.2 Manage Traveler Information

The system integrates, or fuses, information on traffic conditions, freeway network status, roadway conditions and closures, weather conditions, other roadway conditions (i.e., work zones), and other relevant travel or traffic-related information collected from multiple sources into an organized database. Traveler information is organized (as a minimum) into four databases: Incident/Advisories; Freeway Network Status; Historical Data; and Roadway Conditions.

As with any modem information processing system, the value of the information contained on the system potentially becomes a target for unauthorized access or malicious activities. To prevent these activities from causing irreparable loss of data or service, the system monitors and controls information access to ensure data and system integrity are maintained.

DFOU personnel manage this information through administrative tasks; such as, information entry/input and archiving, database management, access management, and information system monitoring, troubleshooting, and built-in test (BIT)/built-in test equipment (BITE) diagnostic capabilities.

4.2.2.3 Disseminate Traveler Information

The system provides open and broad dissemination of traveler information through a wide variety of channels and techniques to promote travel safety and traffic flow management. Information dissemination to freeway network users can be achieved with a variety of technologies. Some of these technologies are included below:

- Roadway Signing (i.e., CMS, portable CMS, variable speed signs, fixed signs)
- Electronic Links (i.e., data links, fax service)
- Radio Frequency Broadcast (HAR/AHAR, broadcast radio (AM/FM), private radio (amateur), FM subcarrier, RDBS)
- Passive Visual Aides (printed material, broadcast TV, CATV)
- Passive Information Services (broadcast TV, remote traflic status displays - passive kiosks, broadcast radio (AM/FM))
- Interactive Information Services (call-in message service, PCS, public/office kiosks, in-vehicle guidance, computer bulletin board service (BBS), CB radio, amateur radio, modem data link, mobile data terminal)
- Third-party traffic reporting services (i.e., Metro Traffic Control, broadcast TV, CATV, and radio)

The primary objective for information dissemination **is** to inform freeway network users of travel and traffic conditions, preferably, to those motorists who are directly affected and can benefit from the information by altering their travel routes and/or departure times. When understanding the behavior that not all users opt to alter their travel routes even though the information is delivered, the system must still provide a level of service to achieve overall freeway network management improvements for travel safety and traffic flow facilitation. Potential users include the following:

- General Public (through broadcast TV/radio, **CATV,** CMS, HAR/AHAR, kiosks in major commercial centers, etc.)
- Metro Traffic Control
- Michigan Emergency Patrol
- Law enforcement/emergency services (i.e., police, fire, medical, HAZMAT, others)
- County Road Commissions/Department of Roads
- Other Traffic Operations Centers
- American Automobile Association (AAA) of Michigan
- Greyhound Bus Lines
- Detroit Department of Transportation
- SMART Regional Transit Bus
- United Parcel Service
- Commuter Transportation Service
- Other fleet services
- Third-party traffic reporting services (i.e., local broadcast TV/radio, CATV, etc.)

4.2.3 System Performance Monitoring Operations

Monitoring of system performance and system/subsystem operations is performed through on-line performance and status interrogating, health checks, and operator-commanded requests. System malfunction monitoring includes all system and subsystems functions where integrated diagnostic capabilities can identify abnormal operating states to the replaceable component level. Reports which indicate the status of functional parameters of the system or any malfunctioning subsystem component(s) are available upon operator request. These include performance reports, daily tallies, malfunction/failure logs, repair orders, etc..

4.2.3.1 Monitor Systems Performance

Monitoring of system operations provides an on-line performance assessment of MOEs for the metropolitan Detroit freeway network. This capability provides a overall performance view of the traffic control system strategies and tactics, and identifies any areas which need specific operator attention. On-line MOEs include corridor throughput/volume flow, flow speed, delay time, total travel times, total minute-miles of congestion, and other measures. Through data reduction, other MOEs (e.g., accident rate reduction, number/percentage of stopping flow, etc.) can be derived to **further** assess system performance. Single-position operator workstations provide MITSC personnel the capability to operate and monitor system operations and performance.

4.2.3.2 Perform Malfunction Management

A system malfunction management capability provides the operator with on-line system monitoring, diagnostics, and record keeping to determine the extent of system malfunctions and failures. All system or subsystem functions provide a level of status which identifies their health. When a malfunction or component failure occurs, the system or subsystem status monitoring function determines the nature of the problem and isolates the level (to the replaceable component level), generates a malfunction or failure message, and displays an indicator at the MITSC to capture the operator's attention. Capabilities to interrogate and diagnose system/subsystem components are also operator-commandable from the MITSC or local on-site. Record keeping of malfunctions and **repairs are** integrated into the system through a maintenance log. Information contained in the log include system/subsystem failure reports, work orders, maintenance forms, repair status and disposition.

4.3 System Requirements

Primary operations considered for this system consist of traffic management, traveler information management, and system monitoring. The system shall support these operations through the following major functions:

- Perform Traffic Network Surveillance and Control
- Display Traffic Network Status
- Perform Traveler Information Management
- Perform System Performance and Status Monitoring

The operational needs and objectives are analyzed to identify system requirements. System requirements identify the functions and characteristics which form the basis on which the system hardware, software, and operations and maintenance (O&M) support are designed or specified In general, functions specify the "tasks" performed by the system, where characteristics specify the design attributes reflected in the system hardware, software, and support components. These categories are listed below:

- System Interfaces
- Functional Processes
- Operational Performance
- System Characteristics
- System Processing Resources
- Logistical (Operations and Maintenance) Support

To develop a Baseline Architecture, system interfaces, functional processes, and operational performance were the primary considerations used to develop the functional and communication allocations which form the underlying architecture framework.

System characteristics, processing resources, and logistical support provide the specific design criteria from which the system is constructed.

4.3.1 System Interfaces

System interfaces consist of DFOU operators and maintenance personnel, external government agencies, external commercial and private businesses, the travelers or users of the freeway network, the current traffic surveillance, control and communications subsystems, and the local metropolitan Detroit freeway network and environment. Interface descriptions include the entity and the type of information transferred (i.e., network status, traffic coordination information, incident information, physical features, environmental effects, etc.). Figure 4-1 illustrates a top-level interface diagram which provides a "context" in which these external interfaces interact with the system.

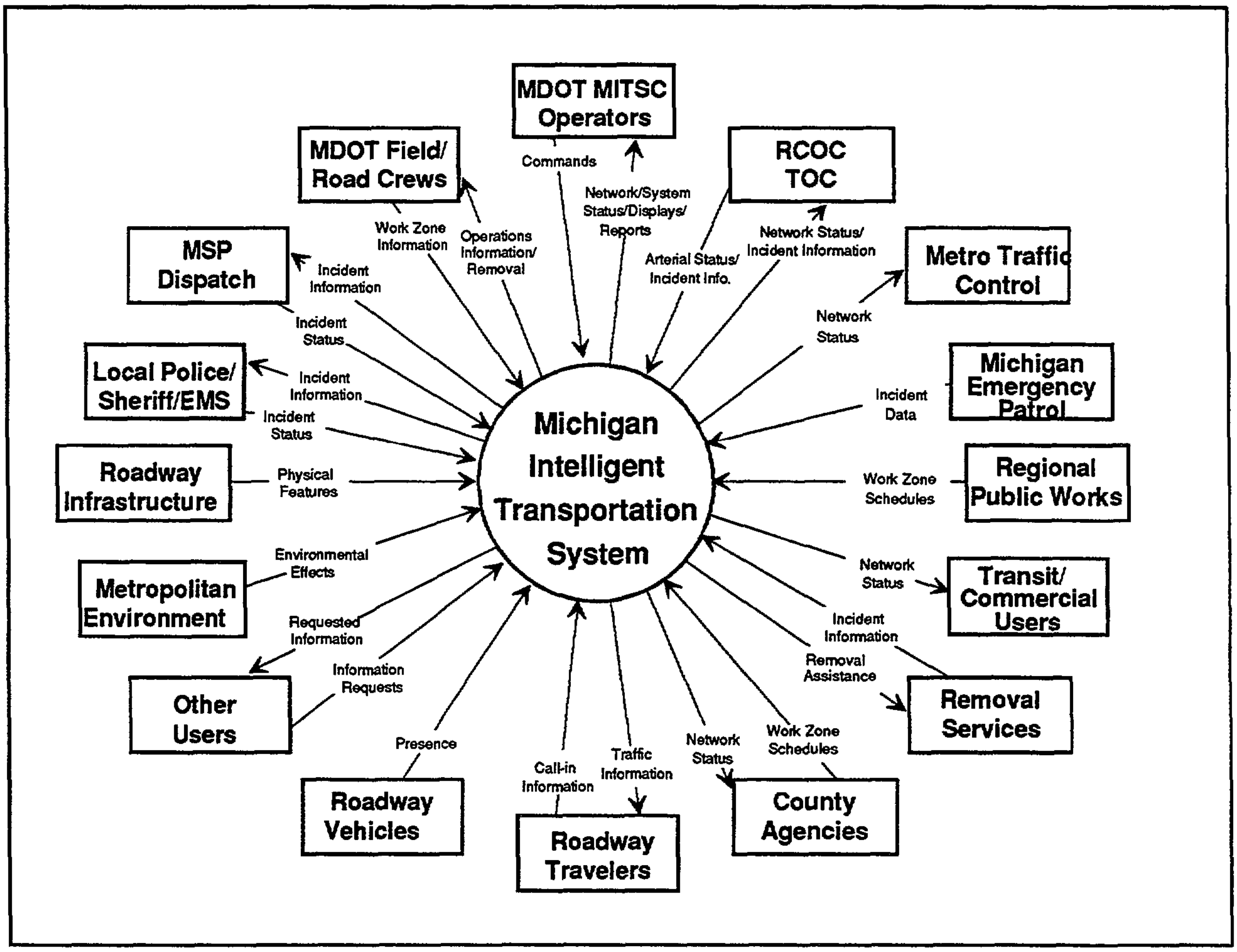

Figure 4-1. Top-Level System Interfaces

4.3.1.1 MITSC Personnel Interfaces

MITSC operator interfaces provide system commands, freeway network status displays and reports, and system status displays and reports.

DFO maintenance/road crews provide an interface for operations information, maintenance information, and work zone information.

4.3.1.2 External Government Agencies

Federal government agencies include the US Department of Transportation (USDOT) Federal Highway Administration (FHWA) and the United States Border Patrol.

State government agencies include the Michigan Department of Management and Budget, Michigan Department of Transportation - Highway Maintenance Division, and Michigan Department of Transportation - District Maintenance, Freeway Lighting.

Law enforcement/emergency services include Michigan State Police (MSP), various County Sheriff/Fire Departments (and Rescue, etc.), and various Local City Police/Fire Departments (and Rescue, etc.), Emergency Medical services, serving the counties and cities of the following:

Counties

- Macomb County
- Monroe County
- Oakland County
- Wayne County

Cities

- Auburn Hills
- Bloomfield Hills
- Dearborn
- Detroit
- Farmington Hills
- Femdale
- Flat Rock
- Hazel Park
- Huntington Woods
- Lincoln Park
- Livonia
- Madison Heights
- Mt. Clemens
- Oak Park
- Pontiac
- Romulus
- Roseville
- Royal Oak

- Southgate
- Woodhaven

County Agencies include the following:

- **Various** County Road Commissions/Department of Roads
- Southeast Michigan Council of Governments (SEMCOG)
- Other Traffic Operations Centers
- Wayne County Departments
- Monroe County Departments
- Macomb County Departments
- Oakland County Departments
- Various City/County Public Works Departments (e.g., power & lighting, water, refuse, etc.)
- Detroit Metropolitan Wayne County Airport

City Departments include the following:

- City of Detroit Department of Transportation
- Public Works (e.g., power, public lighting, water, refuse, etc.)
- Other city departments

4.3.1.3 External Commercial and Private Entities

Public Utilities include Detroit Edison Company, Michigan Bell/Ameritech Telephone Company, Consumers Power Company, and various cable television companies (i.e., Continental Cable, etc.).

External commercial and private entities include Metro Traffic media services, American Automobile Association (AAA), United Parcel Service (UPS), Michigan Emergency Patrol, Other fleet services, and third-party traffic reporting services (i.e., broadcast TV/radio - WDIV, WJR, CATV, etc.).

Removal Services include MDOT-contracted towing service providers and courtesy patrols.

Transit services include Greyhound Bus Lines, Smart Regional Transit Bus, Commuter Transportation Service

4.3.1.4 Freeway Network Users

Roadway travelers using the freeway network include the general public, commercial users, and other users.

Roadway vehicles include passenger cars, commercial trucks, transit vehicles, and motorcycles.

4.3.1.5 Roadway infrastructure

Roadway infrastructures include roadway features, bridges/overpasses, conduit structures, electrical power, and lighting.

4.3.1.6 Local Metropolitan Detroit Freeway Environment

All fielded subsystem equipment and components shall provide protection features against the local metropolitan Detroit urban environment. Equipment and components to be procured shall make maximum use of readily available, multiple source, commercial off-the-shelf (COTS) equipment.

a. General environment: System components shall be designed to function year-round (i.e., rain, ice, snow, etc.) in the local metropolitan Detroit urban environment. These components shall be modular in design, promote ease of maintenance, and include integrated environmental conditioning features (i.e., defogger, cooling, etc.).

b. Outside Ambient Air Temperature (operation or storage): -25°F to +140°F (-32°C to +60°C).

c. Humidity: up to 95 percent, non-condensing.

d. Lightining/Electrostatic discharge: All subsystem equipment shall be incorporate features to prevent damage from transient electrical discharges in the fielded configuration.

e. Radio Frequency Interference RFI/Electromagnetic Interference (EMI): All subsystem electronic equipment shall not be affected by normal RFI/EMI conditions emanating from the surrounding MITSC office and Metropolitan Detroit urban environments. Correspondingly, all electronic equipment shall not emanate RFI/EMI which will interfere with other MITSC and localized fielded equipment.

f. Wind/salt/sand/dust/contaminants: Subsystem components shall be protected from the effects of wind, salt, sand, dust, and other organic and inorganic contaminants emanating from roadway vehicles and the surrounding environment for a period no less than 10 years from field deployment.

g. Other environmental effects: Subsystem components shall be insulated from other (direct or induced) environmental effects. Other effects include acceleration/shock, vibration, acoustics, heating due to solar radiation, etc. due to normal vehicle travel and the local metropolitan Detroit weather conditions.

4.3.2 Functional Processes

The system shall perform the following functional processes to support freeway operations in the metropolitan Detroit area.

- Perform Traffic Network Surveillance and Control
- Display Traffic Network Status
- Perform Traveler Information Management
- Perform System Performance and Malfunction Monitoring

The existing system shall be an integral part of initial new system deployments. The new system shall interface with existing equipment through currently available channel and processing capacities. In general, new subsystem equipment and components will provide capabilities to communicate with both the existing and new systems through industry-standard interfaces (i.e., NEMA, EIA, CCITT, SAE, ANSI, VME, SCSI, NTSC, etc.). The current infrastructure and equipment will be maintained as the primary system for the Early Deployment corridor. Current MJTSC operator interfaces will be augmented (where needed) to manage traffic operations capabilities for the new corridor (i.e., network status displays, ramp control, etc.).

Subsequent deployment phases shall utilize the existing system to the maximum extent possible for continued operations in concert with new system and subsystem equipment. DFOU operation of both systems shall be integrated to minimize differences in operator interface(s) and tasks. As new freeway corridors are instrumented and brought on-line, corresponding operator interfaces shall also be integrated and reflect the additional system capabilities.

4.3.2.1 Perform Traffic Network Surveillance and Control

The system shall provide DFOU personnel the capability to perform recurrent and non-recurrent traffic congestion management through mainline flow surveillance, mainline flow control, coordination of incident management tasks, and area-wide traffic coordination. Additionally, the system shall have the capability to manage mainline work zones, and calculate mainline volume demand and predict traffic flow patterns for scheduled events, planned work/construction zones, and other special events. Specific functional and performance requirements are specified in the following paragraphs. Table 4-l identifies the designated mainline corridors (freeway network) for traffic surveillance and control.

Table 4-1. Freeway Corridor Priorities

Corridor Priority	Corridor Description	Begin Point	End Point
1	I-75 Chrysler	I-94 Ford	9 Mile Rd.
2	I-696 Reuther	US-24 Telegraph	I-75 Chrysler
3*	I-94 Ford	Wyoming Ave.	Moross Rd.
3	I-696 Reuther	I-75 Chrysler	I-94 Ford
4	I-696 Reuther	I-96 Jefferies	US-24 Telegraph
5	I-96 Jefferies	I-75 Fisher	I-275/M-14
6*	I-75 Chrysler	I-375	I-94 Ford
7	I-75 Chrysler	9 Mile Rd.	to Pontiac, MI
8	M-39 Southfield	I-75 Fisher	M-10 Lodge
8	I-275	M-14	M-102
9*	M-10 Lodge	Jefferson Ave.	Greenfield Rd.
10	I-75	I-96 Jeffries	I-275
10	M-10 Lodge	Greenfield Rd.	I-696 Reuther
11	I-94 Ford	Moross Rd.	M-19
12	I-94 Ford	Wyoming Ave.	I-275
13	Davison Freeway	M-10 Lodge	I-75 Chrysler
14*	I-375	Jefferson Ave.	I-75 Chrysler
15	I-275	I-75 Fisher	I-96/M-14
16	M-59 Auburn/Hall Rd.	BR-24	M-53

** - current SCANDI corridors*

4.3.2.1.1 Perform Mainline Flow Surveillance

The system shall perform mainline traffic flow surveillance for the designated corridors in the metropolitan Detroit area. The system shall perform the following functions:

a. Calculate Corridor MOEs. The system shah have the capability to capture vehicle presence counts and detection time differentials (speed traps) for passenger cars; commercial vehicles; transit vehicles; motorcycles; and other roadway vehicles.

1. Vehicle detection points (stations) along the mainline corridor(s) shall be separated by roadway distances of 1/3 mile increments plus or minus 10%. If roadway characteristics in certain areas preclude using this increment tolerance, the next available location shall be selected.
2. Vehicle detection stations shall be located immediately upstream of mainline entrance ramps in accordance with MDOT standards. These stations shah provide traffic flow data to determine ramp metering activation and metering rates.
3. Vehicle detection points (stations) for mainline entrance and exit ramps shall conform to MDOT standards for ramp queue, demand, and passage locations, merge occupancy, and corresponding mainline locations to detect and calculate upstream demand and downstream capacity.
4. System vehicle detection accuracy shall be within 10% of actual vehicle counts. Performance is based upon MDOT metering activation/deactivation threshold levels.

b. Calculate Corridor MOEs. The system shall compute mainline corridor MOEs (average occupancy, total volume, and average speed) from collected vehicle detection data for each detection station.

c. Perform Incident Detection. The system shall utilize an MDOT-approved incident detection capability to identify potential mainline capacity-reducing non recurrent incidents.

d. Manage Corridor MOEs. The system shall maintain traffic flow MOE's in an integrated freeway network status database. This information shall be made available for use with other traffic operations functions (i.e., area-wide traffic coordination, work zone management, traffic demand management and flow prediction, incident management, and traveler information dissemination).

e. Display Corridor MOEs. Mainline corridor MOE data shall be made available for freeway network status displays, entrance ramp status displays, information management, and other DFO activities.

f. Collect Video Images. The system shall capture NTSC broadcast quality color or black and white TV video images at identified locations along mainline freeway corridors and communicate images and control data to the MITSC for traffic flow assessments and incident verification by DFOU personnel.

1. Full color (daylight)/low light black and white (dawn/dusk/night) capability: 0.1 lux (1.0x10-2 FC)
2. Automatic/manual bright/low light compensation and transition
3. Image resolution (minimum): 500 lines horizontal, 400 lines vertical
4. Lens system: Minimum 6: 1 image zoom ratio with a minimum angular field of view of 20° horizontal (15° vertical) at the wide angle position at f1.2, with manual focus, remotely controlled.
5. TV video image resolution and modulation shall be compatible with NTSC TV standard.
6. TV video image modulation shall be compatible with current MITSC TV monitors.
7. Platform mounting shall allow for attachments to poles, buildings, on/under bridges, or other roadway fixtures.
8. Deployed cameras shall be mounted in locations which provide effective viewing of the freeway segment under surveillance. Viewing height shall be a minimum of 40 ft above the roadway surface and minimize occlusion effects of roadway overpasses and curves.

g Control Video Images. The system shall provide remote video image viewing control from the MlTSC. Control functions shall include the following:

1. Remote control viewing direction (i.e., horizontal pan and vertical tilt) and image quality (i.e., focus, color, zoom, intensity, etc.) adjustments shall be provided.
2. Video camera platforms shall provide pan-tilt mounting surfaces. Specifications for the pan-tilt platforms shall be:
   Rotation: Pan: 0 to 355 degrees
   Tilt: +/-90 degrees horizontal.
   Speed: 3 to 11 degrees/second
3. Pan and tilt stops to prevent over rotation.
4. Automatic or manual camera(s) selection control.
5. Manual his control (light intensity control).

h. Display Video Images. The system shall capture video images for viewing at the MITSC (and other locations). The system shall also accept video images from external sources (i.e., RCOC TOC, Metro Traffic Control, local TV stations {e.g., WDIV, WJR}, etc.)

4.3.2.1.2 Perform Mainline Flow Control

The system shall control mainline traffic flow through adaptive entrance ramp management and traffic flow diversion techniques (e.g., message signing, variable speed, lane signing).

a. Determine Ramp Control Mode. The system shall support the following ramp control modes: clear mode; rain/wet mode; and snow/ice mode. These modes are defined as follows:

1. Clear mode - normal mode of operations.
2. Rain/Wet mode - pre-defined metering rates to account for hazardous roadway conditions.
3. Snow/Ice mode - ramp metering is disabled.

b. Provide Ramp Metering Options. The system shall support the following ramp metering modes: pre-timed metering (i.e., operator-defined TOD); and traffic-responsive (adaptive) metering, and occupancy mode metering.

1. Pre-timed metering mode provides ramp metering with predeflned metering parameters (i.e., activation thresholds or time-of-day metering rates, etc.)
2. Traffic responsive metering mode provides ramp metering with adaptive activation in response to mainline MOEs.
3. Occupancy mode metering mode provides activation/deactivation based upon mainline occupancy. Default activation/deactivation is TOD (due to local gore detector failures).

c. Provide Ramp Metering Activation Control. The system shall provide the capability to perform entrance ramp metering control. Mainline traffic flow surveillance (detection stations) immediately upstream and downstream from an entrance ramp shall support ramp metering control functions.

1. Mainline surveillance MOEs (ave. occupancy, total volume and ave. speed) and ramp exit vehicle counts shah be collected to determining ramp meter activation and metering rates.
2. The system shah activate ramp metering by time-of-day scheduling; response to mainline gore MOEs (traffic-responsive and occupancy thresholds); or, DFOU operator command.
3. The system shah provide the capability to set ramp meter activation and metering rates via local, on-site control; corridor processor (for integrated ramp control), or remote download from the MITSC under system or operator control.

d. Provide Ramp Control. Entrance ramp control stations shah provide the following vehicle control capabilities in accordance with established MDOT standards:

1. The system shall determine ramp metering rates by manual operator presets; or, calculated from mainline MOEs (e.g., upstream demand/downstream capacity).
2. The system shall support metering rates of 240 vehicles-per-hour (4 vpm) to 900 vph (15 vpm) for single lane ramps. Metering adjustment capabilities to support two-lane ramps shall also be provided.
3. Advanced ramp control warning indicator for ramp meter operation.
4. Vehicle queue detection
5. Vehicle demand (checkin) detection
6. Vehicle passage (checkout) detection
7. Vehicle merge lane occupancy (where possible)
8. Two-section ramp meter signal indicator for ramp traffic control.
9. Exit ramp vehicle detection

e. Provide Integrated Corridor Ramp Control. The system may support enhanced capabilities to perform integrated ramp control for designated ramps along a mainline corridor segment. This capability provides integrated ramp control along a designated corridor roadway. Coordinated ramp metering is conducted in sequence using upstream demand and metering data, and downstream capacity along a designated corridor length.

f. Display and Control Changeable Messages. The system shall provide a variable roadway signing capability which supports display of traffic diversion/status information for routing of traffic flow onto alternate mainline or trunkline corridors. Traffic diversion shah be accomplished through variable signing (i.e., CMS, HAR/AHAR, speed, lanes). Corridor and status-specific messages shah be developed using MDOT-approved criteria and stored in a message database. Due to sensitive legal, operational, and jurisdictional issues, the system shall protect the database against unauthorized access and modification.

4.3.2.1.3 Facilitate Incident Management Tasks

The system shall facilitate operator actions for logical decision making and integrate execution of the following incident management activities: incident detection, operator verification and declaration, response, removal, and traffic coordination, information dissemination, and incident log record keeping in accordance with the approved Incident Management Plan for Metropolitan Detroit. The system shall provide the capability for the operator to cancel or override any system command at any point in the process, and manually operate the system.

a. Perform Incident Detection. The system shall process and measure data (MOEs) collected from roadway traffic surveillance sensors against MDOT-established incident thresholds and check for potential incident conditions using a MDOT-approved incident detection algorithm.

1. The system shall identify a potential incident within 30 seconds after the receipt of the collected surveillance data.
2. The MDOT-approved incident detection algorithm shall be capable of identifying potential incidents (minimum 60% detection rate) from the traffic flow data collected from the surveillance sensors with relatively low number of false alarms (0.1%).
3. If traffic flow conditions (multiple detection stations) and the incident detection algorithm indicate that a potential incident exists, the system shall issue an incident alarm indicator to capture the operator's attention for subsequent actions.

b. Provide Incident Verification. The system shall provide operator-preferred verification methods. At a minimum, the system shall provide the capability to graphically identify and display incident locations on the freeway network map and configure appropriate CCTV camera(s) and video images corresponding to the identified incident location. The system shall assist the operator to correlate incident reports with incident information. The system shall support facilitation of other verification methods to the maximum extent possible in accordance with the approved Incident Management Plan for Metropolitan Detroit.

c. Record and Manage Incident Information. System-assisted incident declaration and record keeping shall be stored in an incident database and include the following:

- Date of the incident
- Time start/declaration
- Severity level
- Time cleared

- Location (freeway, direction, lane [lane #, shoulder, median, ramp], nearest cross-street or fractional mile marker)
- Incident category (accident, debris, fire, stalled vehicle, flood, other)
- Number of vehicles involved
- Truck involved?
- Incident remarks and comments
- Incident response actions employed (i.e., notification, traffic controls, etc)
- Logging operator

d. Facilitate Incident Notification. The system shall assist the operator to notify the Michigan State Police dispatcher and to inform other traffic-related agencies and organizations. These tasks include:

1. Contact with MSP dispatch center. If the MSP is not aware of the incident, the system shall facilitate notification assistance. Information for notification and transmission methods includes:
   - Incident location via available communications media (i.e., telephone, fax, graphical display, CCTV video image, etc.)
   - Additional information such as diagnosis of the incident cause.
2. If a video image is available, the system configures the appropriate video links for transmission to the MSP dispatch post, Metro Traffic Control, and other capable incident reporting services.

e. Facilitate Incident Response and Coordination. The system shall support incident removal through communications and coordination with the MSP, on-site authorities, MDOT field crews, and emergency and removal services. The system shall facilitate operator monitoring response and coordination

f. Perform Incident Traffic Management. The system shall provide traffic management controls for the incident location. The system shall prepare information and system controls for traffic diversion around the incident (where possible) through alternate route information delivery, metering controls, and other techniques in accordance with the approved Incident Management Plan for Metropolitan Detroit.

1. The system shall identify appropriate Incident Management Plan alternate routes (based upon the local area corridor status).
2. The system shall identify appropriate upstream roadway signing locations, corridor HAR/AHAR transmitters, metered ramps, and other traffic controls for operator option selection(s).
3. The system shall select and display candidate roadway signs, HAR/AHAR messages, system-calculated metering rates, and other control options for operator-commanded selection and deployment. These message options shall be displayed to the operator for final selection and operator-commanded deployment. Once selected and commanded, the system configures the appropriate message packets to the selected target traffic management controls.

g. Disseminate Incident Information. The system shall facilitate information dissemination through available information dissemination links. These links include roadway message signing, in-vehicle delivery, freeway network status update and delivery to interfacing information agencies, and other dissemination channels.

1. Once detailed incident resolution information is compiled, the system shall record the deployed information (i.e., CMS, HAR/AHAR, etc.) into the incident log and action database.
2. The system shall provide operator-selectable information dissemination options (i.e., fax, inter-TOC digital links, graphical status displays/kiosks, etc.) for information delivery.
3. Upon operator command, the system shall notify other traffic-related or emergency agencies through real-time communications media (i.e., telephone, **fax,** graphical display, CCTV video, etc.). Potential agencies include:
   - Michigan State Police
   - Michigan Emergency Patrol
   - Metro Traffic Control
   - Radio traffic reporting services
   - Local Police/Sheriff
   - Local road agencies (per incident jurisdiction)
   - Medical emergency services
   - Hazardous Material (HAZMAT) services
4. The system shall also provide alternate routing information for other traveler information agencies. This information could be potentially used for:
   - Alternate route development and planning
   - Alternate route message deployment, where possible
   - General public education on alternate routes
   - Coordination with local police/sheriff and road agencies

4.3.2.1.4 Perform Area-Wide Traffic Coordination

The system shall provide MITSC personnel the capability to coordinate freeway network status/traffic flow and incident data and traffic control data for the greater metropolitan Detroit freeway network with other transportation centers (TOCs) in the three-county area (Wayne, Macomb, Oakland) through information and data exchanges. Expansion to include the five-county area (Wayne, Macomb, Oakland, Washtenaw, Monroe) is envisioned in subsequent phases.

a. Exchanged traffic data includes video images, and digital, electronic, facsimile, and graphical formats.

b. Exchanged control data includes recommendations for metering and arterial signal timing cycles/offsets.

4.3.2.1.5 Perform Work Zone Management

The system shall provide MITSC personnel the capability to configure traffic management controls to account for work zones, temporary roadway impairments, and roadway closures.

a. The system shall collect and manage schedule information for use with freeway network surveillance and control, area-wide traffic coordination, traffic demand management and flow prediction, incident management, and traveler information dissemination.

b. The system shall accept schedule information from manual operator inputs or formatted electronic media.

4.3.2.1.6 Perform Demand Management

The system shall provide MITSC personnel the capability to develop demand and flow controls (metering) based upon traffic demands detected from mainline gore occupancies. Demand management capabilities include:

a. Modeling and predicting traffic flow patterns based upon known demand generator locations, incidents, and scheduled events, and reductions in roadway capacity due to scheduled roadway construction or maintenance events.

b. Storage of results for use with traffic surveillance and control, area-wide traffic coordination, work zone management, incident management, and traveler information dissemination functions.

4.3.2.2 Display Traffic Network Status

The system shall display a graphical representation of the current corridor mainline traffic flow network status of the metropolitan Detroit freeway system. These displays shah include mainline MOE status, mainline interchange status, ramp metering at entrance ramps, and corresponding exit ramps (if applicable).

a. The system shall support display of a minimum of three hierarchical views. These views will be hierarchical in the sense that the operator can view the entire freeway network, an operator-selected subnetwork, or a specific mainline or entrance ramp interface (i.e., ramp status, metering control, MOEs, and reports) in a single view, as a minimum These views shah each be capable of occupying the entire graphical display area. The system shah also provide a windowing capability to display multiple subnetwork views within a single display. The full mainline freeway network view shall be the default view.

b. Resolution of the graphics display area shall be a minimum of 1024 x 768 pixels and support a simultaneous display of at least 16 colors.

c. The network status shall consist of different contrasted color levels which represent different levels of traffic occupancy for each mainline detection station segment. These levels shall be consistent at all view levels. Except for the full network view, the displays shah also include volume and speed indicators for each detection station segment. Color representations for occupancy levels are specified in Table 4-2.

Table 4-2. Graphic Display Status Definitions

Display Color	Occupancy (%)	Volume (veh/min)	Speed (mph)	Equipment Icon Status
Green	0-9	0-9	over 49	All Operational, On-line
Yellow	10-14	10-19	34-49	Partially Operational, On-line
Orange	15-20	20-29	20-33	
Red	over 20	over 29	0-19	Non-Operational, On-line
Grey	-	-	-	Off-line

d. Network status information shall have a data latency no greater than 1 minute.

e. The system shah also support views of other system operations displays, such as those for:
   1. Subsystem control (i.e., video camera control, video monitor switching, CMS control and verification, HAR/AHAR control, etc.)
   2. Incident management and coordination (i.e., incident location tagging, reports, and untagging)
   3. System performance monitoring
   4. System malfunctions
   5. Information management and dissemination
   6. System administration, archiving, audits, and record keeping
   7. Surface street operations (i.e., intersection controller status (graphic of intersection traffic flow} and control, surface street CCTV image, and surface street/freeway ramp coverage { CCTV, sensors, etc.}.

4.3.2.3 Perform Traffic and Traveler Information Management

The system shall collect relevant travel-related information from system traffic surveillance capabilities and external providers. This information shah be integrated, or fused, into an organized information database for monitoring and dissemination to roadway users and requesting entities. Dynamic traveler information dissemination techniques and technologies shall provide the capability to deliver relevant travel-related information to users of the metropolitan Detroit freeway network. These techniques and technologies include roadway signing (i.e., CMS, HAR/AHAR, speed, etc.), electronic data links (i.e., modem, fax, video), and graphical displays of the freeway network status

4.3.2.3.1 Collect Traffic and Travel Information

The system shall collect accurate information on traffic conditions, freeway network status, roadway conditions and closures, weather conditions, other roadway conditions (i.e., work zones), and other relevant travel or traffic-related information for database management. The system shall collect this information from both infrastructure and non-infrastructure-based sources.

For the metropolitan Detroit area, traffic information is generally collected from (but not limited to) the following sources:

1. Metropolitan Detroit traffic surveillance system
2. Michigan State Police
3. Michigan Emergency Patrol
4. MDOT divisional field units
5. Other TOCs
6. Roadway travelers/general public (cellular call-ins)
7. State and local public works agencies

4.3.2.3.2 Manage Traffic and Travel Information

The system shall provide information management for all traveler-related data. The system shah organize the collected information for storage, viewing on system displays, and dissemination to freeway network users.

a. The system shall integrate, or fuse, collected information on traffic conditions, freeway network status, roadway conditions and closures, weather conditions, other roadway conditions (i.e., work zones), and other relevant travel or traffic-related information collected from multiple sources into organized databases. Candidate databases include:
   1. Traffic Surveillance
   2. Traffic Control
   3. Traffic Demand
   4. CMS Message
   5. Communications Link Management
   6. Incident Log
   7. Traffic Network Status
   8. Historical Data
   9. Roadway Conditions
   10. System Map Data
   11. System Status Data

b. The system shall store the information in a manner which can be retrieved for viewing on system displays and dissemination to users.

c. The system shall monitor and control information access to ensure data and system integrity are not corrupted or compromised. The system shall manage information for administrative tasks, such as, information entry/input and archiving, database management, access management, and information system monitoring, malfunction troubleshooting, and built-in test (BIT)/built-in test equipment (BITE) diagnostic capabilities.

4.3.2.3.3 Disseminate Traffic and Travel Information

The system shall disseminate traffic and travel information to the general public, government agencies, transit services, requesting users, media reporting services, and other roadway users. Information dissemination and access to users shall be accomplished through roadway signing (i.e., CMS), HAR/AHAR transmissions, electronic data links (i.e., modem, fax, video), and graphical displays of the freeway network status.

a. Provide Dissemination and Access Control. The system shall disseminate and allow access to traffic and travel information in primarily three modes: dissemination to roadway users through system facilities; dissemination and access to government agencies and users; and dissemination and access to requesting entities. The system shall monitor and control information access and integrity to prevent corruption and destruction of system information, facilities, and resources. The system shall provide simultaneous operation of the dissemination and access modes.

1. The system shall disseminate traffic and travel information to roadway users through system-operated dissemination media (i.e., CMS, HAR/AHAR, public kiosks, etc.).
2. The system shall disseminate and allow access of traffic and travel information to government agencies and user through interagency communications media (i.e., electronic links, video links, facsimile, voice, data, etc.).
3. The system shah disseminate and allow access of traffic and travel information to requesting entities through system-operated and third-party dissemination media (i.e., Metro Traffic, local TV, CATV, and radio, call-up telephone, etc.).

b. Support Information Clearinghouse Activities. The system shall support information management and coordination capabilities for a traffic and travel information clearinghouse. Through these capabilities, the system shall provide open and broad dissemination and access of traffic and travel information through a wide variety of methods and delivery channels. Candidate methods and channels are listed below:

1. Roadway Signing (i.e., CMS, portable CMS, variable speed signs, fixed signs)
2. Electronic Links (i.e., data links, fax service)
3. Radio Frequency Broadcast (HAR/AHAR, commercial AM/FM radio, private radio (amateur), FM subcarrier, RDBS, CB radio)
4. Passive Visual Aides (printed material, commercial TV, CATV)

5. Passive Information Services (commercial TV, remote traffic status displays - passive kiosks, commercial AM/FM radio)
6. Interactive Information Services (call-in message service, PCS, public/office kiosks, in-vehicle guidance, computer bulletin board service (BBS), CATV, CB radio, amateur radio, modem data link, mobile data terminal)
7. Third-party traffic reporting services (i.e., Metro Traffic Control, MEP, commercial TV, CATV, and commercial AM/FM radio)

4.3.2.4 Perform System Performance and Malfunction Monitoring

The system shall monitor operational performance and system / subsystem status operations through on-line interrogation, health checks, and operator-commanded requests. The system shall monitor detectable malfunctions in all system and subsystems functions and components. These functions and components shall integrate diagnostic capabilities which identify abnormal operating states to the replaceable component level. Reports which indicate the status of functional parameters of the system or any malfunctioning subsystem component(s) shall be available upon operator request. These include performance reports, daily tallies, malfunction/failure logs, repair orders, etc..

4.3.2.4.1 Monitor Traffic Network Performance

The system shall monitor traffic network to ensure proper and effective traffic controls promote travel mobility. The system shall perform on-line operational performance assessments of MOEs for the metropolitan Detroit freeway network. This capability shall provide a overall performance view of traffic control system strategies and tactics to optimize traffic flow controls, and identify any operational function which may need specific operator attention. On-line MOEs include corridor throughput/volume flow, flow speed, delay time, total travel times, total minute-miles of congestion, and other measures. Through data reduction, other MOEs (e.g., accident rate reduction, number/percentage of stopping flow, etc.) may be derived to further assess system performance. Single-position operator stations shall provide MITSC personnel the capability to operate and monitor integrated system operations and performance.

4.3.2.4.2 Perform System Malfunction Monitoring

The system shall integrate malfunction monitoring, reporting, and diagnostics functions. As a minimum, failures and malfunctions shall be reportable to the lowest replaceable component level (i.e., mainline detectors, ramp controllers, etc.). Failure and malfunction status shall be maintained and dispositioned for appropriate action. Failures and malfunctions shall also be reported on the system map display in accordance with Table 4-6.

4.3.2.4.2.1 Perform Routine Status Monitoring

The system shall monitor system operations for malfunctions or abnormal conditions or states through built-in test (BIT) during startup (power-on) and routinely during operations (background processing). The system shall provide the DFOU operator with an integrated, on-line system monitoring, diagnostic trouble shooting, maintenance management, and record keeping for system malfunctions and failures. All system or subsystem functions shall determine and provide health status to the MITSC.

4.3.2.4.2.2 Determine System Malfunction

When a malfunction or component failure occurs, the system monitoring function shah determine the nature of the anomaly and isolate the level to the replaceable component level, generate a malfunction or failure message, and display an indicator at the MITSC to capture the operator's attention. The system shah provide the capability to interrogate and diagnose system/subsystem components upon operator command from the MITSC or locally on-site. The system shall maintain record keeping information of malfunctions and repairs in a maintenance log. This information shall include system/subsystem failure reports, work orders, maintenance forms, repair status and disposition.

4.3.3 Operational Performance

The approach used in these assessments consist of a logical framework of analyses to define low-level performance and timeline requirements which are used to provide a basis to partition and organize functional processing and communication requirements into a system architecture.

Specifically, this assessment framework consists of a series of supporting analyses which, individually, define detailed functional performance requirements for specific processing tasks/aspects of the traffic management and information systems, and collectively determine performance interdependencies between processing tasks. The individual requirements are analyzed and correlated to identify interdependencies between tasks and whether these interdependencies directly influence performance aspects of the operational system. These interdependencies are then used to determine appropriate operational and cost-efficient performance ranges.

Functional performance and timeline requirements are derived from analyses of freeway traffic surveillance and control operations, incident management operations, and techniques used in the management and dissemination of traffic information. Traffic management objectives and philosophies adopted by the MDOT Detroit Freeway Operations Unit will be used as the model to conduct these assessments.

Minimum, or worst case, performance requirements are defined through analysis and correlation (and parametric studies) of operational system capabilities and traffic flow behavior (e.g., nominal traffic flow relationship models and observed incident flow characteristics) to establish performance baselines. These baselines will be used to establish interdependencies between performance parameters; such as, vehicle presence detection and accuracy, MOE processing timelines supporting incident detection, mainline ramp control, freeway network status displays, and traffic network performance evaluations. Cost considerations in terms of loss of operations fidelity, equipment required, communication timeline Penalties and constraints, and corresponding architecture constraints are also examined.

These assessments correlate performance requirements and functional processes with functional allocations and partitions in order to specify operationally-efficient subsystem groupings. These subsystem groupings and their interdependencies are then configured into a system architecture (framework). This architecture configuration provides a high-level, functional baseline or point of departure (POD) design basis where more detailed subsystem, interface, and communications designs and implementations can be defined and developed. Functional allocations **and** partitions are used to balance operational effectiveness and cost-efficiency drivers, while incorporating MDOT-desired architecture attributes (i.e., flexibility, adaptability, and operations efficiency). Application of "functional modularity" and interface standardization helps to promote interchangeable, modular design implementations.

The following specific performance analyses were conducted and are summarized in the following paragraphs. Full analysis details are contained in Appendix IV.

Traffic Surveillance Performance

- Traffic Flow Sensor Adequacy Analysis
- Vehicle Presence Collection Performance Analysis
- Traffic Surveillance/Incident Detection/Control Period Analysis
- MOE Monitoring and Display

Traffic Control Processing Performance

- Entrance Ramp Control Performance
- Mainline Control Performance
- Integrated Corridor Control Performance

Information Management and Dissemination Processing

- Traffic and Travel Information Collection
- Traffic and Travel Information Organization and Management
- Traffic and Travel Information Dissemination and Control

System Monitoring Performance

- Equipment/System Health and Status Monitoring
- Traffic Flow Performance Monitoring

4.3.3.1 Traffic Flow Surveillance Performance

Traffic flow surveillance provides critical information for effective traffic management. Not only does surveillance provide current flow conditions necessary to assess roadway status for incident detection, traffic control, or other functions, it also provides a feedback capability to assess the effectiveness of deployed controls and traffic network performance along monitored traffic corridors. The fidelity of surveillance data (MOEs) depends upon the application for which it is used. MOEs can be obtained for a single lane of traffic flow to monitor and control mainline ramps, or averaged over multiple lanes **to** yield surveillance zone **"averages"** for network statusing traffic flow characteristics and throughput at a particular detection station. Care must be taken to define the methods and data collection frequency used to derive these MOEs so that accurate flow conditions are represented and collection cycles are balanced with system operations, capacities, and resources. Adherence to maintaining system operational effectiveness and cost-efficiency is a paramount objective when defining and developing these performance measures.

Surveillance performance requirements for low-level functional processes (i.e., vehicle detection , ramp control, etc.) need to provide a wide fidelity range to support higher-level functions (i.e., traffic network surveillance, incident management, traffic control, etc.) and to balance operational effectiveness (e.g., area-wide traffic management) and efficiency. The following analyses were conducted to aid in this determination:

- Traffic Flow Sensor Adequacy Analysis
- Vehicle Presence Collection Performance Analysis
- Traffic Surveillance/Incident Detection/Control Period Analysis
- MOE Monitoring and Display

4.3.3.1.1 Traffic Flow Sensor Adequacy Analysis

A worst-case analysis is performed to determine whether sensor latency impacts affect detector output signals. In this case, the widely-used and accepted inductive loop detector technology is used as the candidate sensing technology to establish this minimum performance baseline.

This analysis determines the minimum speed at which vehicles passing through a sensing zone begin to exceed minimum detection capabilities. This analysis examines minimum vehicle detection performance requirements for two loop detector orientations: traditional square (or rectangular); and MDOTs diamond shape. Figure 4-2 illustrates these orientations for both configurations.

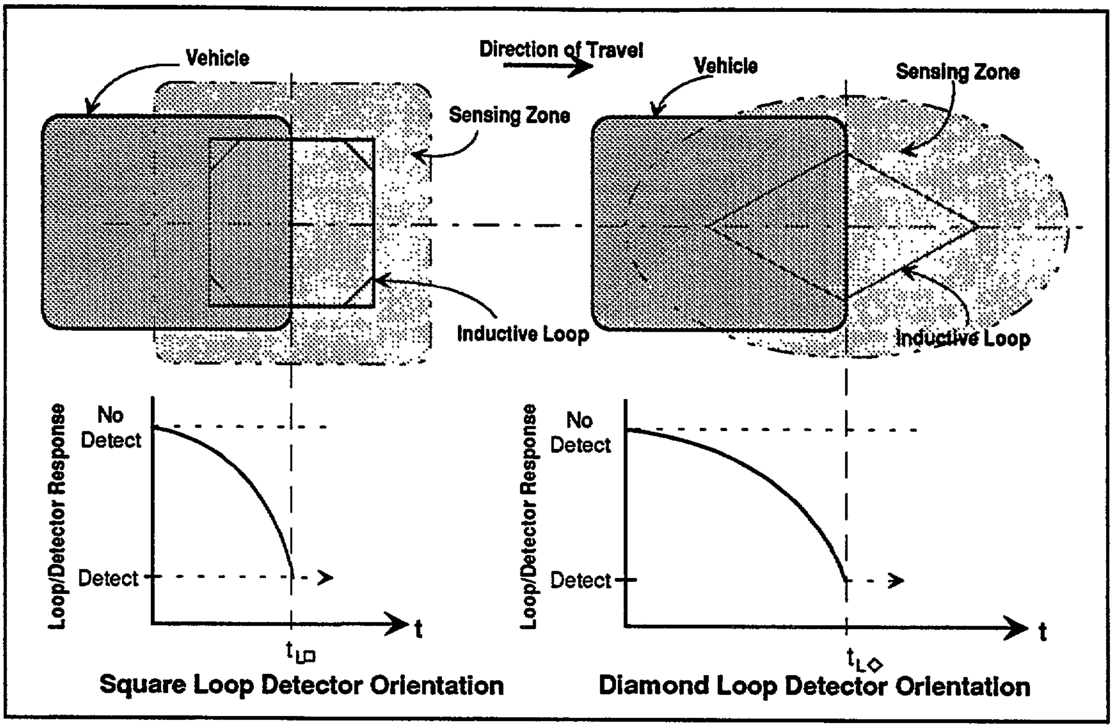

Figure 4-2. Loop Sensor Detection Latency

Assumptions:

Nominal vehicle: $L_s = L_e = 12$ ft. (physical sensing length); Class 3 car
Sensor latency: $t_L = 50$ ms (worst-case excitation time)
Sensing Zone = max. 36" outside loop perimeter
Loop excitation/relaxation (rise and fall) times are approximately equal
Sensitivity: Detect @ 50% sensing zone area (worst-case)
Loop dimensions: 6 ft. x 6 ft.
Orientation: square or diamond configuration
Sense speed range: 5 mph $\leq v_i \leq$ 80 mph; $v_n = 60$ mph
Detector output delay: Negligible (typical $\leq$ 0.1 ms.)

Find:

Using the stated assumptions, the following are determined:

[1] v_L (min) = minimum vehicle speeds where loop sensor latency begin to impact detection capabilities; and,

[2] whether sensor latency impacts the timeliness of detector outputs.

Analysis:

Based upon the loop sensor configurations shown in Figure 4-3, minimum impact speeds are calculated using the formula:

(latency velocity: v_{Lmin}) x (latency time: t_L) = 50% sensing zone traveled

v_L (min) = (50% sense zone traveled) / (t_L)

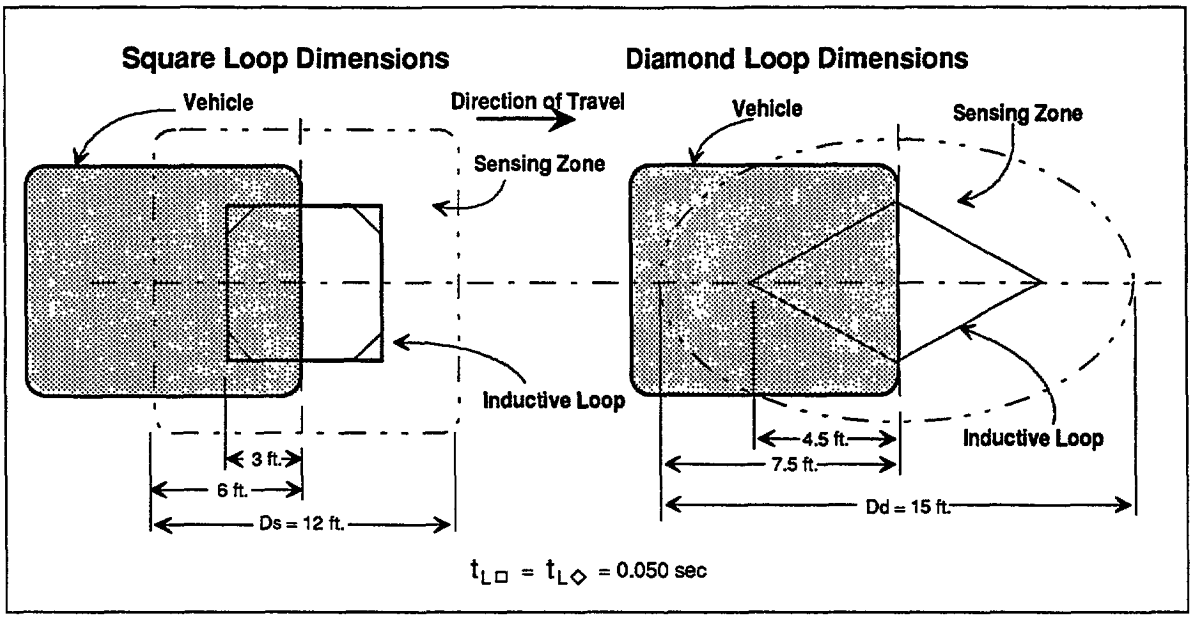

Figure 4-3. Loop Sensor Configurations

For the square loop configuration: D_s = 3 ft. + 3 ft. = 6 ft.

v_{Ls} (min) = (50% sense zone traveled: D_s) / (t_L)
v_{Ls} (min) = (6 ft.) / (0.050 sec.) x (0.681818 mph-sec./ft.)
v_{Ls} (min) = 81.8 mph

For the diamond loop configuration: D_d = 3 ft. + 4.5 ft. = 7.5 ft.

v_{Ld} (min) = (50% sense zone traveled: D_d) / (t_L)
v_{Ld} (min) = (7.5 ft.) / (0.050 sec.) x (0.681818 mph-sec./ft.)
v_{Ld} (min) = 102.3 mph

Conclusions:

[1] Minimum threshold speeds where loop sensor latency (for both square and diamond loop configurations) begin to impact detector excitation, reaction, and output measurements are estimated as follows:

Square loop configuration: v_{Ls} (min) = 81.8 mph

Diamond loop configuration: v_{Ld} (min) = 102.3 mph

[2] Worst case loop sensor latency errors due to electrical properties (50 ms excitation/relaxation transition delays) begin to migrate into MOE calculations when these speed thresholds are reached. At nominal freeway speeds (60-70 mph), latency impacts for both square and diamond-shaped inductive loop

detectors should not affect the accuracy of MOEs for vehicle detection applications.

Inductive loop sensors and detectors are still the foremost and most widely preferred vehicle sensor technology in use today; although, this detector technology still presents drawbacks and disadvantages associated with maintenance activities and associated costs. Establishment of minimum vehicle detection performance standards using the loop detector technology provides a baseline for new traffic flow sensors and data collection methods to maintain an upward operational compatibility and interchangeability for evolving advanced traffic management techniques and other IVHS user services. Maintenance aspects are also considered in this baseline to provide measurement criteria for new, reliable, low-cost, low-maintenance alternative traffic sensors.

4.3.3.1.2 Vehicle Presence Collection Performance Analysis

As a vehicle passes through a sensing zone, presence data (and other information: speed, vehicle type, vehicle ID, etc.) can be collected as a measurement of traffic flow conditions at a particular detection station within a surveillance zone. Presence data is currently used to calculate a variety of MOEs such as: total vehicle counts, average occupancies (%), average speeds, vehicle lengths and classifications, etc. Traditional inductive loop detector technologies are designed to output a discrete signal, when a vehicle is sensed, to a separate processor or controller for measurement of the output signal to collect presence data and cumulative calculation of corresponding MOEs for a given surveillance period.

New vehicle detector technologies can collect and also process MOE information (along with other traffic flow parameters) in an integrated fashion using a variety of techniques. These techniques include integrated detector state sampling, detector state change timers, image frame sampling, composite data sampling, infrared and low power RF (radar/microwave) measurements, laser tracking and range sensing, and acoustic sensing. For the purpose of this analysis, these technologies are acknowledged as potential replacements to the inductive loop detector and must satisfy the minimum detection requirements.

This analysis provides a performance and timeline baseline for the collection and calculation of traffic flow MOEs using the minimum sensing capabilities of inductive loop detector sampling techniques.

For inductive loop detector sampling, the detector output signal is typically read on a continuous time basis, independent of vehicle presence (location). When a vehicle passes over a loop sensor, the inductance in the loop wire(s) sensor decreases and is measured by a detector unit. The detector unit generates a corresponding output signal when the inductance signal recognition thresholds are reached. Based upon detector output performance requirements (NEMA), the electrical output state transition properties (identified for detector input-output latency) are considered negligible when compared to the minimum dwell time for recognized vehicle presence (< 0.1 ms transition [NEMA] vs.

> 30 ms dwell, or 0.3%). Therefore, detector sampling errors can be assumed to not be attributed from detector input-output latency. Therefore, loop sensor states are essentially "passed through" to the detector output for processor/controller data sampling. In addition, current detectors have been designed to filter loop sensor "noise" to minimize output sensitivity and false detection errors.

Detector states are typically sampled for presence data by an local processor and/or controller, regional corridor/node processor, or central system master/host on a continuous "real-time" basis. Sampling rates can vary, but are typically read in 10 ms cycles. Presence data are typically collected and "averaged" over a larger time scale (30-60 seconds) to derive traffic flow MOEs and other parameters.

For this analysis, minimum (general) data collection performance requirements (and timelines) for calculation of traffic flow MOEs are defined from worst case (acceptable) data collection/sampling rates and traffic flow characteristics. Inductive loop detector output sampling is examined as the baseline measurement technique to provide compatibility and familiarity with current collection methods, and to provide minimum performance requirements for emerging vehicle detection technologies.

Assumptions:

Nominal vehicle:	$L_s = L_e$ = 12 ft. (physical sensing length): Class 3 car
Sensing Zone =	max. 36" outside loop perimeter
Sensitivity:	Detect @ 50% sensing zone coverage (worst-case)
Loop dimensions:	6 ft. x 6 ft., square or diamond configuration
Sense speed range:	5 mph < v_i < 80 mph; also up to 120 mph
Vehicle time on loop:	$t_i = L_, / V_i$ = (8.1818 sec-mph)/vi; where:
	i = speed range index;
	t,, in seconds (use 60 mph/88 fps conversion factor)

Find:

[1] Minimum acceptable sampling rate to detect vehicle presence; and,
[2] an acceptable sampling error tolerance.

Analysis:

Based upon the loop sensor configurations shown in Figure 4-3, the number of samples that can be read for vehicle dwell time (t_i) over the loop are tabulated in Table 4-3 for a defined speed range. The following relationship is used to calculate vehicle presence (dwell) time over the sensing zone for worst case loop sensor sensitivity (50% coverage).

distance traveled = (rate of speed) x (travel time); or rearranging,
travel time = (distance traveled) I (rate of speed);

$t_i = L_, / V_i$ = vehicle dwell time over loop sensor (for 50% coverage - worst case)

$t_i = (8.1818 \text{ sec-mph})/v_i$; includes conversion factor for feet-miles and hour-seconds

Table 4-3. Detector Sampling Rates per Vehicle Speed

Vehicle Speed v_i (mph)	Vehicle Dwell Time t_i (sec)	Number of Samples @ 1 ms	@ 5 ms	@ 10 ms	@ 25 ms	@ 100 ms
5	1.636	1636	327	163	65	16
10	0.818	818	163	81	32	8
20	0.409	409	81	40	16	4
30	0.272	272	54	27	10	2/3
40	0.205	205	41	20	8	2
50	0.164	164	33	16	6	1/2
60	0.136	136	27	13	5	1
70	0.117	117	23	11	4	1
80	0.102	102	20	10	4	1
90	0.091	91	18	9	3/4	1/0
100	0.082	82	16	8	3	1/0
110	0.074	74	14	7	2/3	1/0
120	0.068	68	13	6	2	1/0

Conclusions:

[1] For the defined vehicle speed range, acceptable sampling (in worst case detection conditions) can be accomplished every 10 ms, as indicated by the shaded column in Table 4-3. Data samples read at higher rates provide a more accurate measure and greater fidelity of vehicle presence dwell time; however, the increased frequency of data collection may adversely impact processing performance and operational efficiency (i.e., processor throughput requirements, software executive (kernel) task scheduling complexity, communication requirements, etc.).

Specifically, the processor (or subsystem) allocated to perform this function needs to provide adequate processing capacity and reserves to operationally-support current and future processing and communication timeline needs. The executive kernel must be able to schedule not only detector data sampling, but other functions and tasks as well (i.e., MOE calculation, incident detection, ramp control, communications, health and status checks, data housekeeping, etc.). Data samples collected at lower rates may cause a reduction in data fidelity; potentially causing significant collection errors to propagate into MOEs, generation of incident detection false alarms, and premature activation/deactivation of traffic control functions.

The performance of current inductive loop sensor and detector technology still provide adequate fidelity for collection of surveillance data based upon careful application and data interpretation. These minimum performance requirements (standards) provide a reasonable baseline for new sensor technology and vehicle presence collection techniques, and maintains operational compatibility for advanced traffic management strategies and other IVHS user services.

[2] The margin of error calculated for a 10 ms sampling rate (@ 80 mph) equates to +l (one) data sample. This could be translated into a nominal 10% error tolerance assuming excessive speeds (< 80 mph) are not encountered. In actuality, the electronic vehicle length tends to be longer than the physical length due to inductive loop sensor sensitivities having the capability to "detect" vehicle presence before actual vehicle presence or worst case detection conditions (50% sensing zone coverage). This effect actually enables a greater vehicle dwell time detected by the loop sensor, whereby, a greater number of data samples can be collected, and thus, effectively reducing the sampling error.

New vehicle detection technologies could minimize these errors from occupancy calculations (and other MOEs) directly-measured from detection zone/state dwell time. Average occupancies, speeds (timing gate), and travel times, and total volumes can be directly calculated from detector output actuation time, electronic vehicle length adjustments, and actuation differential times. Average occupancies can then be more accurately calculated for accumulated detector/zone actuation time for a given surveillance period/cycle. These measurements would then be dependent upon clock accuracies used for the trigger and state measurement functions. These methods can also provide a more accurate measure for calculating average speed and other MOEs for traffic-responsive functions.

4.3.3.1.3 Traffic Surveillance/Incident Detection/Control Period Analysis

Periodic traffic data and information collection and MOE processing performance must support traffic operations on a timely basis to enable effective and efficient traffic management. A balance between accuracy and frequency of MOE measurements (i.e., average lane occupancies, vehicle/volume counts, average flow speeds, etc.) is critical to traffic control strategy effectiveness. If sensor technologies are assumed to provide adequate accuracy, then determination of surveillance/control periods tend to define the data collection frequency and functional processing performance required to service traffic control, demand prediction, incident detection, and system monitoring and housekeeping tasks.

Traffic surveillance, incident detection, traffic control periods need to accommodate both maximum traffic flow rates and high congestion conditions. The basic traffic control model illustrated in Figure 4-4, organizes traffic flow surveillance, demand calculation, control strategies, and network behavior into a sequential/cyclic process, and also includes the effect of driver perceptions (behavior) provided as a reactive influence to traffic network status. Identification of these two process cycles provide the means to bound the traffic flow model and identify the functions needed to effectively manage this traffic flow environment. Effective and efficient traffic mobility relies upon the system's ability to provide appropriate traffic controls and adequate feedback mechanisms to manage traffic flow and solicit driver behavioral responses or reactions consistent with management strategies. This feedback arrangement enables the surveillance function to provide traffic flow conditions and status to the demand prediction and control functions, and support driver influence mechanisms to solicit driver behavior consistent with traffic management strategies. Since driver behavior is not a directly controllable system function, this analysis will focus on traffic flow behavior to identify and determine surveillance and control performance parameters.

Surveillance performance requirements are defined for traffic flow conditions encountered at extreme flow conditions: free-flow speeds, and congested flow (e.g., incidents). These requirements are also balanced with other interdependent functions (e.g., incident detection, traffic control) to provide the data feedback necessary for operational efficiency.

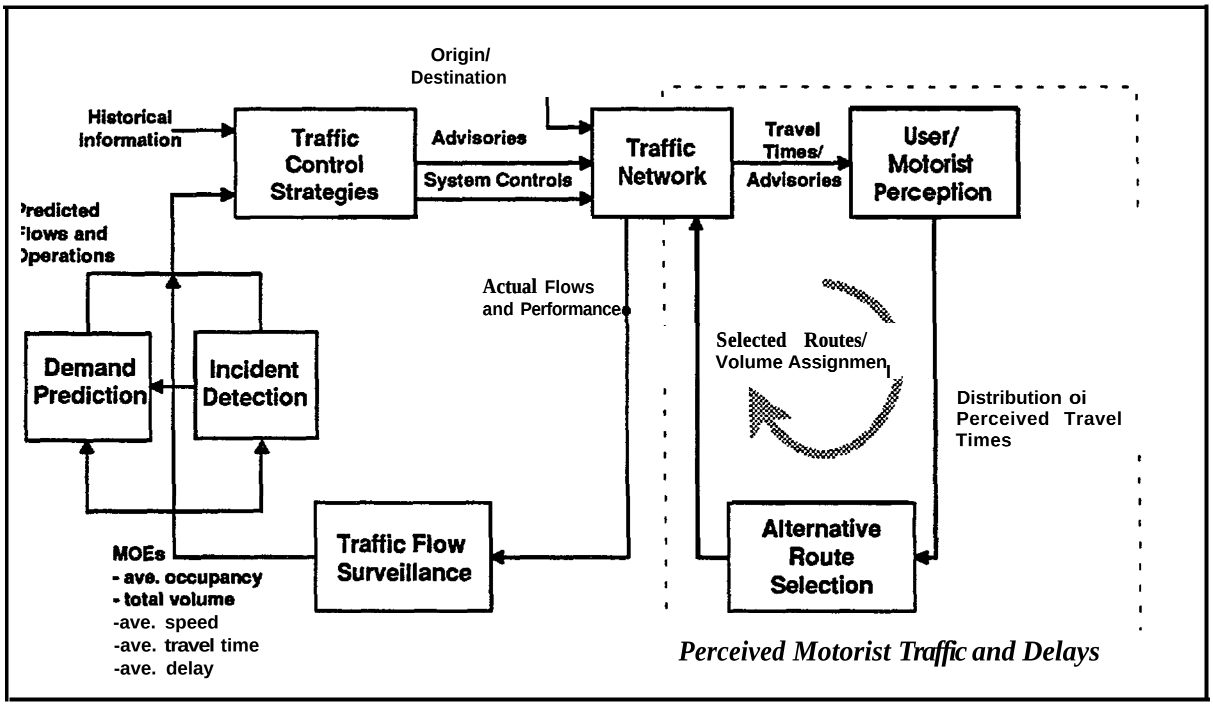

Figure 4-4. Basic Traffic Control Model

Traffic flow behavior is examined to characterize the relationships between these extreme flow regions. Free-flow traffic conditions are analyzed to determine the maximum surveillance performance required to maintain effective and efficient flow monitoring at high flow rates. Congested flow conditions are analyzed to determine congestion development effects and functional interdependencies between surveillance performance and other processes (i.e., demand prediction, traffic control, incident detection, etc.).

The following related analyses document a methodology to determine traffic surveillance, incident detection, and traffic control periods which are functionally interdependent to achieve a balance in operational performance.

Assumptions:

Traffic Flow: Greenshield's Linear Model Hypothesis: steady-state stable flow - ideal traffic flow conditions1
Driver demographics: Commuter traffic: cars only - no trucks
Roadway terrain: Level - no hills/grades

Nominal vehicle: L_0 = 16 ft. (total physical length), NEMA Class 3 passenger car

Roadway dimensions W, = 12 ft. (nominal mainline lane width)
W, = 6 ft. (min. mainline median/shoulder width)
70 mph design speed - 8 lane freeway
Maximum lane capacity - 2000 pcphpl (vphpl)

Vehicle sensor: Minimum capability - loop detector

Detection orientation: Longitudinal, no lane transitions

References:

1. McShane, W. R. & Roess, R. P., Traffic Engineering, Prentice-Hall 1990, pp 68, ***285-306,603-632.***
2. Secondary to reference 1: Drake, Schofer, and May, A Statistical Analysis of Speed-Density Hvpotheses, Highway Research Record 154, TRB 1967
3. A Policy on Geometric Design of Highways and Streets, AASHTO 1990, Chapter II, pp19-116
4. Traffic Engineering Handbook, ITE 1992, Chapter 5, pp 117-131
5. Chassiakos, A.P., Stephanedes, Y-J, Smoothing Algorithms for Incident Detection,
6. Secondary to reference 5: Payne, H.J. and Tignor, S.C., Freewav Incident Detection Algorithms Based on Decision Trees with States in Transportation Research Record 682, TRB, National Research Council, Washington DC., 1978, pp30-37

Find:

Related analyses are conducted to determine the following:

[1] Ideal freeway traffic flow characteristics;
[2] Required flow surveillance performance for the ideal traffic flow case;
[3] Minimum acceptable traffic flow surveillance performance driven by associated system functions (i.e., incident detection)

Analysis: ***General Discussion***

Let us examine traffic flow using an analogy with viscous fluid flow through a pipe. A surveillance system can be thought of a network of flow monitoring sensors (along a pipe) used to follow the movements of given particles of fluid as they flow down a pipe in a laminar fashion (i.e., fastest flow occurs at the pipe centerline; slower flow occurs at the fluid/pipe wall interface). The ideal surveillance system monitors all fluid particles and their longitudinal and lateral (spatial) translations within the pipe for given temporal conditions.

Unfortunately, traffic flow is not uniform and real surveillance systems cannot monitor temporal and spatial conditions of all vehicles moving down a roadway corridor, nor, do they operationally need to. However, this analogy provides a surveillance framework from which spatial and temporal characteristics can be used for application to traffic flow.

Vehicle detection sensors have enabled collection of traffic flow data; however, the data only depicts point characteristics of traffic flow as vehicles pass through the sensor. To obtain true flow characteristics, sensors could be positioned in tandem along a roadway, one after another, to obtain a microscopic view of the flow; however, this approach proves to be unfeasible from a deployment perspective (e.g., MOE processing, operations resource, communications, costs, etc.) when considering the enormity of roadway miles for a given freeway network. Therefore, a balance between sensor spacing and MOE processing frequency must be determined.

Surveillance operations and processing economy must be balanced to achieve an operationally-efficient system. A macroscopic approach (instead of microscopic) is examined in this analysis to use flow “averages” to represent temporal and spatial traffic conditions within given roadway segments, or “zones” to provide manageable MOE parameters and to filter traffic flow effects of one-time events.

Current surveillance systems have adopted the use of “detection zones” or “surveillance zones” to represent the networked series of roadway segments on which traffic flow conditions are reported. “Detection stations” provide the sensor(s) implementation location within a zone for the measurement of point traffic flow conditions. For certain areas, weather conditions may also need to be collected to adjust traffic controls. Surveillance of traffic flow by zones tend to be more manageable from an operations and cost perspective due to averaging of flow parameters and the operations and maintenance costs associated with implementation of system components.

Detection or surveillance zones can vary in size and length based upon the traffic application (e.g., arterial versus freeway mainline). Arterial surveillance tends to require tightly-coupled zones (by lane) to measure right-of-way demands and queue lengths at signalized intersections. In this case, surveillance provides a “demand’ indicator for signal control functions and operate on a real-time, cyclic basis due to the nature of intersection signal timing (offsets) and control. On the other hand, mainline freeway surveillance require zones, aligned in tandem to encompass extended lengths of roadway, are used to provide traffic flow status, incident detection, ramp metering, and other traffic functions. In these cases, surveillance provides “averaged” traffic flow (and weather) data used for traffic network monitoring and activation/deactivation of real-time control operations (e.g., traffic-responsive ramp metering).

This analysis examines the relationship between zone lengths and corresponding surveillance periods to define surveillance performance requirements. Intuitively, maintaining surveillance of a vehicle as it moves downstream requires the system to “hand-off’ the implicit surveillance task to adjacent zones as vehicles move downstream. Using basic traffic flow relationships, zone lengths and period lengths are directly proportional.

Analysis [1]: ***Ideal Traffic Flow Characteristics***

In large-scale ideal (freeway) traffic flow models, vehicles can be viewed as constituents of a flow body that move down a section of roadway, at a steady rate of speed, similar to the manner in which a body of incompressible fluid flows through a length of pipe. Traffic flow surveillance along equal-length roadway segments (surveillance zones) yields collection, processing, and reporting of traffic flow conditions (MOEs) as vehicles travel from one segment to the next. The frequency at which MOEs are collected and updated can impact the structure of the system architecture, communications media, methods, and required performance, and functional processing timelines. The following describes a method to determine surveillance periods required to monitor freeway traffic flow.

Traffic flow surveillance must measure changes in traffic flow conditions as a result of behavioral reactions from perceived conditions exhibited by drivers traveling on the roadway. Due to the practical nature of sensor deployments and traffic management strategies, flow measurements cannot be collected from a continuous stream of sensors along a roadway; instead, traffic flow conditions and characteristics are collected at specific points (detection stations) to represent flow conditions for each surveillance zone.

The surveillance period for measuring temporal and spatial traffic flow conditions are dependent upon flow rates and the spacing between detection stations. Since the level of surveillance fidelity tends to be limited primarily by processing limitations and costs associated with deployment, operations, maintenance, and administrative decisions, a means to define performance characteristics are derived from traffic flow itself. At a minimum, surveillance performance periods need to accommodate traffic operations when traffic flow is ideal and traveling at free-flow speeds, and also when flow conditions are congested and other system functions predominate. The following assessment summarizes ideal traffic flow.

Ideal Traffic Flow Behavior. To better understand traffic flow behavior, several mathematical expressions have been hypothesized2 to describe speed-flow-density relationships for data collected from actual observations. These observations are mapped as flow vs. speed, flow vs. density, and speed vs. density. These expressions are calibrated to minimize the differences between the mathematical expressions and observed data. This analysis uses these hypotheses with ideal traffic flow parameters instead of observed data to determine the upper flow limits for the surveillance function. Figure 4-5 illustrates these flow-speed-density relationships with the following definitions:

c = capacity, the maximum rate of flow (vph or vphpl or pcphpl);
Ideal = 2000 vphpl or pcphpl

S_f = free-flow speed; theoretical speed when density = zero (mph);
Ideal conditions: = 85% of roadway design[1]
*= (0.85)*70 mph = 59.5 mph*

S_c = critical speed, the speed at which capacity occurs (mph) - mathematically derived

D_c = critical density, the density at which capacity occurs (vpm or vpmpl) - mathematically derived

D_j = jam density, the density at which all movement stops, i.e., S = 0 mph (vpm or vpmpl) - mathematically derived

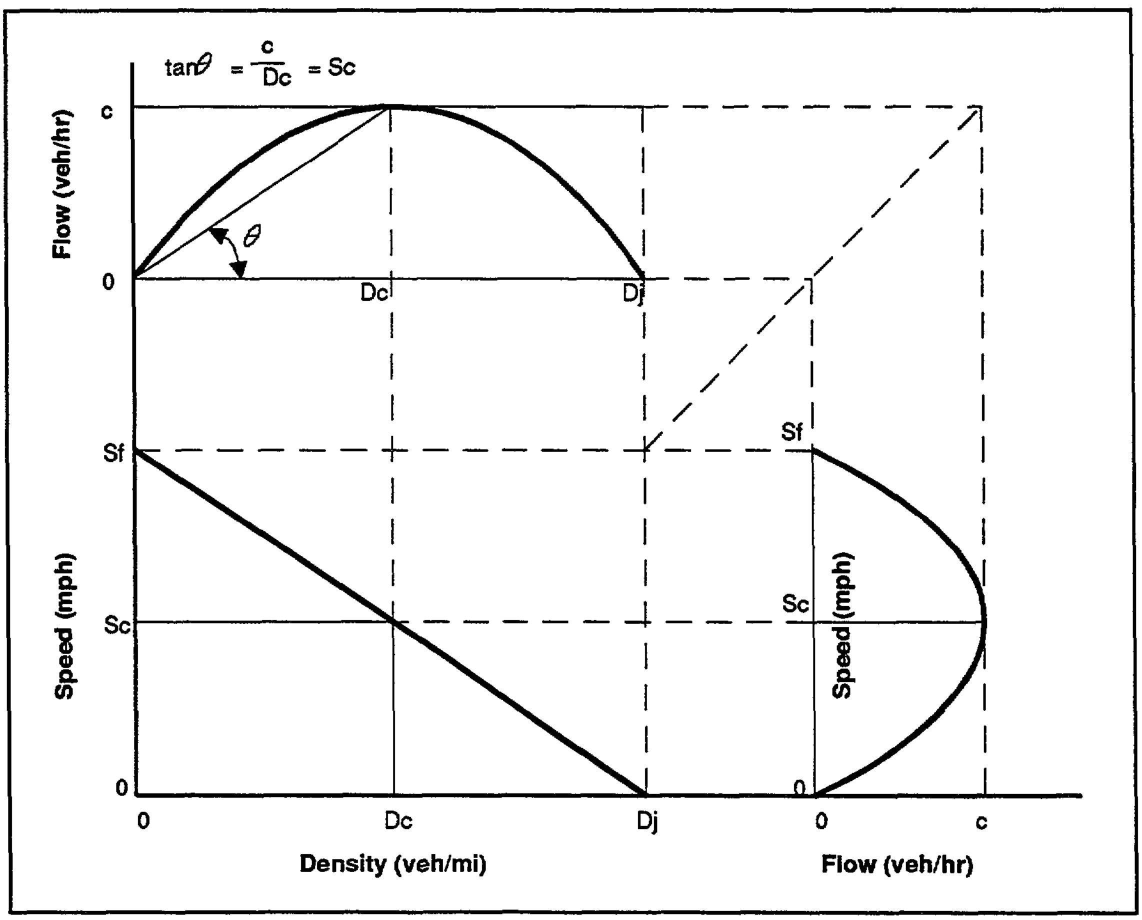

Figure 4-5. Basic Form of Speed-Flow-Density Relationships

Understanding the limits of the speed-flow-density relationships provide a mathematical approach to describe specific relationship interactions. In this case, ideal traffic flow conditions are used in place of observed data. The general mathematical expression relating flow, speed, and density* is:

$$F = S \times D;$$

where: ***F*** = rate of flow (vph or vphpl)
S = space mean speed (or average running speed in mph)
D = vehicle density (vpm or vpmpl)

Conclusions [l]:

Flow constants corresponding to ideal flow conditions are defined as follows:

Maximum flow (volume) rate:	c ***= 2000 vphpl or pcphpl***
Maximum free-flow speed:	S_f ***= 59.5 mph***
Critical density (@ capacity):	D_C ***= 67.2 vpmpl***
Jam density (S = 0 mph):	D_j ***= 134.5 vpmpl***
Critical speed (@I capacity):	S_C ***= 29.8 mph***

Substitution of these constants into the ideal speed-flow-density equations yield the following:

Speed - Density Equation;

S = (59.5 mph) - [(59.5 mph) / (134.5 vpmpl)] D ;

S = (59.5 mph) - (0.44 vphpl) D ;

Flow-Density Equation;

F = (59.5 mph) D - [(59.5 mph) / (134.5 vpmpl)] D2 ;

F = (59.5 mph) D - (0.44 mph/vpmpl) D2 ;

Flow-Speed Equation;

F = (134.5 vpmpl) S - [(134.5 vpmpl) / (59.5 mph)] S2;

F = (134.5 vpmpl) S - (2.26 vpmpl/mph) S ;

For calibration purposes, surveys of moderately-traveled interurban freeways (c 10% occupancy on 55-mph posted speed limits) were taken and found that travel speeds actually exceed the assumed free-flow speed of 59.5 mph. Observed speeds ranged between 61-65 mph (e.g., I-96 Jefferies Freeway), and for freeways with posted 65mph speed limits, observed travel speeds ranged between 64-69 mph (e.g., I-275). Thus, using a simple average of these two ranges as a "calibrated" free-flow speed value, S_f, (65 mph), the resulting speed-flow-density equations become the following:

Speed-Densitv Equation; $S = (65\ mph) - (0.528\ vphpl)\ D$;

Flow-Densitv Equation: $F = (65\ mph)\ D - (0.528\ mph\ /\ vphpl)\ D^2$;

Flow-Speed Equation: $F = (123.1\ vpmpl) S - (1.89\ vpmpl\ /\ mph)\ S^2$

Analysis [2]: ***Flow Surveillance Performance (Periods)***

Efficient traffic flow surveillance must enable non-duplicated coverage of flow movement between zones on a periodic basis. This requires a detection station to "hand-off' flow surveillance to an adjacent detection station as vehicles move downstream. Figure 4-6 illustrates a layout of this model. The timing of each flow surveillance period (1,2,3, etc.) is such that traffic data is collected, processed, and reported for a given flow body for a particular detection station (1,2,3, etc.) until the leading edge of that body reaches the next downstream detection station (zones A, B, C, etc.). At this point, the cycle is re-initiated starting with the next traffic flow body. This period or cycle length depends upon the traffic body flow speed and the separation distance between detection stations (surveillance zones).

Since maximum traffic monitoring performance is required when roadway and travel conditions are ideal and the theoretical free-flow speed is at its maximum, the surveillance system (detection station spacing and processing period) must maintain a monitoring cycle consistent with the free-flow speed. In other words, the (maximum) surveillance period must be consistent with the vehicle flow travel time required to cover the distance between detection stations. All flow conditions are measured/ collected, calculated, and reported within this period.

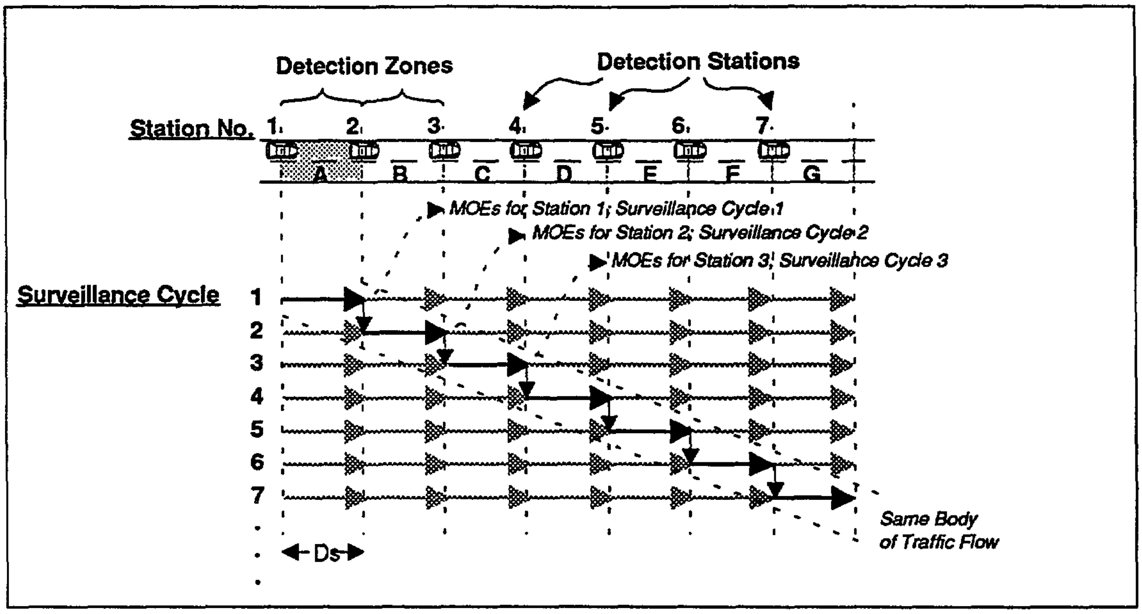

Figure 4-6. Ideal Surveillance Flow Model

Given these conditions, the maximum free flow speed, S_f, for ideal conditions (59.5 mph) is used as a determining factor to define detection station spacings (D_s) and corresponding maximum surveillance periods (P_s). The following equation illustrates this relationship and is used to develop the parametric values listed in Table 4-5. The calibrated free-flow speed value (65 mph) is also calculated and used as a basis for comparison..

$$D_s = S_f \, x \, P_s \, ;$$

solving for the surveillance period P_s yields:

$$P_s = D_s / S_f = D_s / (59.5 \text{ mph}) \, x \, (3600 \text{ sec/hr}) \, ;$$

and substituting:

$$P_s = D_s / (59.5 \text{ mph}) \, x \, (3600 \text{ sec/hr}) \, ;$$

	$P_s = D_s \, x \, (60.5 \text{ sec})$	; for $S_f = 59.5$ mph
and;	$P_s = D_s \, x \, (55.38 \text{ sec})$	; for $S_f = 65$ mph

where:

D_s	distance between detection stations points (mi)
S_f	traffic flow speed (mph)
P_s	surveillance period (sec)

Table 4-5. Flow Surveillance Periods

Detection Station Separation Distance *D*, (mi)	Maximum Surveillance Period (@ Sf= 59.5 mph) *P*, *(sec)**	Maximum Surveillance Period (@ Sf= 65 mph) *P*, *(sec)**
0.10	6.06	5.54
0.20	12.11	11.08
0.25	15.13	13.85
0.33	19.97	18.28
0.50	30.26	27.70
0.66	39.94	36.56
0.75	45.38	41.53
0.90	54.46	49.85
1.00	60.51	55.39
1.25	75.64	69.24
1.50	90.76	83.08
2.00	121.01	110.77

* values have been rounded up to the nearest 0.01 sec.

Conclusions [2]:

Further parametric analysis could define a endless range of periods due to the proportional nature of the distance-speed-time relationship. Based only on traffic surveillance functions, operations administrators could simply choose a desired detection station/surveillance period pair and develop au operations strategy around them. If simple traffic monitoring (no control functions) is desired, the surveillance period could be chosen based upon available budget, communications, and computing platforms and resources. This approach, taken in isolation, tends to be influenced by administrative preferences rather than true operational needs, and does not specify or "bound" *real* traffic operation performance requirements. Therefore, other determining factors must be used to identify a balance between operational needs and administrative preference.

Analysis [3]: ***Minimum Surveillance Performance Determinants.***

This analysis employs the relationships defined in the traffic control model (refer to Figure 4-4) to determine surveillance performance limits required to support interdependent traffic operations for ideal flow conditions. In the model, the surveillance function provides traffic network status "feedback" to demand prediction and traffic control functions. The previous analysis identifies maximum performance required to maintain flow surveillance for "ideal" traffic flow conditions. For degraded traffic flow, as found in traffic congestion, maximum performance surveillance periods can still provide operationally-relevant traffic flow data, however, the data now represents segments of contiguous traffic flow bodies.

Determining a range of operationally-efficient surveillance periods/cycles are introduced in this analysis using other interdependent functions and system aspects.

Freeway traffic demand prediction, entrance ramp metering control, and incident detection functions are considered the primary determinants to define these operationally-efficient surveillance periods.

Diagnosis of incident traffic patterns must be balanced with respect to the rate at which traffic congestion develops. There may be instances when incidents occur during off-peak hours. In these cases, traffic densities can be very low with substantial time required for congestion to build up to the point where the queue spans multiple detection stations before sensing incident congestion patterns. The probability of incident occurrence at low densities tends to be much less than during peak-hour traffic, and thus does not provide a viable determinant Surveillance performance must then be related to the scale of congestion (incidents) impact and the time interval required for detection and recognition of incident patterns. Thus, this analysis uses incident traffic flow conditions; namely, queue buildup, to determine surveillance performance requirements (periods/cycles).

Performance Limit Determination. This method will employ traffic and system characteristics observed during roadway incidents to focus on definition of operational surveillance performance limits to support incident detection processing. Implementation costs are considered to determine the minimum number of detection stations (maximum spacing) required to support overall traffic flow monitoring (free-flow traffic and incident detection). Characterization of the congestion development rate and incident detection capabilities are used as specific determinants to define surveillance periods and detection station spacing.

When traffic flows at or around its maximum/ideal rate, the surveillance function must update flow data (MOEs) at a corresponding rate. When traffic becomes heavily congested, the same relationship may not apply to be operationally-efficient. In this flow region, incident detection becomes a more prevalent function and relies heavily upon the periodic traffic MOEs provided by the surveillance function.

The incident detection/surveillance relationship is examined further to develop a means for specifying and balancing free-flow surveillance performance (i.e., periods and detection station spacing) with incident detection processing timelines.

First, the observed rate of congestion development will be used to calculate the time and distance required for the leading edge of a compression wave to travel upstream through the traffic flow. Tabulation of these times and distances are presented in Table 4-6. The worst case distance a compression wave must travel in order to be detected can be defined as the distance between adjacent detection stations (i.e., incident location is immediate upstream from a detection station to the next upstream station). These propagation times will be used with baseline incident detection processing timeline limits to identify detection station spacing.

Table 4-6. Compression Wave Propagation Times

Travel Distance (miles)	Propagation Time of Compression Wave @ 10 mph (seconds)
0.00	N/A
0.10	36
0.20	72
0.30	108
0.40	144
0.50	180
0.60	216
0.70	252
0.80	288
0.90	324
1.00	360
1.10	396
1.20	432
1.30	468
1.40	504
1.50	540
1.60	576
1.70	612
1.80	648
1.90	684
2.00	720

Secondly, a baseline for incident detection performance (detection time) is established through assessments of various (comparative) algorithms in current operation or test. This baseline requires definition of acceptable detection and false alarm rates, corresponding detection assumptions, and the number of (MOE) data samples required for processing. For most algorithms, detection and false alarm rates tend to follow a similar trend; that is, as the detection rate increases, the false alarm rate also increases. Some algorithms have developed improvements to minimize false alarm rates through the use of statistical smoothing of the surveillance data5. Others use multiple algorithms which process the same MOE data to look for different patterns and examine algorithm results through a comparator.

To determine appropriate incident detection time performance, most detection algorithms (e.g., California, time series, etc.) compare sequences of processed temporal and spatial traffic flow data to determine incident conditions or patterns. These algorithms adopt the objectives to maximize the probability of detection and to minimize the mean-time-to-detection[5] (MTD) and corresponding false alarm rates. In the referenced study, MTDs are based from the time an incident is reported into the operator's log. From a system performance perspective, this data may be insufficient due to time omitted between actual occurrence and entry into a log. The following analysis provides an estimation of the overall detection time.

Detection accuracy and traffic management center (TMC) operator perspectives are examined to define thresholds for incident detection and false alarm rates; that is, high detection with a low false alarms. From the operator's perspective, low false alarm rates are emphasized due to the tendency to ignore frequent alarms within short time periods. Based upon studies5, acceptable rates are considered to begin at 60% detection (ratio of detections of all identified incidents) with corresponding 0.1% false alarm rates (percent of false alarm decisions to all decisions). This can be interpreted as approximately 1 false alarm per peak hour traffic at a minimum 60% detection rate for all incidents.

Higher detection rates from single algorithms potentially carry a timeliness penalty; in that, these algorithms use a larger data sample set over time to statistically "smooth" the surveillance data for filtering out data noise, or to check the persistency of an incident pattern. For these algorithms5, corresponding MDTs (@ 60% detection/0.l% false alarm rates) range from 1.1 minutes (DELOS3.3) up to **2.1** minutes (DELOS 1.1). However, these time values were measured from the time reports are entered into the operator's "incident log". These mean times are considered offsets **to** the actual occurrence-to-incident log reporting time and do not provide an adequate performance value for this analysis.

Another method to determine actual detection time could be obtained from the number of data samples required to perform incident processing. Through examination of the same algorithms, study data samples, and assumptions5, a baseline incident detection performance range can be determined by summing the number of sample collection time (surveillance periods) required for detections. **As** a minimum (no detection time offsets), the modified California algorithm (Los Angeles) requires three data samples to initiate detection processing for comparison of occupancy thresholds, and two additional samples to check for incident pattern persistency. As a maximum, the DELOSl.1 algorithms uses up to ten-samples to perform statistical smoothing and threshold/history comparisons. These incident detection algorithms were calibrated using 30-second data samples. Therefore, a baseline minimum incident detection processing interval requires five surveillance periods, or 150 seconds (2.5 minutes); and a baseline maximum interval requires ten surveillance periods, or 300 seconds (5 minutes).

Determine Operational Surveillance Period To determine operationally-compatible surveillance periods, minimum and maximum detection times (intervals), corresponding number of data samples, and compression wave travel distances are used to calculate the required detection station spacing and corresponding minimum surveillance period lengths (for Sf = 59.5 mph and 65 mph) to support incident detection.

The most prominent incident flow characteristic is identified as the compression wave of vehicles (as their speed slows to a stop) which moves in an upstream direction at a rate of approximately 10 mph[5,6] and persists over an extended period. The data from Table 4-6 is plotted in Figure 4-7 with minimum and maximum incident detection time limits to derive the corresponding travel distances of the compression wave.

The intersections at which the compression wave propagation line crosses the incident detection time limits depict the range in which the surveillance function must perform. These intersection points also identify corresponding compression wave travel distances which can be used to derive a detection station spacing; hence, the corresponding operational surveillance period.

Mathematical derivation of propagation distances corresponding to the detection limits can be obtained from the following relationship:

propagation distance = (compression wave travel rate) x (detection time)

or expressed as: $P_{cw} = S_{cw} x T_d$

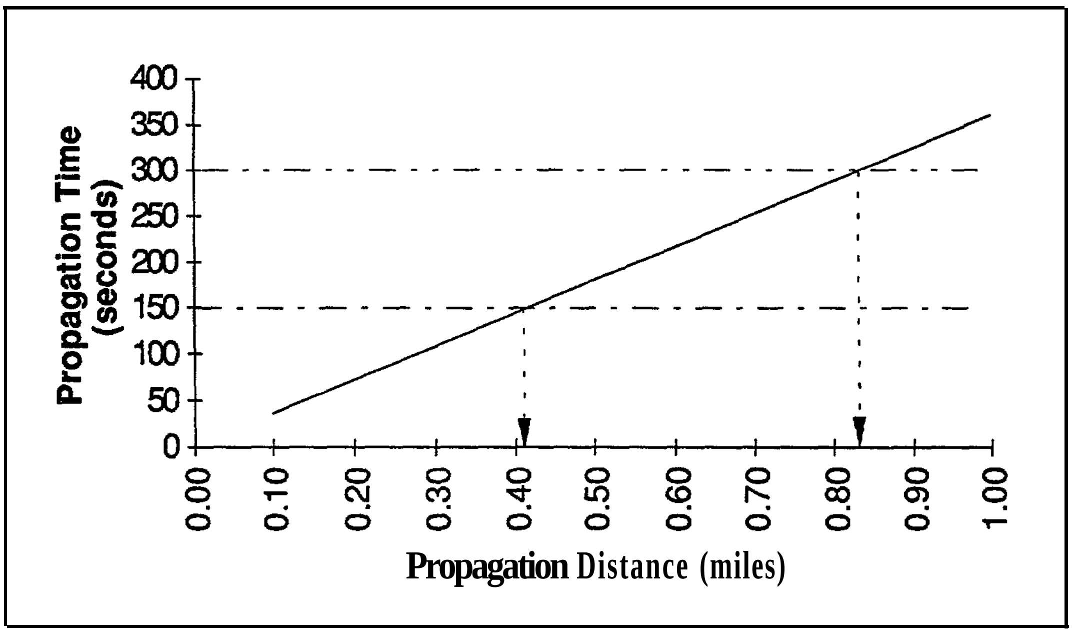

Figure 4-7. Incident Compression Wave Propagation

The following values are used for propagation speed and incident detection times:

S_{cw} **= 10 mph;** T_{dmin} **= 150 seconds (minimum)**
T_{dmax} **= 300 seconds (maximum)**

Thus, compression wave propagation distances corresponding to incident detection time limits are:

P_{cwmin} ***= 0.42 mile; and,*** P_{cwmox} ***= 0.83mile***

These distances do not directly correspond to detection station spacing, but can be used to derive spacings based upon the number of data samples used for incident detection.

To find the detection station spacing for the minimum detection time, the worst case situation (incident immediately upstream) is assumed For minimum detection time (modified California algorithm), 5 data samples were required to signal a detection alarm, of which 2 samples were used for persistency checks. Therefore, when the alarm is issued, the compression wave, or queue length, has traveled 2/5 of 0.42 mile, or 0.17 mile passed the first adjacent upstream detection station. Thus, detection stations are spaced at 3/5 of 0.42 mile, or at 0.25 mile intervals.

A similar derivation can be performed for the maximum detection time where 10 data samples were required, of which 6 samples were used as a historical base and 4 samples used for measurement and persistency. Similar ratios are used on the corresponding maximum propagation distance of 0.83 mile. In this case, detection station spacing results in 0.50 mile intervals (6/10ths of 0.83 mi.).

Conclusions [3]:

Improvements in automated incident detection accuracy and false alarm rate reductions are consistently being studied. Given that short surveillance periods can always support long detection intervals, the maximum surveillance performance required to support incident detection processing needs correspond to a period length which supports traffic data collection at both low density, free flowing speeds, and at high density - low speed, unstable traffic flow.

Correlation of detection station spacing derived from incident detection processing is linked to spacing derived from the free flow/ideal traffic flow model (Sf = 59.5 mph). Spacing values yield a surveillance period range of 15.1 seconds to 30.3 seconds. These values correspond to detection station spacings of 0.25 mile and 0.50 mile. If the observed free flow traffic speeds (Sf = 65 mph) are used, the surveillance period range reduces to 13.9 seconds to 27.7 seconds. Also, since the surveillance function is closely coupled with the traffic control and demand functions, the same (surveillance) processing cycle/period would also apply to those functions to ensure the latest information is used within the control cycle and the system feedback path is maintained..

Actual detection station location placement and spacing for surveillance zones along freeway mainlines can vary based upon a number of conditions. Entrance and exit ramp spacing, weaving areas, roadway curvatures, communications media access, and demand and average daily traffic volumes all provide input into the layout and frequency of detection station spacing and surveillance zones. Overall, typical detection station location selection ranges between +/- 0.2 mile of the desired spacing distance.

Recommendations. As a guideline for system implementation based on performance and cost, detection stations should be spaced between 0.25 mile to 0.50 mile apart Within this range, If system incident detection performance is a priority, 0.25 mile spacing of surveillance zones is recommended. If budgetary constraints do not allow a close spacing, then up to 0.50 mile spacing intervals should be sufficient to provide adequate surveillance and incident detection performance.

4.3.3.1.4 MOE Monitoring and Display

As traffic surveillance flow data is collected and processed, traffic MOEs and system performance information must be made available to other system-level functions for traffic control performance monitoring, traffic network status management, information dissemination, and operator feedback. MOE updates are dependent upon the collection rate of the surveillance system. Information access to MOEs should be available on demand

4.3.3.1.4.1 MOE Monitoring

Traffic flow MOEs provide the principal measures for traffic management perfomance. MOEs are used at different processing levels within the traffic management system and are required in three primary timeline categories: [l] "on-line" processing functions (i.e., traffic control feedback and incident detection processing); [2] "routine" processing functions (i.e., traffic network management and status displays); and [3] "off-line" functions (i.e., traffic network information management, access, and dissemination). Figure 4-8 illustrates these levels and corresponding timeline scales for MOEs are use and application.

MOEs for traffic control and incident detection processing need to be directly provided by the surveillance function. The surveillance function tends to be closely-coupled with these processes to provide the timely feedback needed to support control activities and monitoring functions. This coupling also ensures the MOE data is representative of up-to-date traffic conditions and minimizes latency conditions which could trigger inappropriate controls and alarms. Functions which use MOEs in this "on-line" fashion typically operate on a near real-time timeline (seconds to minutes). For example, integrated corridor flow control collects and processes MOE data at the corridor level. In these applications, MOE value is measured more by the recency of the data in order to assess proper system responses.

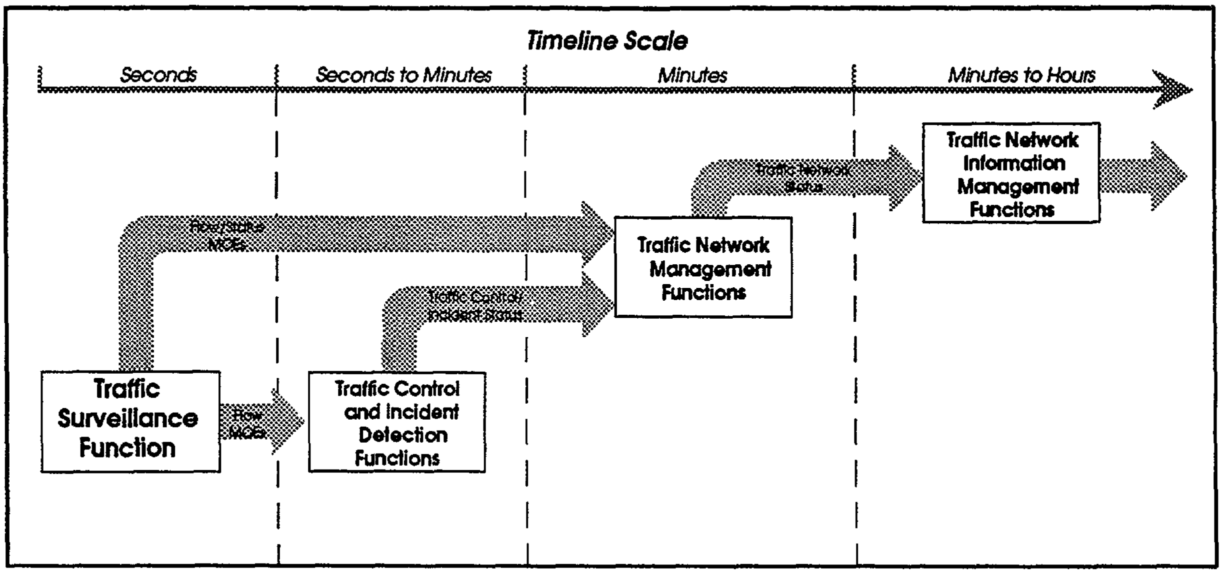

Figure 4-8. MOE Processing Application Levels

MOEs used for traffic network management and status displays need to be readily available (on demand) for traffic control functions and operator presentation and feedback. MOEs available on demand are defined as the latest reported status (within the last surveillance cycle - typically 20-30 seconds) retained by the system. On demand performance minimizes latency effects and operator frustration when having to wait for system feedback and status displays.

MOE processing and availability at this level require periodic updates to support ongoing "strategic" management activities, or possibly "tactical" traffic views (i.e., mainline section, entrance ramp status, etc.). Where traffic control and incident detection functions involve more critical MOE processing timelines (direct access), monitoring activities are more involved with the organization, interpretation, and presentation of the MOEs on a system status display in an operations center environment to conduct routine traffic management and information dissemination activities.

Off-line functions, such as, traffic network information management, information access control, and information dissemination, tend not to require stringent MOE update timelines. The term "off-line" is used to make reference to information processing performed external to the traffic surveillance and control subsystems. This processing is primarily oriented towards information services to provide traffic status to external (to traffic operations) entities. MOEs used in this capacity are processed into more relevant travel information involving corridor congestion, incidents travel times, and delays. This information can be disseminated to outside parties or individuals for independent traffic reporting services, assessments, and reports.

4.3.3.1.4.2 Traffic Network Status Displays

Traffic network surveillance status displays include overall traffic network flow (system map), corridor-level flow (mainline segment - multiple surveillance zones), sub-corridor-level (i.e., single surveillance zone, entrance/exit ramps), video surveillance, and traffic management subsystems status. Control of the data displays and media are processed through two basic functions: [l] the traffic surveillance and control subsystems; and [2] the TMC operator interface(s). Organization of user/operator interface controls need to be self-contained where all pertinent information is available to aid operator selection. The latter function focuses the operator's attention to a single interface to promote ease of use and operator productivity. System-generated response actions (decision aids) need to automate repetitive tasks and actions (standard operating procedures) to streamline operator workload. User presentations should incorporate graphical forms to maximize operational utility, control, and user friendliness.

Status displays processed through the traffic management subsystems should automatically collect and update traffic status on a routine (periodic) basis. These displays include the following:

- Overall traffic network status including roadway congestion status and incident detection processing
- Traffic surveillance and control subsystems status
- System/component health status
- Information system maintenance

Control and data displays commanded by the TMC operator should be processed through an integrated and interactive user interface for display and control functions (e.g., function selection, scale, data types, etc.). These displays need to be available on-demand for the following management functions.

- Traffic surveillance and control monitoring
  - Traffic surveillance (plus environmental data)
  - Mainline/Ramp control
  - Changeable message control (CMS/HAR)
  - Network performance monitoring
  - Database maintenance
- Incident management
  - Detection/Prediction (e.g., special events, work/construction zones, etc.)
  - Verification
  - Notification
  - Response and removal coordination
  - Incident traffic management
  - Incident information dissemination
  - Incident database maintenance

- Video surveillance and control
  - Image selection (camera) and control (PTZ)
  - Image display control (monitor)
- Information management
  - Information collection and management
  - Dissemination and access control
  - Database maintenance
- Malfunction monitoring
  - System status monitoring
  - System/component health checks and diagnostics
  - Database maintenance
- System administration
  - Housekeeping
  - Database maintenance

4.3.3.2 Traffic Control Performance

Traffic control systems provide the flow control facilitation mechanisms to collect, calculate and execute traffic management strategies. The FHWA Traffic Control Systems Handbook, FHWA-IP-8511, defines traffic control as the regulation, warning, and guidance of traffic for the purpose of improving the safety and efficiency of moving people and goods. Implementing this control process involves the installation, operation, and maintenance of various traffic control strategies and control devices, such as signs, signals, and lane barriers.

The MDOT ATMS/ATIS will primarily involve management of traffic on freeways and expressways surrounding the metropolitan Detroit area. Freeway Operations will include mainline flow management and control, incident management, driver/traveler information dissemination, and system maintenance. Mainline flow management and control activities include entrance ramp activation and metering control, mainline flow control, and integrated corridor management and control. Evolution of mainline flow management can extend into integrated surface street/mainline flow controls to optimize traffic flow between high capacity trunklines/arterials and freeways during peak traffic periods.

The following assessments are intended to identify levels of control processing to support allocation of those processes and functions into the system architecture. Detailed performance characteristics are defined where possible.

4.3.3.2.1 Traffic Control Assumptions

Assumptions associated with this assessment involve behavioral aspects of traffic flow, metropolitan Detroit roadway characteristics, and MDOT DFO traffic control modes and strategies. These assumptions reflect the perspective from which the system will be designed, implemented, operated, and maintained. Operational-efficiency objectives (i.e., operational-effectiveness and cost-efficiency) are incorporated into this analysis to define feasible performance requirements consistent with DFO strategies.

Traffic Flow Behavior. The traffic model illustrated in Figure 4-4 depicts a closed process relationship between traffic flow surveillance, demand prediction, incident detection, traffic control, and the traffic network. Driver perceptions result in reactions to the traffic controls and network status and are displayed in driver behaviors. These behaviors are a result of route re-evaluation and the exercising alternative route choices. These perceptions tend to be accounted for through the collection of traffic MOEs, however, may modify traffic strategies to adapt to the changes in traffic flow and routes taken. The traffic control system must formulate and execute these strategies in response to flow changes measured by the surveillance system and predicted by potential traffic demands and incidents.

Metropolitan Detroit Roadway Characteristics. Traffic control for metropolitan Detroit roadways, more specifically freeway mainlines, will include entrance ramp controls, mainline controls, and corridor controls. Portions of freeway mainlines exhibit non-capacity-reducing bottleneck characteristics. These characteristics include sight-occluded curves, narrow roadways, weaving sections (e.g., transition lanes), and severe roadway surface inconsistencies. Seasonal weather conditions tend to amplify the effects of these bottleneck characteristics with heavy rain and transitional snow/ice roadway surface conditions. The traffic control system needs to sense and adjust traffic controls for these conditions.

MDOT Traffic Control Strategies. Traffic control strategies for metropolitan Detroit currently consist of entrance ramp control and variable message signing (i.e., CMS, HAR/AHAR). Current control strategies use the freeway mainlines as the primary conduits for traffic movement. Limited deployment of traffic surveillance and control infrastructure has constrained the system’s ability to effectively manage traffic flow. Strategies for the future system will enable areawide integrated corridor management with coordinated operations, variable mainline speed signing, integrated ramp control, and integrated surface arterial/mainline control. In addition, traffic information will be available and disseminated to other TMCs, media reporting services, and roadway users to provide improved traffic awareness and travel planning capabilities.

Reference Sources. The following references are used in this assessment:

1. Wilshire, R., Black, R., Grochoske, R. & Higinbotham, J., Traffic Control Systems Handbook. Revised Edition - 1985, FHWA-IP-85-11, USDOT FHWA, pp 4.3-4.70.
2. Pline, J. L., Traffic Engineering Handbook, Institute of Transportation Engineers, pp 360-390, 391-418

4.3.3.2.2 Traffic Control Performance Assessments

Traffic control performance needs to be responsive to control strategies and appropriately scaled to be effective. The traffic control functions to be assessed include mainline ramp control, variable mainline speed signing, integrated corridor control, and coordinated areawide traffic operations.

4.3.3.2.2.1 Entrance Ramp Control Performance

Limiting the volume rate of vehicles entering a freeway mainline is the most widely used form of freeway traffic control. The primary objective of entrance ramp control is to eliminate, or at least reduce, traffic flow problems resulting from mainline congestion. In principle, the ramp control function limits the number of vehicles which enter the mainline by modulating the (entering) traffic demand with the mainline's downstream capacity. In consequence, vehicles may need to wait at the ramp before entering the mainline; queues may develop and cause spillover onto surface arterials; drivers may be diverted to other downstream ramps, avoid traveling on the mainline altogether, use surface arterials, or avoid traveling at that time; or ultimately, use another travel mode (i.e., transit bus, light rail, etc.). In any case, entrance ramp control helps promote smooth and efficient mainline traffic flow by deferring the travel delay onto the ramp and helps improve safety resulting from smoother traffic flow.

Performance for entrance ramp controls are summarized in Table 4-7 and described in the following paragraphs.

Table 4-7. Entrance Ramp Control Operational Performance

Control Method	Control Device	Activation Mode			Control Mode		
		Fixed	Traffic Rsp	Opr-Cmd	Normal	Rain	Snow/Ice
Ramp Closure	Signing	scheduled	real-time	real-time	enabled	enabled	enabled
	Barriers	scheduled	real-time	real-time	enabled	enabled	enabled
Ramp Metering	Pre-timed	scheduled	real-time	real-time	enabled	enabled+	disabled
	Traffic Resp.	scheduled	real-time	real-time	enabled	enabled+	disabled
Intgr. Rmp Cntl	Interconnection	scheduled	real-time	real-time	enabled	enabled	disabled

+ -modified normal mode.

Control Strategies. Ramp control strategies are categorized as diversionary or non-diversionary. Diversionary strategies specify ramp control parameters so that entering traffic demand is diverted to another ramp, to an alternate route or travel period, or to an alternate mode. Non-diversionary strategies service, or assimilate, the entire traffic demand at the ramp.

Activation Modes. Activation modes are those control processes which determine the conditions in which ramp control is activated and deactivated For most systems, ramp control activation is determined by a fixed schedule (time-of-day, day-of-week), response to mainline traffic conditions (traffic responsive), or through direct operator commands (operator override). When activation conditions are no longer valid, controls should be deactivated to promote motorist trust in the system.

Control Modes. Like other areas with a very diverse climate, the metropolitan Detroit area occasionally experiences inclement weather conditions which degrades the roadway surface and visibility. The system must provide the capability to determine local environmental conditions. These conditions include adverse roadway surface conditions due heavy rain (flooding) and snow and ice. The system will enable, disable, and modify ramp controls as weather conditions vary. Normal mode is the default mode and applied for clear weather and roadway surface conditions. Rain mode is applied when significant (rain) precipitation is experienced. Metering rates are also modified to increase the intervals (spacings) between vehicles to allow more merging space. Snow/ice mode is applied when snow or ice conditions are experienced on the roadways and ramps. This mode deactivates ramp metering to account for marginal roadway surface conditions which may compromise vehicle traction in stop-start-stop maneuvers.

Ramp Control Implements. Three methods of ramp control include [1] Ramp Closure; [2] Ramp Metering; and [3] Integrated Ramp Metering.

1. Ramp Closure is utilized to restrict entrance ramp access for congestion elimination or safety reasons. Ramp closure must be applied with care due to its inflexibility to accommodate mainline access. Ramp closure is applied when roadway capacity immediately upstream from the ramp is at capacity, inadequate vehicle queue storage capacity on the ramp, major incidents downstream from the ramp, and severe weaving problems exist at the ramp gore. Methods to implement ramp closure include message signing and moveable barriers. Specific infrastructure accommodations also need to be in place in order to utilize the ramp closure method. These include adequate alternate routes and alternate ramps.

2. Ramp Metering is the most widely used method of ramp control. Ramp metering is normally applied to alleviate mainline congestion and/or to improve the safety of merging operations.
   a. Activation control is determined by a fixed schedule (TOD/DOW), in response to mainline traffic conditions, or by operator command (override).
   b. Metering methods used for metropolitan Detroit include pre-timed and traffic responsive metering (see Table 4-7). Pre-timed ramp metering typically uses preset metering rates (not directly influenced by mainline traffic conditions). Traffic responsive metering calculates metering rates based upon a mainline demand-capacity relationship whereby real-time upstream demand and downstream capacity determines the rate.
   c. Single-entry metering rates are varied from 180-900 vehicles per hour (vph), and platoon metering rates are used when > 900 vph are required.
   d. Control implements used for ramp metering include a standard 3-section (red-yellow-green) or 2 section (red-green) metering signal head, an advance ramp

control warning sign with a flashing beacon or "blank-out" ("METER ON") sign, a local ramp controller, environmental sensors (optional), and vehicle sensors to detect vehicles at the complementary ramp exit, at the ramp entrance, at the stop line (check-in), just passed the stop line (check-out), and optionally in the primary merging area of the ramp and freeway mainline.

3. Integrated Ramp Control applies the principles of ramp metering to a series of adjacent ramps. Integrated pre-timed metering and integrated traffic responsive metering consists of coordinated control where adjacent ramp controllers adjust metering rates based upon traffic conditions throughout an entire corridor. Typical processing calculations use the demand-capacity traffic relationship for metering rates at each ramp, with implementation options which use a central system master a corridor (node) master; or logically-interconnected controllers coordinating metering rates.

4.3.3.2.2.2 Mainline Control Performance

Mainline control provides a means to [1] improve the stability and uniformity of traffic flow; [2] disseminate pertinent traffic information directly to roadway users to provide warnings and promote awareness; [3] divert traffic to alternate routes make better use of corridor capacity; [4] facilitate incident clearance and recovery by diverting traffic to alternate routes; and [5] change the directional capacity of the freeway mainlines by using reversible lanes. Performance of mainline controls vary depending upon the type of operation. Performance parameters are summarized in Table 4-8 and described in the following paragraphs.

Table 4-8. Mainline Control Operational **Performance**

Control Method	Control Device	Activation Mode			Control Mode		
		Fixed	Traffic Rsp	Opr-Cmd	Normal	Rain	Snow/Ice
Variable Speed (Restriction)	signing	N/A	real-time thresholds	real-time	enabled	enabled+	enabled+
Info. Dissemin. (Restriction)	signing	N/A	real-time	real-time	enabled	enabled+	enabled+
Altern. Routing (Diversion)	signing	N/A	real-time	real-time	enabled	enabled+	enabled+
Lane Control (Restriction/ Diversion)	signing	scheduled	real-time thresholds	real-time	enabled	enabled+	enabled+
	barriers	scheduled	real-time thresholds	real-time	enabled	enabled+	enabled+

+ - moditied nom I mode.

Control Strategies. Mainline control strategies are applied to regulate, warn, and guide mainline traffic to achieve more stable and uniform traffic flow. The primary strategy is to detect impending congestion and hazardous roadway conditions and deploy mainline controls to facilitate smoother traffic flow.

Activation Modes. Activation modes are those control processes which determine the conditions in which mainline controls are activated or deactivated. Activation modes include fixed (scheduled), traffic responsive, or operator commanded (override). Except for lane controls established for recurrent traffic patterns (reversible lanes), all mainline controls are activated through pre-defined thresholds based upon real-time traffic conditions and operator concurrence. When activation conditions are no longer valid controls should be deactivated to promote motorist trust in the system Controls for reversible lanes are scheduled (with operator concurrence) to conform with established recurrent traffic patterns. Scheduling enables predictability for drivers and roadway availability.

Control Modes. The system must provide the capability to determine local environmental conditions and adjust mainline controls to appropriate levels. These conditions include adverse roadway surface conditions due heavy rain (flooding) and snow and ice. The system will enable, disable, and modify mainline controls as weather conditions vary.

1. Normal mode is the default mode and applies to clear weather and roadway surface conditions. This mode specifies mainline controls (speed, mainline demand, integrated ramp demand, alternate routing) to promote system-wide traffic flow stability and uniformity.
2. Rain mode is applied when significant (rain) precipitation is experienced. Controls are modified/adjusted to account for degraded roadway surface conditions and cautious motorist behavior.
3. Snow/ice mode is applied when snow or ice conditions are present on the roadways and ramps. This mode provides similar adjustments as Rain Mode with the addition of deactivating ramp metering to account for marginal roadway surface conditions which may compromise vehicle traction in stop-start-stop maneuvers. This mode may specify closure of designated ramps and mainline interchanges due to hazardous roadway conditions.

Mainline Control Implements. Four methods of mainline control applicable to the metropolitan Detroit area include [l] Variable Speed Control; [2] Driver Information Dissemination; [3] Alternate Routing; and [4] Lane Control. Mainline metering could also be applied in the future if the use toll roads become evident as a means to fund new roadway infrastructure developments.

1. Variable Speed Control is utilized to reduce the speed of the mainline traffic during peak-flow conditions so that the flow is adjusted to mainline capacity. At best, variable speed control may delay congestion occurrence. Speed control improves the stability and uniformity of traffic flow during peak-flow periods, thus helping reduce the occurrence of rear-end collisions as congestion develops. Speed control can also be applied as an advance warning system when downstream incidents are detected. Care must be used with speed control to ensure traffic flow conditions warrant use, i.e., control activation to anticipate peak-flow conditions, and deactivation once

congestion conditions are prevalent. Methods to implement speed controls include specific speed signing or integrated with general messages.

2. Driver Information Dissemination is utilized to provide pertinent, real-time traffic information directly to roadway users. Information dissemination is normally applied when abnormal traffic conditions exist and warnings for roadway, traffic, and incident conditions, speed reductions, and route diversions. Methods to disseminate information include variable message signing, variable speed signing, and lane control signals.

    a. Variable message signing direct to roadway drivers using overhead and roadside equipment (CMS/HAR/AHAR).
    b. Variable speed signing to provide advance warning for downstream roadway and traffic conditions.
    c. Lane control indicator to identify lane closures and diversions from typical lane use.

3. Alternate Routing Control is applied when traffic congestion, roadway conditions, and major incidents warrant diversion of mainline traffic to other under-utilized corridors. Methods to provide alternate routing include variable message signing (CMS/HAR/AHAR) and lane control indicators.

4. Lane Control is applied to improve the efficiency and safety of mainline traffic flow. Use of lane control is usually warranted for advance warning of lane blockage, for improvement of ramp merging operations, mainline traffic diversion, mainline tunnel control, and construction/work zones. Methods to provide lane control include variable message signing and permanent/moveable barriers.

4.3.3.2.2.3 Integrated Corridor Control Performance

Integrated corridor control provides a means to improve the stability and uniformity of traffic flow within a corridor through management of all available regulatory traffic controls on both the freeway mainline, service roads, and parallel surface arterials. The fundamental system requirement to achieve integrated corridor control is surveillance and control of both freeway mainlines and surface arterials through coordinated management.

Performance of integrated corridor controls vary depending upon the type and extend of operations. Performance parameters are summarized in Table 4-9 and described in the following paragraphs.

Table 4-9. Integrated Corridor Control Operational Performance

Control Method	Control Device	Activation Mode			Control Mode		
		Fiied	Traffic Rsp	Opr-Cmd	Normal	Rain	Snow/Ice
Ramp closure	signing	N/A	real-time	red-time	enabled	enabled+	enabled+
	barriers	N/A	real-time	real-time	enabled	enabled+	enabled+
Intgr. Rmp Cntl	ramp control interconnection	N/A	real-time	real-time	enabled	enabled	disabled
Variable Speed (Restriction)	signing	N/A	real-time thresholds	real-time	enabled	enabled+	enabled+
Info. Dissemin. (Restriction)	**signing**	**N/A**	**real-time**	**real-time**	**enabled**	**enabled+**	**enabled+**
Altern. Routing (Diversion)	**signing**	**N/A**	**real-time**	**real-time**	**enabled**	**enabled+**	**enabled+**
Lane Control (Restriction/ Diversion)	**signing**	**N/A**	**real-time thresholds**	**real-time**	**enabled**	**enabled+**	**enabled+**
	barriers	**N/A**	**real-time** thresholds	**real-time**	**enabled**	**enabled+**	**enabled+**

+ -modified nod mode.

Control Strategies. Integrated corridor control strategies are placed into two categories: [l] restriction; and [2] diversion. Restriction limits corridor traffic demand to below corridor capacity levels to stall congestion levels and promote traffic throughput. Restriction strategies are accomplished through regulatory controls, such as, ramp, mainline, and mainline/surface arterial intersections. Diversion transfers excess traffic demand onto alternate corridors with excess capacity. Diversion strategies are also accomplished through regulatory controls with the addition of driver information signing. System integration of these control elements will provide the means to implement the following techniques:

1. Coordination of traffic signals on frontage/service roads and parallel alternate routes

2. Coordination of traffic signals at freeway interchanges with surface arterials (i.e., diamond interchange).

3. Coordination of the ramp control queue-override feature with frontage/service road intersection control to prevent queuing across the intersection.

4. Provisions for turning phases at frontage/service road and alternate route intersections with cross-streets that lead to freeway ramps.

5. Detection of incidents and provisions for rapid response and removal to minimize capacity impacts.

Activation Modes. Activation modes are those control processes which determine the conditions in which corridor controls are activated. Activation modes are traffic responsive or operator commanded (override). All corridor controls are determined by the system and activated through pre-defined thresholds based upon real-time traffic conditions and operator concurrence. Controls for reversible lanes are determined (with operator concurrence) to conform with established recurrent corridor traffic patterns.

Control Modes. The system must provide the capability to determine local environmental conditions and adjust mainline controls to appropriate levels. These conditions include adverse roadway surface conditions due heavy rain (flooding) and snow and ice. The system will enable, disable, and modify mainline controls as weather conditions vary.

1. Normal mode is the default mode and applies to clear weather and roadway surface conditions. This mode specifies corridor controls (speed, mainline demand, integrated ramp demand, alternate routing, and surface signals) to promote corridor traffic flow stability, uniformity, and roadway efficiency.

2. Rain mode is applied when significant (rain) precipitation is experienced. Controls are modified/adjusted to account for degraded roadway surface conditions and cautious motorist behavior.

3. Snow/ice mode is applied when snow or ice conditions are experienced on the roadways and ramps. This mode provides similar adjustments as Rain Mode with the addition of deactivated ramp metering to account for marginal roadway surface conditions which may compromise vehicle traction in stop-start-stop maneuvers. This mode may specify closure of designated ramps and mainline interchanges due to hazardous roadway conditions.

Corridor Control Implements. The control implements use for integrated corridor management coordinate the traffic responsive controls for ramp and mainline controls and integrate the control coordination with surface arterial signal timing and control. Integration with the surface arterial signal network requires real-time coordination with the surface arterial TMC and jurisdictional agreements. In addition, corridor controls need to be directly integrated with incident management plans to provide rapid response coordination and incident traffic diversion deployment.

4.3.3.3 Information Management and Dissemination Processing

Advanced Traveler Information Subsystems (ATIS), in conjunction with Advanced Traffic Management Subsystems (ATMS), will provide a variety of information services to assist travelers in arriving at their destinations whether the mode is via private vehicles, law enforcement, commercial dispatchers, public transportation, and intermodal travel systems. The ATIS will collect travel and traffic information from the ATMS, coalesce and manage the information into presentable forms, and disseminate the information in a variety of methods, to a variety of users. For the metropolitan Detroit area, this ATIS will be integrated with the Michigan Department of Transportation (MDOT) ATMS located at the MITSC. ATMS/ATIS operations are envisioned to be managed from the MITSC.

Disseminated information includes congested and incident locations, alternate routing, roadway/freeway network status, weather and road conditions, roadway limitations and closures, and speed recommendations. Dissemination of traffic information will evolve over several phases, beginning with currently available communications media (i.e., AM/FM radio, variable message signing, printed material, etc.), then to more specialized telecommunications devices (i.e., personal communication devices, intelligent terminals and kiosks, roadway infrastructure devices, full featured call-up services, and other interactive information services), and finally to autonomous, in-vehicle navigation systems, pre-trip planning services from homes, offices, and roadside kiosks, and portable personal data assistants which interact with the infrastructure for real-time traffic and traveler information.

This evaluation examines the performance required to manage and disseminate traveler and traffic information from within the ATIS. Performance for information delivery to users will vary depending upon the telecommunications device and the service used, and is considered beyond the scope of this evaluation.

4.3.33.1 Information Management and Dissemination Assumptions

Traffic and roadway information has the potential to be collected from a variety of sources. These include the ATMS, MDOT highway maintenance/construction crews, weather service bureaus, other TMCs, local and state government agencies (i.e., MSP, Detroit Police, Sheriff departments), courtesy patrols, public volunteer services, and local businesses. The following list represents a candidate list of the sources and users that may provide or receive traffic, weather, and roadway status information.

- ATMS traffic surveillance subsystems
- Michigan Emergency Patrol
- Michigan Department of Transportation (MDOT) divisions
- Michigan State Police (MSP)
- Metropolitan Detroit cities and counties public works (i.e., city/county road departments, etc.)
- Edison electric, Ameritech/Michigan Bell
- Local/national weather bureaus
- Roadway commuters and travelers (i.e., cellular call-ins)

4.3.3.3.2 Information Management and Dissemination Processing Assessments

Before any information can be effectively disseminated, it has to be collected, validated, and organized into a form that can be identified, processed (if necessary), and **logged.** Management of this information needs to occur in an efficient manner in order for effective MDTS operations and to provide timely, valid traffic information and status to outside users. In addition, the operators must be able to easily manage the information and system functions from a integrated work station which minimizes excessive operator actions. This information subsystem interfaces with the various subsystems (i.e., traffic surveillance and control subsystem [ATMS], CMSS, etc.). Figure 4-9 illustrates a candidate information systems architecture which manages traffic information flow into and from the system.

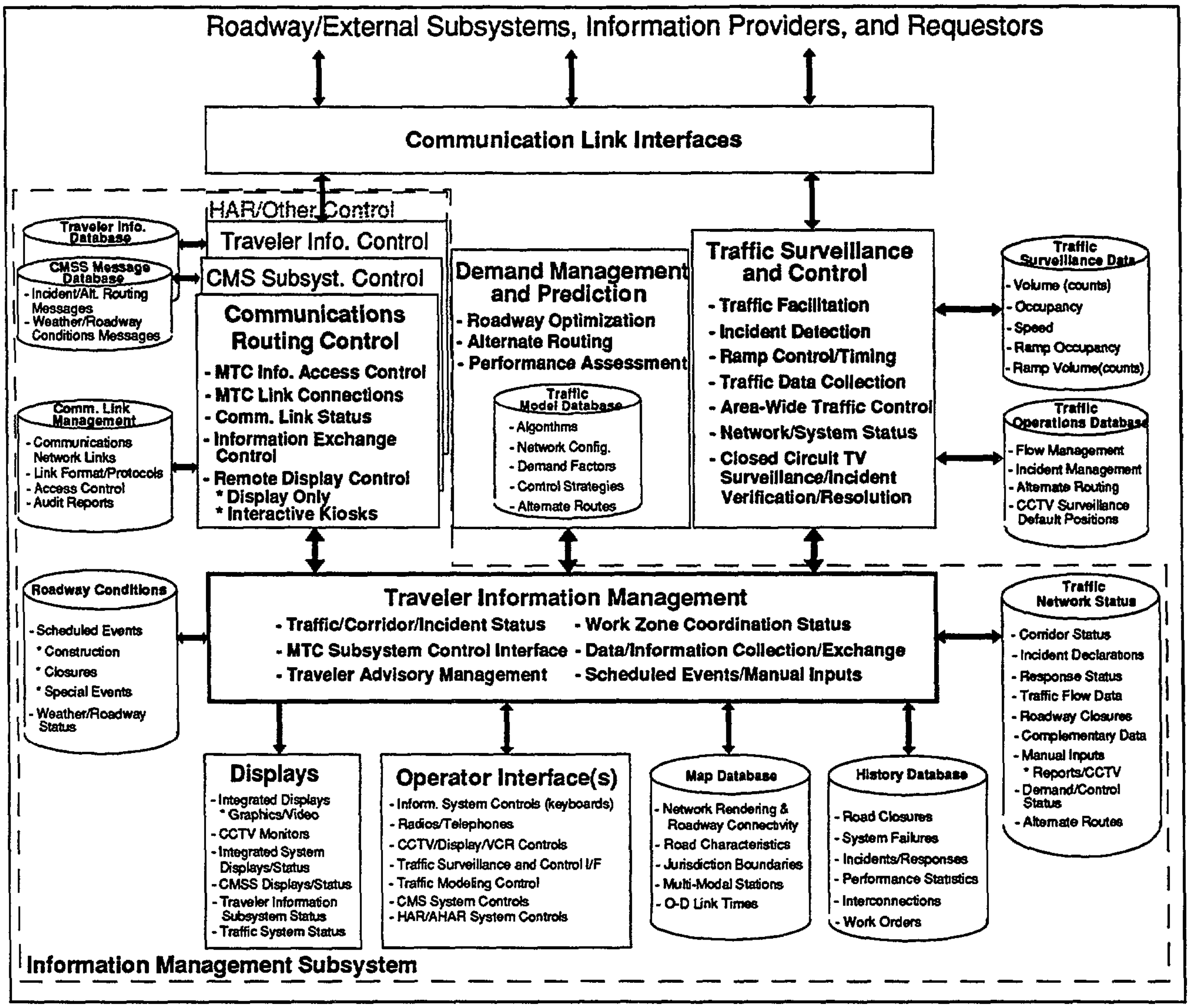

Figure 4-9. ATMS/ATIS Information Management Architecture

4.3.3.3.2.1 Traffic and Travel Information Collection

The traffic and roadway information will be collected by the ATIS from many sources. The primary sources are summarized in Table 4-10 and described below.

Table 4-10. Information Management Subsystem Inputs

Input Information	Source	Input Method	Destination/Database
Traffic Conditions - Traffic Flow Data - Corridor Status - Demand/Control Status - TOC Data Exchanges	- MDTS traffic surveillance subsystems (ATMS) - Michigan State Police (MSP) - Operator - Roadway commuters and travelers (i.e., cellular call-ins)	- Manual - Electronic	- Traffic Network Status Database - History Database - Roadway Conditions Database
Incident Declarations - CMS messages - Advisories - Alternate Routing	- Operator - MSP - MEP	- Manual	- Traffic Network Database - History Database
Incident Response Status	- Operator - MSP - MEP - Removal Service	- Manual	- Traffic Network Database - History Database
Maintenance Work Orders	- Operator	- Manual	- Traffic Network Database - History Database
Scheduled Events - Sports - Conventions - Public Works	- Operator - Data Exchange Link - Metropolitan Detroit cities and counties public works (i.e., city/county highway departments, Edison electric, Ameritech/ Michigan Bell, water departments, etc.)	- Manual - Electronic	- Traffic Network Database - History Database - Roadway Conditions - Traffic Modeling Database - Traffic Operations Database
Weather Reports	- Operator - Local weather bureaus/ reports	- Manual	- Traffic Network Database - History Database - Roadway Conditions - Traffic Operations Database - CMSS - Traveler Info. Subsystem
Roadway Closures - Construction - Maintenance	- Operator - Data Exchange Link	- Manual - Electronic	- Traffic Network Database - History Database - Roadway Conditions - CMSS Message Database - Traveler Info. Subsystem
System Status - Performance Statistics - System Failures - Work Orders	- Operator - ATMS - MITSC Subsystems	- Manual - Electronic	History Database Roadway Conditions
System Configuration - Comm. Network Links - Access Control	- Operator	- Manual	Comm. Link Management
Operator Control Commands - ATMS - Traffic Modeling - CMSS - Communications - Traveler Information - Information System Administration	- Operator	- Manual	- Traffic Operations Database - Traffic Modeling Database - CMSS Message Database - Comm. Link Management - Traveler Info. Subsystem - System Database

1. The ATMS will provide traffic flow statistics, potential incidents displays/alarms, system status (i.e., Failure Status, Controller Status, Traffic Page, and Incident Page), and CCTV video signals.

2. MITSC operators monitor the ATMS displays/status, MSP dispatcher radio frequencies, MEP printouts, DFOU field crews, weather reports, and perform other MITSC duties (i.e., secretarial) to input and log incidents, system failures, repair work orders, weather and road conditions, and daily summaries.

3. Information from local and state government agencies, public services, and sporting and special event organizers, and businesses may provide schedules for events which could impact traffic flow. Information regarding these pre-planned events may be input (by MITSC operators) into the information management subsystem to provide traffic advisories through advanced equipment (i.e., CMS displays, HAR/AHAR announcements, etc.) and implementing traffic control strategies.

4.3.3.3.2.2 Traffic and Travel Information Organization and Management

The Information Management Subsystem (IMS) provides the 'virtual" database for management of all system and subsystem data. The IMS will fuse data received from multiple sources, both internal and external to the system. The IMS will serve as a centralized information clearinghouse for up-to-date traffic information. Information access is provided through roadway signing devices, media reporting services, dial-up, and point-to-point/electronic information exchanges.

Operator commands and controls will be routed through the IMS to electronically interface to other subsystems. The information management subsystem must provide timely information upon operator request. System responses and requested information should be provided to the operator without disrupting the continuity of the task (e.g., respond within 10 seconds of the request). CCTV camera controls will be routed through the MITSC operator interface and must be an integrated station where all freeway operations can be managed. Traffic information management and control displays will be integrated to handle [l] overall system status, [2] freeway network surveillance and control, [3] subsystem displays and controls, [4] administrative management (i.e., operator inputs, incident reports, system status reports, work orders, communications link access control. etc.), and [5] software and system updates.

At a minimum, information will be organized into the following categories:

Table 4-11. Database Organization

Database	Data Types (examples)
Traffic Flow Surveillance	Congestion levels/MOEs
	Link times/delays
	Incident detection locations
Traffic Operations	Current control operations
	Incident Management
	Control modes
	Control plans
	System status
Demand Management	Control strategies
	Traffic Demand factors
	System performance statistics
	Predictive control plans
Traffic Network Status	Corridor status/Coalesced MOEs
	Link times/delays
	Incident declarations/locations
	Road closures
	Manual reports
	Alternate route data
History Database	Compiled traffic MOEs/Congestion levels
	Link times
	Incident Data
	System status/failures
	System work requests/status
Incident Management	Incident Data
	Responding agencies
	Jurisdictions
Map Database	Displays/Map coordinates
	Equipment location
	Surveillance zones
	Jurisdiction boundaries
	Roadway characteristics
Roadway Conditions	Scheduled events
	Weather condition status
	Roadway condition status
Message Signing Database	Changeable Message Signs
	Highway Advisory Radio/Automatic HAR
	Other signing
Communications Management	Network connections
	Communications protocols
	Access controls
	Audit reports

4.3.3.3.2.3 Traffic and Travel Information Dissemination and Control

The IMS will provide MITSC personnel with an integrated station from which to monitor and control all ATMS/ATIS subsystems. Outputs from the IMS consist of electronic data and information exchanges with subsystems, and also administrative reports for the purpose of record keeping, traffic studies, data reduction, and maintenance work orders. Table 4-12 identifies information and corresponding output methods used for dissemination to freeway network users.

Table 4-12. Information Management Subsystem Outputs

Output Information	Output Method	Destination
Traffic Conditions **- Traffic Flow Data** - Corridor S tams - Incidents/Response Status	**ATIS** **- CMSS** - HAR/AHAR syst. - Traveler Info. Syst. - Electronic Data Link	**- Travelers** **- Public/Private Kiosks** **- MSP** - Emergency Services - Commercial Business - Public Transit
Roadway Conditions - Weather - Closures	**ATIS** **- CMSS** - HAR/AHAR syst. - Traveler Info. Syst. - Electronic Data Link	**- Travelers** - Public/Private Kiosks **- MSP** - Emergency Services - Commercial Business - Public Transit
Traffic Modeling and Prediction	**ATMS** **- Electronic** **- Printouts**	- Traffic Operations Database - History Database
MDTS Work Orders	**- Hard copy Printouts** **- Electronic Storage**	**- MITSC Personnel** **- History Database**
System Reports - Traffic Data - Weather Reports - System Performance Reports **- Incident/Response Reports** **-**	- Bard copy Printouts - Electronic Storage	- MITSC Personnel - System Archives
Operator Control Commands **- ATMS** **- Traffic Modeling** **- CMSS** - HAR/AHAR Subsystem - Communications - Traveler Information **- System Administration**	**- Electronic Storage**	**- Traffic Operations Database** **- Traffic Modeling Database** **- CMSS** - HAR/AHAR Subsystem - Communications Routing - Traveler Information Subsystem - Information Management **Subsystems**

4.3.3.4 System Monitoring Performance

The ATMS/ATIS must be capable of evaluating subsystem components for performance effectiveness and malfunction conditions. Two types of monitoring functions are evaluated in this assessment: [l] Traffic Control Effectiveness; and [2] System Health Status. Monitoring could be accomplished at various levels; however, reports must be delivered to the TMC for evaluation and disposition.

4.3.3.4.1 System Monitoring Assumptions

Assumptions used in this performance assessment encompass the following:

1. Traffic Control Effectiveness is measured from reported surveillance MOEs and compared with current traffic control plans.

2. System Health Status is monitored for all surveillance and control components. Each component has the capability for built-in test (BIT) and executes BIT/self test upon power-on, periodically consistent with MOE reporting periods, and on operator command (local or from MITSC).

3. Central monitoring functions have the capability to further interrogate each component for diagnostic testing to identify malfunctions to the removable module level. Diagnostic testing is commandable through MITSC system operator interfaces.

4.3.3.4.2 System Monitoring Assessments

Real-time system monitoring shall be accomplished from the MITSC through available subsystem equipment. These equipment are primarily the collection points for traffic MOE data and field equipment status. In addition, these equipment also provide the means to assess traffic control effectiveness (via comparison of control plans with MOE data) and malfunction diagnostics (i.e., operator commanded self test).

4.3.3.4.2.1 Traffic Flow Performance Monitoring

Traffic flow performance monitoring is conducted **to** evaluate the effectiveness of traffic control plans. The primary goal of this function is to ensure the traffic control system is properly configured to meet the traffic demand and does not inadvertently cause traffic congestion problems.

This monitoring function can be thought of as a traffic demand/control assessment function where deployed traffic control plans are used with measured flow volumes to model calculated traffic flow MOEs. These "modeled" MOEs are then compared with measured MOEs and evaluated for consistency (compared to thresholds). Inconsistent values are analyzed and correlated with other data to identify the cause for the inconsistency. If traffic controls or detected incidents are determined as the cause, the system provides the operator with recommended responses (traffic control plan changes, incident responses) and resolution. The performance of this function requires real-time access to MOE data and current traffic control plans (ramp metering, closures, etc.). Statistical results are compiled (per hour) and stored to document the system's performance.

4.3.3.4.2.2 Equipment/System Health and Status Monitoring

Equipment/system health and status monitoring is conducted to maintain a current view of the system health and operational status. The primary goal of this function is to ensure the system is operating properly and malfunctions are identified and dispositioned. This function requires real-time access to complementary equipment status data (which is reported with traffic flow MOEs). Monitoring of this data also requires interfaces to system status displays and an interrupt capability to perform ancillary operator-commanded functions (diagnostics).

Malfunction indicators shall be automatically issued through visual or audible alarms. The system should automatically issue an initial self test command to ensure the malfunction is not an occasional anomaly. If frequent malfunctions are detected within a short period of time (once every 10 cycles or 10% - approximately every 3 - 5 minutes), the system should automatically flag the anomaly and issue an alarm to the operator.

The system should automatically manage system malfunction information and maintain a historical database for malfunction type, time of malfunction, equipment ID, disposition (i.e., work order issued), operation restoration status, and other pertinent maintenance information.

4.4 Architecture Approach Assessment

The baseline architecture shall be designed from requirements and characteristics derived and analyzed from MDOT operational goals, objectives, and needs to provide a safe, efficient, and cost-effective freeway network infrastructure for the surrounding metropolitan Detroit area. The preferred architecture needs to provide a balance of the following MDOT-defined criteria: [l] supports all current functional processes and open to future desired capabilities and capacities; [2] adaptable to evolving technologies; [3] flexible (modular) in operational configuration; [4] cost-efficient to implement, operate and maintain. Table 4-13 defines evaluation weights corresponding to each of these criteria. This architecture provides the design framework on which hardware, software and support functions (designed from system requirements) are implemented and integrated into an operational ATMS/ATIS.

Table 4-13. Architecture Evaluation Weights

Criteria	Weight Factor
Supports current and future functional capabilities	10
Cost-efficient to implement, operate, and maintain	10
Supports growth capabilities	9
Flexible to configure (modular)	8
Adaptable to evolving technologies	8

To support current MDOT efforts, ATMS/ATIS architecture development has been separated into two levels: Baseline Architecture and Early Deployment Architecture. The Baseline Architecture development includes a broader system design that incorporates the Initial Deployment architecture and provides a general framework on which subsequent phased deployments shall expand integrated system operation for management of traffic flow and roadway information for the entire network of MDOT-defined freeway corridors serving the metropolitan Detroit area. The Initial Deployment architecture development primarily focuses on a design to support the addition of surveillance and control capabilities on a currently uninstrumented priority corridor.

4.4.1 Top Level Architecture Approaches

Architecture configurations tend to be based upon trade-off factors consisting of operational considerations, technological feasibility, growth/evolutionary characteristics, and costs associated with construction/implementation, operation, and maintenance of the configured system Operational command hierarchies, technological feasibility, and implementation cost considerations primarily influence partitioning and location of functional processing; while, growth and evolutionary characteristics and operations and maintenance cost considerations influence the structure or framework in which these functions are integrated.

As a means to determine a preferred top-level architecture approach, a trade analysis was conducted using the stated MDOT criteria and several candidate architecture configurations. Architecture configurations considered include [l] centralized command and control of system functions, [2] centralized command/decentralized control, and [3] distributed processing and control. For centralized command and control configurations, all command and control of the system is performed from a central location. For centralized command/ decentralized control configurations, commands originate from a central location down to decentralized locations where the commands are executed and system elements execute local control. For distributed processing and control, strategies are established and distributed to local processors; where local processors execute command coordination and local control of system elements between local processors.

These configurations each have the potential to support ATMS/ATIS applications (i.e., traffic surveillance and control and information management and dissemination). Table 4-14 summarizes general advantages and disadvantages of each architecture configuration approach.

Table 4-14. Architecture Configuration Features

Architecture Configuration	Traditional Application	Advantages	Disadvantages
Zentralized Command and Control	Traffic Control Systems Fleet Management Systems Military Command Centers	- Raw surveillance data available at operations center for reduction. - Real-time supervisory command and control over all field functions. - Simple field components/sensors.	- Large communications requirement for data collection and control. - Large processing capacity required at central master to coordinate data collection. - Limited growth capability (function of processing/ communication capacity @ central master). - Relatively high implementation and recurrent costs
Centralized Command/ De-centralized Control	Traffic Control Systems Air Traffic Control Systems Automated Assembly Liies Military Strategic Missile Systems	- Real-time supervisory command over all distributed functions. - Localized control processing. - Preprocessed MOEs to central master. - Broad range of communication link options due to lower bandwidth requirements. - Modular growth capability.	- Complex field components/ sensors. - Limited central control. - Complex field processing functions.
Distributed Processing and Control	Automated Factory/ Inventory Systems Modem Electronic Manufacturing	- Supervisory command over all distributed functions - non real-time. - Localized command and control processing. - Preprocessed MOEs to central master. - Modular growth capability.	- Complex field components/ sensors. - Complex field processing functions. - Relatively high development and implementation costs. - Limited non real-time central control. - High inter-node communications.

Trends of typical and anticipated traffic subsystem procurement costs are illustrated in Figure 4-10. These trends identify costs related to implementation of subsystem equipment and hardware. Operations and maintenance costs of system are directly related to the structure of the architecture (i.e., communications) and types of hardware used.

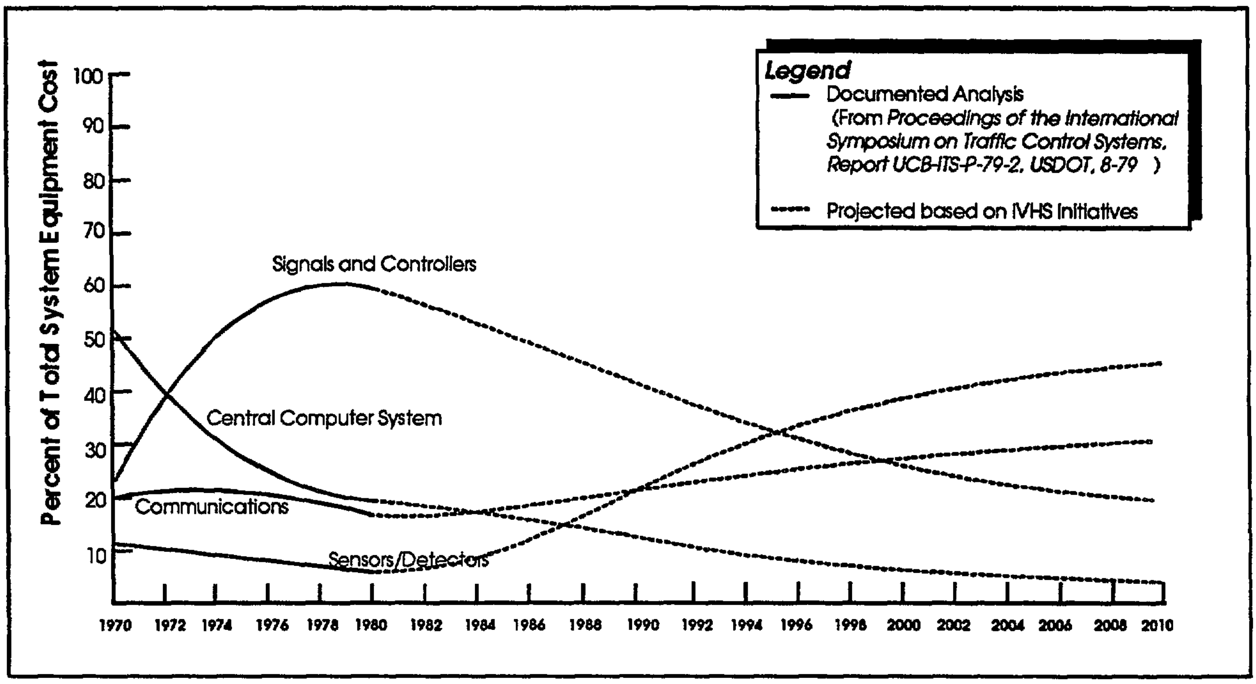

Figure 4-10. Relative Procurement Costs for Major TMS Subsystems

4.4.2 Evaluation of Architecture Approaches

The three basic architecture configuration approaches were evaluated based upon the criteria listed in Table 4-13. In general, the architectures were evaluated in terms of relative assessments for computer processing, communications bandwidth, hardware and software complexity, technology adaptability, configuration expandability, and implementation, operations and maintenance cost. A relative assessment approach was chosen in order to be consistent with the qualitative nature of the architecture attributes as specified by the system goals and objectives. This qualitative approach provides a comparative measure without detailing implementation-specific architecture configurations. In this fashion, architecture attributes are used in conjunction with the functional processes and performance requirements to define the architecture partitioning drivers. An architecture that is implementation-neutral provides modularity in functional processing and operation while offering adaptability through defined (standardized) interfaces, and flexibility and expandability in configuration. Modularity and standardization in architecture design also promotes cost-effective operations and maintenance.

Table 4-15 identifies and compares each architecture configuration relative to system processing capacities, openness, technology adaptability, flexibility, expandability, and cost-efficiency (i.e., implementation, operations, and maintenance).

Table 4-15. Architecture Configuration Approach Comparisons

Architecture Attributes	Centralized Command and Control	Centralized Command / Decentralized Control	Distributed Processing and Control
Required Processing Capacities	@ central master	@ central master and local nodes	@ central master and local nodes
Surveillance MOE Processing	high @ central master	medium @ local nodes	high @ local nodes
Traffic Control Processing	high @ central master	low @ local nodes or central master	medium @ local node to node coordination
Communications Bandwidth	high - critical timing for central communications	medium - sensor to local node. medium - local node to central master	medium - sensor to local node medium - node to node coordination low - local nodes to central master
System Complexity			
- Hardware	high - central master computing capacity	medium - central master medium - local nodes	medium - central master medium - local nodes
- Software	medium - time critical communications management	medium - central master medium - local nodes	medium - central master high - local nodes
Technology Adaptability	limited to central master capacity	good - based on modularity	good - based on modularity
- surveillance	limited - modular component	good - modular component	good - modular component
- communications	limited	good - modular component	good - modular component
- motorist information	limited	good - modular component	good - modular component
- incident mgmt.	good - data and capacity availability	good - integrated @ central master	good - integrated between local nodes and central master
- information mgmt.	limited to central master capacity	good - modular component to central master	good - modular component to local nodes or central master
Configuration Flexibility (Modularity)	limited due to centralized processing and critical communications	good - modular components - sensors - communications - processing platforms - data management platforms	good - modular components - sensors - communications - processing platforms - data management platforms
Costs			
- Implementation	medium	medium	high
- Operations	high	low	low
- Maintenance	medium	low	low

Institutional Issues Relating To ATMS/ATIS Deployment

Additional considerations which influence the architecture approach and deployment exist within the non-technical area and may provide reasons to avoid certain conditions or situations to enhance system acceptance and inter-agency cooperation. (Suggested roles and responsibilities of other agencies are also discussed in Section 4.2; System Operations.) These considerations are identified in following paragraphs.

a. ATMS/ATIS Technology Deployment. Advanced technologies in computer processing and communications can significantly reduce travel delays, provide coordinated incident management, and improve safety. However, the acceptance of deployment of these technologies has been proceeding slower than implementation of high technology components into automobiles. This action can potentially be attributed to the fact that implementation of ATMS/ATIS components on roadways are almost exclusively the responsibility of the public sector.

Streets and highways which are deployed with ATMS and ATIS technologies are under the jurisdiction and control of state and local governments. In most cases, more than one government jurisdiction is involved. Therefore, the cooperation and coordination among various level of government and different departments within government is necessary.

b. Inter-agency Coordination. Negotiations and institutional arrangements is actually a larger task than the technology implementation phase itself. However, the task of developing inter-agency relationships and cooperation must precede the installation and operations of ATMS and ATIS. The metropolitan Detroit area participants have taken the first step in creating such relationships by assembling the Metropolitan Detroit Incident Management Coordinating Committee. Monthly Early Deployment of ATMS/ATIS status meeting are also convened to keep various agencies within deployment jurisdictions of the progress abreast of the implementation architecture, operations, and deployment corridor selection. A draft memorandum of understanding is included in Appendix III.

c. Technology Barriers. Key aspects of ATMS/ATIS technology deployment are not only system design, technology selection, and installation; but are also operations and maintenance. Traffic engineers who are employed by state and local governments have a significant role in making ATMS/ATIS deployment a success. These traffic engineers, most of whom had early training as civil engineers, may not have complete understanding of deploying advanced technologies of computers and communications. However, they do have the knowledge and understanding of traffic operations needed to assure that new technologies be applied to solve current operational problems. Even though the electrical and computer engineers designed the ATMS/ATIS using system components of advanced technologies, it is traffic engineers who have the understanding of the traffic system that will apply these technologies. Therefore, cooperation and understanding between system designers and system users must be strictly maintained.

d. IVHS Application. Not all Intelligent Vehicle-Highway Systems (IVHS) components face the level of institutional barriers. Advanced traveler information systems, advanced public transportation, and commercial vehicle operations are examples of IVHS components which have minimal institutional ties. Decisions to purchase in-vehicle navigation systems can be decided by a single person and the decision to deploy advanced communication systems on board commercial vehicle operations or public transportation can be made by fleet managers. Decisions involving the use of public road, however, are more difficult since responsibilities are spread among different levels of government and different agencies within government.

An example of such difficulties are areas where ATMS are deployed among state controlled highway systems and city or local government controlled arterial systems. Highway ATMS may divert significant volumes of traffic onto arterial streets to support highway incident management strategies. Many local agencies view that their role is to provide the adjacent street system to absorb diverted traffic. A truly integrated ATMS would integrate freeway operations and the arterial street traffic control systems so both operations benefit. Such integration, however, may be difficult due to different agency priorities of utilizing public funds to support the inevitable increase in traffic demand.

e. Incident Management. Incident management can be considered one of the most important aspect of ATMS. Incident management activities must be coordinated among agencies to properly respond to motorist emergencies, accidents, and other travel delay causing events. Some institutional issues involving the incident management component of ATMS are:

- Legislative encouragement is needed to remove vehicles from immediate accident scenes for accident reporting
- Who takes control of an incident scene
- Removal of abandoned vehicles must be accomplished in a timely manner (faster than the current 48 hour requirement)
- Budgets for or means to recover over-time pay for responding personnel
- Standardize jurisdictional boundaries
- Elevate incident management to a higher level priority for responding agencies
- Make funds available to upgrade and maintain alternate routes
- Require periodic vehicle safety inspections to help prevent incidents
- Enforce a minimum speed limit on freeways to reduce congestion
- Cite motorist for running out of fuel on major freeways
- Allocate a common communications channel or frequency for inter-agency communications (i.e. state, local, and international access)
- Search for means of compensating service patrols (tax credits, public funding, fuel tax, etc.)
- Coordination of any construction projects which may impact system capacity
- Benefits from cooperative participation should be advertised

f. Other Institutional Functions. Other government administrative departments such as human resources, accounting, information systems, finance, purchasing, and legal departments are other groups who need to participate in ATMS/ATIS deployment. These organizations are important in providing operational support and planning.

Functional Relationship to USDOT FHWA National IVHS Architecture User Services

In addition to the attribute and non-technical assessments, the architecture and functional constituents were also compared against the USDOT FHWA National IVHS Architecture User Services Requirements (dated October 13, 1993). The table maps currently-identified low-level MITS (architecture) functions into the structure of identified National IVHS Architecture User Services. The objective of this mapping is to identify synergism between MITS functionality and the 27 identified user services. But, due to the high-level nature of the IVHS User Services, multiple low-level functions were found to be contained within the scope of a single service, or fragmented over several services. Table 4-16 provides an index for each of the 27 user services. A summary of this comparison is illustrated in Table 4- 17.

Table 4-16. National IVHS Architecture User Service Index

#	USER SERVICE
1	Pre-Trip Planning
2	Driver Information
3	En Route Transit Advisory
4	Traveler Service Information
5	Route Guidance
6	Ride Matching and Reservation
7	Incident Management
8	Travel Demand Management
9	Traffic Control
10	Electronic Payment Services
11	Commercial Vehicle Preclearance
12	Automated Roadside Safety Inspection
13	Commercial Vehicle Administrative Process
14	On-Board Safety Monitoring
15	Commercial Fleet Management
16	Public Transportation Management
17	Personalized Public Transit
18	Emergency Notification and Personal Security
19	Public Travel Security
20	Emergency Vehicle Management
21	Longitudinal Collision Avoidance
22	Lateral Collision Avoidance
23	Intersection Collision Avoidance
24	Vision Enhancement for Crash Avoidance
25	Safety Readiness
26	Pre-Crash Restraint Deployment
27	Automated Vehicle Operation

Table 4-17. IVHS User Service Mapping

Low-Level Function		I V H S U S E R S E R V I C E																									
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1.2.1.1.1	Perform Vehicle Detection									✔																	
1.2.1.1.2	Calculate Corridor MOEs									✔																	
1.2.1.1.3	Manage Corridor MOEs									✔																	
1.2.1.1.4	Display Corridor MOEs								✔	✔																	
1.2.1.1.5.1	Collect Video Images									✔																	
1.2.1.1.5.2	Control Video Images							✔		✔																	
1.2.1.1.5.3	Display Video Images							✔		✔																	
1.2.1.2.1.1	Determine Ramp Control Mode				✔			✔		✔																	
1.2.1.2.1.2	Provide Ramp Metering Mode Options							*		✔																	
1.2.1.2.1.3	Provide Ramp Metering Activation Control									✔																	
1.2.1.2.1.4	Provide Ramp Control							*		✔																	
1.2.1.2.1.5	Provide Integrated Corridor Ramp Control							*		✔																	
1.2.1.2.2	Display and Control Changeable Messages							*		✔																	
1.2.1.3.1	Perform Incident Detection		✔					✔		✔																	
1.2.1.3.2	Provide Incident Verification Capabilities							✔													✔						
1.2.1.3.3	Record and Manage Incident Information							✔																			
1.2.1.3.4	Facilitate Incident Notification and Response							✔																			
1.2.1.3.5	Facilitate Incident Response and Removal Coordination							✔													✔						
1.2.1.3.6	Perform Incident Traffic Management							✔								*					✔						
1.2.1.3.7	Disseminate Incident Information	✔	✔	*	✔	*		✔	✔	✔																	
1.2.1.4	Perform Wide-Area Traffic Coordination		✔		✔			✔		✔																	
1.2.1.5	Perform Work Zone Management				✔			✔		✔						✔	✔				✔						
1.2.1.6	Perform Traffic Demand Management				✔	*		✔		✔						*											
1.2.2	Display Traffic Network Status								✔							*	*	*			✔						
1.2.3.1	Collect Traffic and Travel Information	✔			✔					✔																	
1.2.3.2	Manage Traffic and Travel Information				✔																						
1.2.3.3.1	Provide Dissemination and Access Mode Control				✔																						
1.2.3.3.2	Support Information Clearinghouse Activities	✔	✔		✔			✔		✔																	
1.2.4.1	Monitor Traffic Network Performance	✔	✔	✔	✔			✔																			
1.2.4.2.1	Perform Routine Status Monitoring								✔	✔																	
1.2.4.2.2	Determine System Malfunction				✔					✔																	

✔ - denotes direct service support; * - denotes indirect service support

Each architecture configuration is assessed against the criteria listed in Table 4-13 and assigned scores using a scale of 10 to 1; where 10 completely satisfies the criteria, and **1** does not satisfy any aspect of the criteria. Scores are assessed based upon currently known capabilities and application maturity. Table 4-l 8 defines the evaluation scoring guidelines for assessing each architecture configuration approach..

Table 4-18. Evaluation Assessment Guidelines

Level of Evaluation	Score
Exceeds Criteria	10
Fully Satisfies Criteria	9
Good Compliance with Criteria	8
Above Average	7
Average Compliance	6
Minimum Requirement Satisfied	5
Marginal Satisfaction	4
Partial Satisfaction	3
Poor Satisfaction	2
Does Not Satisfv	1

Once individual attribute categories are scored, each score is multiplied by its corresponding weight factor to obtain a weighted score. All weighted scores are then summed for a total score. The largest score identifies the best approach/option based upon current technology capabilities and related costs. Evaluation scores for this trade analysis are summarized in Table 4-19.

Table 4-19. Architecture Approach Trade-off Summary

		Scores		
Evaluation Criteria	Weight Factor	Central Command and Control	Central Command/ Decentral Control	Distributed Processing and Control
Supports current and future functional capabilities	10	score = 6 subtotal = 60	score = 9 subtotal = 90	score = 9 subtotal = 90
Cost-efficient to implement, operate, and maintain	10	score = 7 subtotal = 70	score = 9 subtotal = 90	score = 7 subtotal = 70
Supports growth capabilities	9	score = 6 subtotal = 54	score = 9 subtotal = 81	score = 9 subtotal = 81
Flexible to configure (modular)	8	score = 7 subtotal = 56	score = 9 subtotal = 72	score = 10 subtotal = 80
Adaptable to evolving technologies	8	score = 7 subtotal = 56	score = 8 subtotal = 64	score = 8 subtotal = 64
TOTAL SCORES		296	397	385

For this assessment, a centralized command, decentralized control architecture approach indicates the best balance for an ATMS/ATIS serving Metropolitan Detroit. This approach allows the system to be commanded from a central location (DFOC), and those commands are executed by local controllers/processors within the corridors.

4.5 Baseline Architecture Description

The objective of the Baseline Architecture is to develop the system framework on which to implement traffic sensors, instrumentation, and controls, controllers, communications, operations command and control, and traffic information processing and management for the greater Metropolitan Detroit freeway network. This system will expand MDOT's current traffic management capabilities to priority corridors to promote traffic mobility and highway safety on the freeway network

With the centralized command, decentralized control architecture approach, certain system constraints are levied. The communications path between the central facility and field locations require only command and summary data traffic. An assumption is made that pre-processing and local control takes place in the field to **allow** for a lower communications bandwidth requirement with the central facility. Only summary data and status-type reports are returned to the central facility for further processing.

With the use of these processing constraints, an allocation was developed for all identified functions. Three levels of processing were defined to accommodate central processes, node-level processes, and line processes. Central processes interface with a system operator, provide "strategic" level commands to nodes and field components, and provides the functions to manage traffic and travel information. Node-level processes provide the collection point for data, and execute commands issued from the central processes. Node-level processes also perform data processing to "package" data summaries and monitor equipment status. Line processes provide the "tactical" controls for the traffic manager.

Based upon performance levels, the functions identified in section 4.3.2 have been analyzed and allocated to different processing levels as listed in Table 4-20. It is noted that some functions are allocated to multiple levels. In those cases, the functions have been identified to potentially reside in more than one level based upon potentially different implementation approaches. This characteristic supports the architecture attribute for flexibility to allow implementation of varying degrees of technical capability.

This allocation provides the basis on which to examine processing and communication requirements for the system A goal to minimize the amount of "raw" traffic surveillance data required at the central facility was the primary criteria used in this examination. An illustration of this allocation is depicted in Figure 4- 11.

Table 4-20. ATMS/ATIS Functional Allocation

Function Name	Central Process	Corridor Process	Line Process
Perform Traffic Network Surveillance and Control	N/A	N/A	N/A
Perform Mainline Flow Surveillance	N/A	N/A	N/A
Perform Vehicle Detection			✔
Calculate Corridor MOEs		✔	✔
Manage Corridor MOEs	✔		
Display Corridor MOEs	✔		
Perform Video Surveillance	N/A	N/A	N/A
Collect Video Images			✔
Video Image Control	✔	✔	✔
Display Video Images	✔		
Perform Mainline Flow Control	N/A	N/A	N/A
Perform Mainline Ramp Control	N/A	N/A	N/A
Determine Ramp Control Mode	✔		
Provide Ramp Metering Mode Options	✔		
Provide Ramp Metering Activation Control	✔		✔
Provide Ramp Control			✔
Provide Integrated Corridor Ramp Control	✔	✔	
Display and Control Changeable Messages	✔	✔	
Facilitate Incident Management Tasks	N/A	N/A	N/A
Perform Incident Detection	✔	✔	
Provide Incident Verification Capabilities	✔		
Record and Manage Incident Information	✔		
Facilitate Incident Notification and Response	✔		
Facilitate Incident Response and Removal Coordination	✔		
Perform Incident Traffic Management	✔	✔	
Disseminate Incident Information	✔		
Perform Area-Wide Traffic Coordination	✔		
Perform Work Zone Management	✔		
Perform Traffic Demand Management	✔		
Display Traffic Network Status	✔		
Perform Traffic and Travel Information Management	N/A	N/A	N/A
Collect Traffic and Travel Information	✔		
Manage Traffic and Travel Information	✔		
Disseminate Traffic and Travel Information	N/A	N/A	N/A
Provide Dissemination and Access Mode Control	✔		
Support Information Clearinghouse Activities	✔		
Perform System Performance and Malfunction Monitoring	N/A	N/A	N/A
Monitor Traffic Network Performance	✔	✔	✔
Perform System Malfunction Monitoring	N/A	N/A	N/A
Perform Routine Status Monitoring	✔	✔	✔
Determine System Malfunction	✔	✔	✔

During the period where new corridors are being instrumented and brought on-line, the architecture must be able to accommodate a coexistence of existing SCANDI equipment and new equipment. A transition period will provide the operational changeover form SCANDI to the new system.

DFOC operations will require integration of the different existing traffic subsystems (i.e., CMSS, HAR/AHAR, SCANDI, CCTV, and system operations) and new subsystems HAR control. The approach to integrate these subsystems relies upon a modification of the current operations. This is meant to functionally integrate those functions which are currently operated on an individual basis. In addition, the new DFOC operations environment will include an additional capability to collect, manage, and disseminate traveler information.

Integration of new corridors the inputs and outputs of the three relatively independent subsystems, (i.e., video monitor/camera, CMS, and traffic surveillance and control), must be isolated for independent communications and routing control; however, Tie-Division Multiplexing (TDM) of the various controls and status will accomplish the modulation required to interface with the current RF cable system Selection of where TDM is performed is based primarily on implementation cost and minimizing impacts to existing resources. Candidate locations for TDM include locations where the existing SCANDI system is used as a communications link to the DFOC headend.

4.51 Modifications to Current Subsystems and Additional Equipment

Deployment of the Baseline Architecture shall require equipment modifications and additions to provide traffic surveillance and control and information capabilities to the priority corridors. The following paragraphs describe the nature of these modifications and additions.

General Hardware Modifications. Additional headend communications hardware and DFOC information server equipment will be required to implement the Baseline Architecture. These primarily involve new communications and modulation equipment to receive traffic data and equipment status from field controllers and transmit traffic control commands to the same controllers.

New instrumentation to be installed in the corridor infrastructure includes controllers, communications equipment, vehicle detection sensors, signal heads, variable speed signs, changeable message signs, highway advisory radio transmitters, and other ancillary equipment.

General Software Modifications The Concurrent computer will remain the central computing resource in the DFOC, however, it will no longer be required to collect and calculate individual vehicle detection station MOEs, and control entrance ramp operations. The Concurrent computer will provide the command platform to conduct overall traffic operations ranging from corridor link performance and status monitoring, areawide incident detection, and areawide traffic control strategy development. In addition, the computer may be used to perform traffic demand prediction through the use of scheduling data received from traffic generators such as employment sites, special events, or highway maintenance and construction zones. The current GDS system will be augmented and modified to display the entire Metropolitan Detroit freeway and tnmkline network and provide an integrated user interface platform for the entire ATMS/ATIS.

Software will be developed to interface the additional sensors, ramp controllers, video cameras, and CMS and HAR resources to provide, as a minimum, the same capabilities in the current system.

The current Graphic Display Subsystem (GDS) software and database shall be modified to process traffic network and system status on a more operator-timely basis. Waiting time for new map screens, lower-level mainline flow details, and traffic flow updates will be reduced to display the current traffic and system status at the time of the request.

Due to the decentralized command approach, it is noted that when intelligent remote ramp controllers are used (as opposed to central control of the ramp activities on a 250 ms basis), it may not be possible to provide the low-level vehicle passage and ramp signal on/off information for real-time display, and that this capability, when weighed against communications and other costs, may not provide much value-added benefits. If low-level operations are needed, monitoring of vehicle passage may be obtained through CCTV. If the ramp display capability is important for diagnosis of incidents and system faults, generation of the necessary GDS inputs at 250 ms intervals for a specified ramp may be provided by software simulation on the Concurrent central computer, based on the ramp flow volume, metering rate, queue and demand information received from the ramp controller during the last reporting interval.

4.5.1.1 Sensor Requirements

Additional sensors to monitor traffic volume and occupancy shall be compatible with existing inductive loop resources. The sensors shall cover all lanes of the freeway in both directions. The sensors shall be capable of sensing all vehicle types from motorcycles to multiple-trailer trucks traveling at speeds from 0 to 100 mph. The sensors shah provide reliable detection under all environmental conditions possible in southeast Michigan including rain, snow, ice, fog (with visibility greater than 25 feet) and clear conditions at air temperatures from -25 to +120 degrees Fahrenheit.

4.5.1.2 Sensor Processing

Local processing of sensor information shall be provided in the roadway infrastructure to yield total volume, average occupancy, and average speed (using "timing gates", where required) at a minimum interval of 10 seconds and a maximum interval of 20 seconds. The resulting data shall preserve individual lane information consistent with current system formats. The data shall contain all required information, including time tagging, so that it is usable (possibly after conversion / combination) by the existing 3280MPS algorithms to provide data fusion into 1 minute periods at 20 second intervals.

Status of the remote sensor subsystems shall be provided at the same interval as the sensor information to enable fault isolation to the field replaceable unit (Line Replaceable Unit {LRU}) level. The subsystems shah be capable of maintaining and outputting additional status information, upon request, to isolate malfunctions and faults to the lowest circuit card / shop replaceable unit (SRU).

4.5.1.3 Ramp Control Processing

Local autonomous entrance ramp control shall be provided at those ramps which are designated for that purpose. The ramp control shah be operational without the need for any special commands from the DFOC to provide, as a minimum, a (pre-set) vehicle entrance rate of from 4 to 15 vehicles per minute (vpm) at a minimum of 2 (pre-set) time of day (TOD) intervals. Metering rates and TOD schedules shall be downloadable from the DFOC.

a. The ramp control subsystem shah accept commands from the DFOC to modify the time and rate settings within specified intervals including full start-up and shut-down override operations.

b. The ramp control subsystem shall maintain occupancy and volume information, even when flow is not being regulated. The ramp control subsystem shall be capable of sending status information to the DFOC at a rate of 10 seconds minimum to 20 seconds maximum containing, at a minimum, the following:

1. Ramp identification
2. Ramp occupancy
3. Ramp traffic volume
4. Current metering rate
5. Time tagging information / sequence number
6. Subsystem status which allows fault isolation down to the LRU

c. The ramp control subsystem shah be capable of maintaining and outputting additional status information upon request to isolate faults down to the lowest circuit card / shop replaceable unit (SRU).

4.5.1.4 Changeable Message Sign Processing

New CMS resources will be added to the system. They shall be compatible with the existing CMS monitor and control subsystem. Software changes to the CMS control system to incorporate the new CMS shall be limited to database updates necessary to bring the new CMS on-line. Operator command will be enabled through an integrated user interface.

4.5.1.5 Video Surveillance

Full-motion video shall be provided at those locations designated for surveillance. The infrastructure shall accommodate a 6 MHz video bandwidth using standard NTSC video. The video signal(s) shall be routed to the MDOT DFOC at the nearest junction point to the new equipment using spare existing cable capacity wherever possible.

4.5.1.6 Communications

Communications between corridor processing and the DFOC shall be designed to provide the following capabilities for each corridor (as a minimum).:

a. Sufficient communications bandwidth capability shall be designed into the each deployment corridor to provide full-motion NTSC video signals and bi-directional data transfer.

b. Communications facilities shall be provided for one-way video transfer to the DFOC, remote camera Pan-Tilt-Zoom (PTZ) and camera switching, communication with entrance ramp meter controllers on a 10 second minimum interval, processed (volume, occupancy, speed, status) inputs from mainline detectors on a 10 second (minimum) interval, and control / status collection from Changeable Message Signs (CMSs).

c. Sufficient processing capacity shall be available for control of Highway Advisory Radio (HAR) transmitters.

Each corridor deployment shall not require more than 50 percent of the design communications capacity. The remainder is reserved for future expansion. Alternative temporary communication facilities, such as wireless radio or leased lines, may be considered to enable quick deployment.

The Baseline Architecture will use an entirely new communications networking system to cover the extended ranges required to communicate with field components. This new system is required to accommodate the vast expanse through the Metropolitan Detroit areas with additional growth and expansion capabilities. When a communications “backbone” media is embedded on one side of a roadway, the use of short-distance wireless communication from equipment cabinets located on the backbone side to equipment cabinets located on the opposite side of the roadway shall be weighed against the life-cycle cost (LCC) of trenching across the freeway for the installation of fixed wire / fiber link required to reach the backbone. Similarly, the life cycle costs of using wireless communication methods from video cameras to a nearby cabinet shall be weighed against the installation of fixed lines for both video signal return and camera PTZ controls.

Because pre-processing of sensor inputs and autonomous operation of ramp controllers is specified, the communication bandwidth for these functions will be quite low and well within the capability of UHF, VHF packet or spread-spectrum radios. CMS communications could also be handled within this bandwidth or the current CMSS. The primary communication difficulty is with the full-motion video. Even using compression techniques, a minimum of 1.5 MHz bandwidth (T1 Carrier) is currently required

Commercially-available means for communicating with cameras using short-distance wireless radio is available. Further evaluation of these means are required based upon system requirements and cost considerations. It is also possible to avoid costly trenching operations between ramp controllers on the opposite side of a roadway to the communications backbone cable or fiber using wireless radio.

4.5.1.7 Baseline Architecture DFOC / MTC Headend

Figure 4-12 shows the DFOC headend interfaces. At the DFOC, video inputs will use the existing blonder-tongue (B-T) demodulator / Vicon Switcher and video control architecture. It is envisioned that additional B-T video demodulator(s) will be required for additional corridor cameras or as the system expands beyond the current design capacity, the unit will be replaced altogether.. The Vicon equipment currently provides a sufficient number of spare ports for camera video inputs and monitor outputs.

Similarly, new camera controllers will remain compatible with the current camera control system. Some modifications may be required to the PC database to accommodate new cameras and addressing, but there should be adequate spare margin for additional cameras. The same cable frequency modulator will be used as for all other cameras, operating at a frequency of 18.1 MHz with a 56KB data rate during the transition phase, and then the entire system may be replaced to better accommodate CCTV operations on a wider scale..

The details of the new Vultron CMS controller interfaces are unclear at this time, but it is believed that the standard “modem” type of interface (TCP/IP, RS-232, RS-422) can be used as for existing wireline-connected CMS facilities. To conserve cable resources, however, this infrequent control information will be multiplexed in a straightforward manner with the (also infrequent) new ramp control parameter overrides and ramp / loop status requests. The multiplexing may be as simple as controlling the Clear-to-send (CTS) line(s) going back to the Vultron CMS controller and new Concurrent serial interface to assure that only one device is sending data at a time with a digital selector used to route the appropriate input to the output. Responses coming back from the remote CMS controllers will be routed to the Vultron CMS controller by a demultiplexing process based on a simple algorithm such as received data parity. The throughput of the 56KB RF cable modem should be adequate to satisfy the currently-programmed response requirements of the Vultron software operating on a 2400 bps wireline modem.

Since the remote ramp controllers and loop controllers contain intelligent processing, they do not need to be polled to return the ramp MOE's (occupancy, queue , and demand, flow volume, metering rate, time, status) or the loop MOE's (volume, occupancy, speed). The remote controllers are expected to send this data at their pre-set rates once commanded "on" without further polling. Commands to the ramp controllers to change metering rates or activate / deactivate metering may also be sent. The capability to poll the controllers for additional status (primarily faults) is also provided.

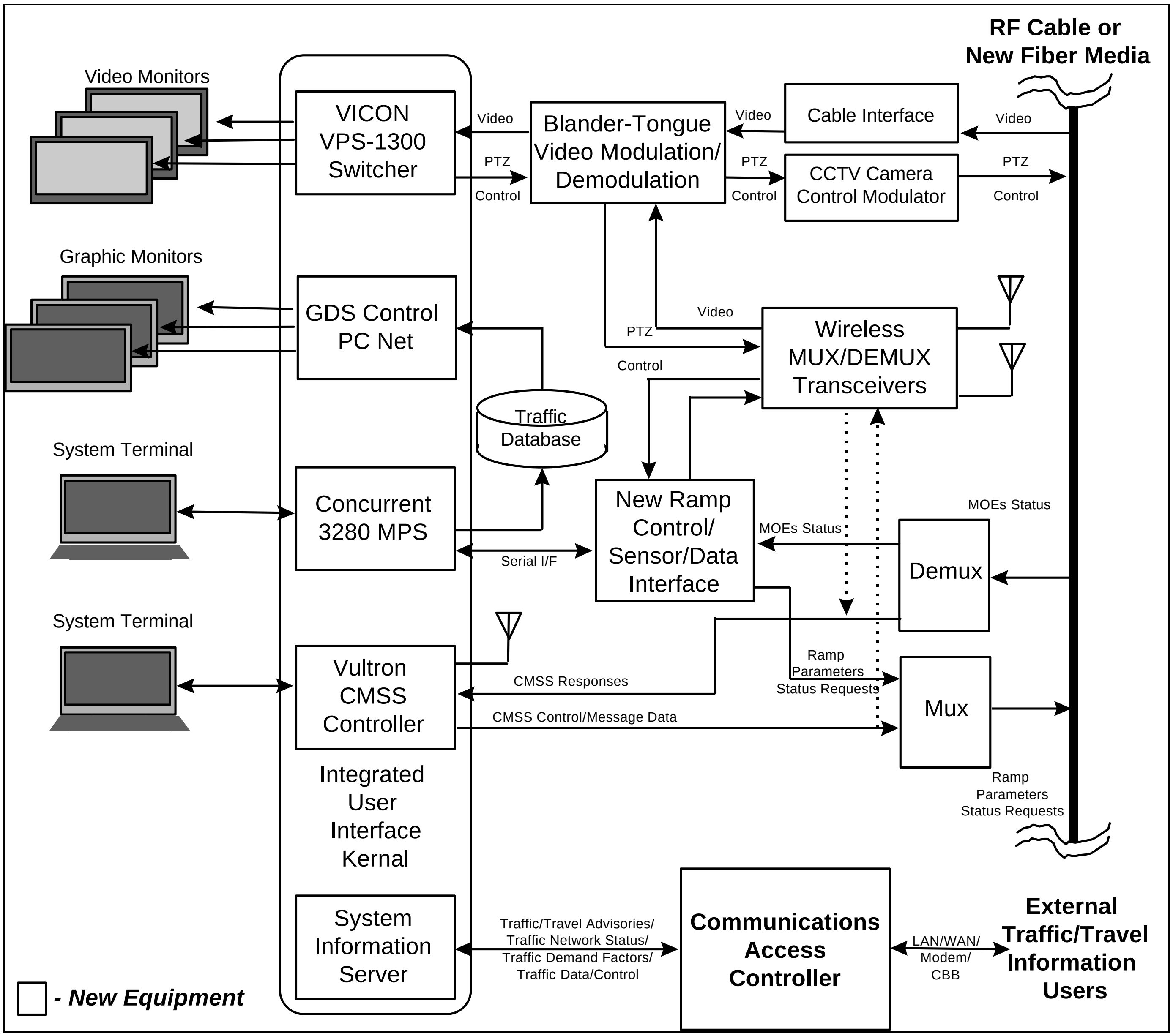

Figure 4-12. Baseline Architecture MTC/DFOCHeadend Detail

4.5.1.8 Communications Media Junction

Figure 4-13 shows the internal detail for a "junction box" which will provide the interface between differing communications media. The equipment converts between any of 3 possible communications media to media for a given node controller..

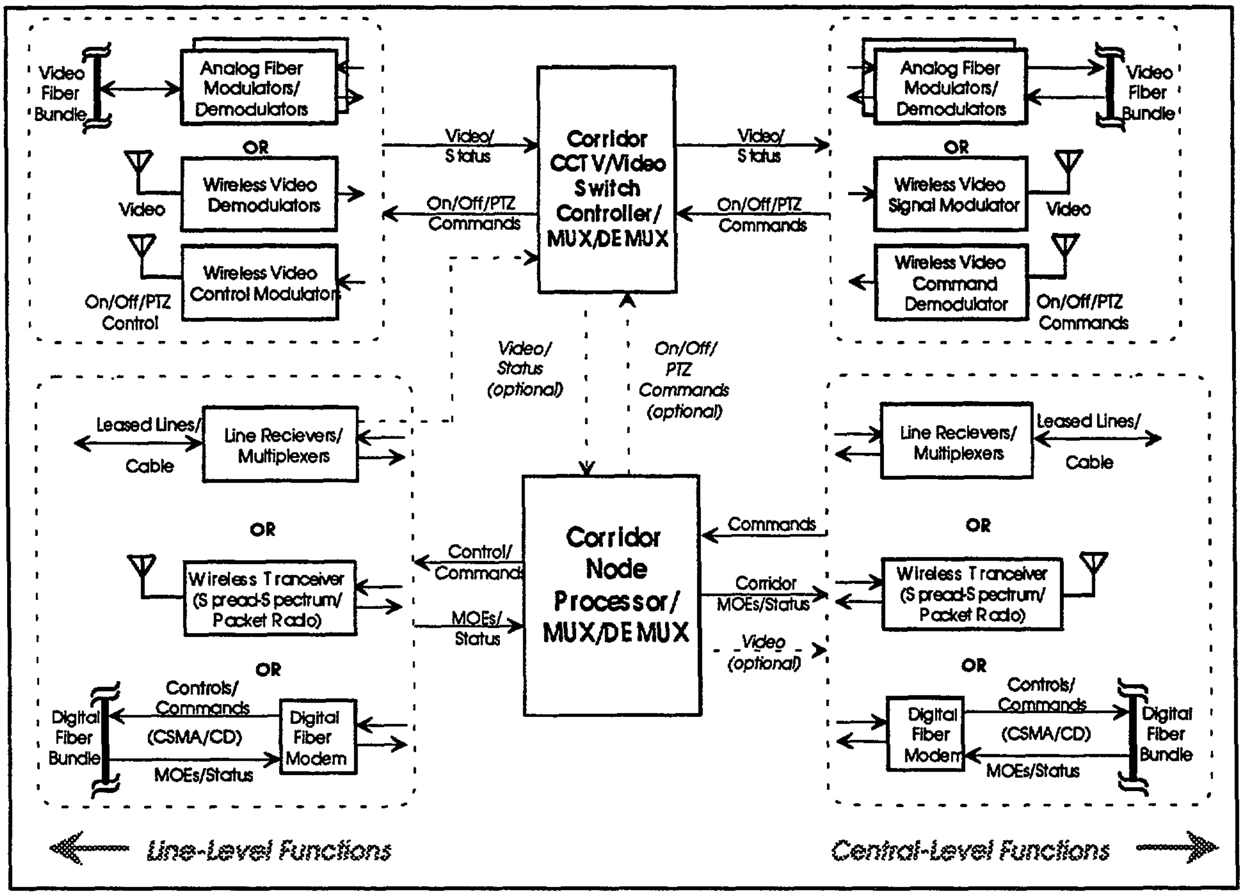

Figure 4-13. Communications Junction Node Detail

Camera video will require either fiber-optic transmission line or wireless video transmitters from remote locations or leased cable facilities. If trenching must be performed to install cable, the additional cost to use fiber-optic bundles is negligible.

Normal fiber LAN architecture details include a fiber "backbone" with "spurs" that connect with this backbone (Star configuration) at hub locations. The "spurs" run on a separate fiber bundle (or even wireline cable) to somewhere between 8 and 15 nodes. This type of architecture usually has a hub every 4 or 5 miles along the fiber backbone so that a smaller number of nodes will be impacted should there be a break in the spur (or in the event a cabinet is damaged by maintenance crews knocking it over, as sometimes happens). Since some corridors already have conduits for the SCANDI system, it is proposed to dispense with the expense of a backbone / hub architecture and simply run the fiber through the conduit for those corridors with a conduit run.

Since remote sensors, CMS, and ramp controllers require a much smaller bandwidth, the option exists to use wireless media such as spread-spectrum radios or packet radios as well as leased (or switched) voice-grade wirelines. This is reflected in the figure, where options exist for bringing in data (or sending data) via radio, leased line, or a fiber digital modem (if fiber is used for the video).

4.5.1.8.1 Video Signal Return

When fiber-optic cable is available, the most cost-effective use is to allocate one fiber of a bundle for each camera chain (more than 1 camera can be in a chain) with standard COTS analog modulation / demodulation equipment. This avoids costly digitization and/or multiplexing of the signal. A camera chain consists of one or more cameras whose modulator and camera are all capable of being switched off or on via remote command Only 1 modulator at a time (using simple LED's) may be carried on the fiber. Note that COTS equipment is available which will multiplex 4 or more NTSC video signals on a single fiber. This is useful for co-located cameras, and would be an exception to the "single camera chain, single fiber" approach. The group of cameras would then be treated as a single camera for switching on or off the chain.

Multiple fibers in a bundle are used to accommodate multiple camera chains for simultaneous viewing of several locations. This technique will cover 99% of the real-time surveillance requirements where incidents statistically happen frequently at only 1 location on a chain and infrequently at others. The high-incident location would normally be selected for viewing with the others switched in or out as indicated by the received MOE's from the field sensors. This switching could even be done automatically on a round-robin **basis** to present (for example) 10 seconds of a given camera view before switching to the next camera on the chain. This would, however, require significantly more software modifications than a simple operator-commanded switch mechanism. It would also result in a fraction of a second of "black" on the monitor before the next camera were switched on, which could be aesthetically disturbing.

Demodulated video, either from the fiber or leased cable, is presented to a video chain switcher, if required, prior to being sent to a standard cable modulator for frequency-division multiplexing on the existing cable. The video switcher is required only if there are fewer cable video channels available than there are camera chains on the fibers. At the switcher, a second level switching occurs to select the chain to be sent back to the DFOC. Control for the secondary switcher will be time multiplexed with other control functions at the DFOC.

4.5.1.8.2 Video Camera Control

The camera PTZ control that is currently sent on the 18.1 MHz digital channel from the DFOC will be demodulated at junction nodes and input to a 2-way multiplexer (effectively a packet switch). The control commands occur infrequently, and can easily be combined with ramp control and status requests.

4.5.1.8.3 Ramp Control and Status Requests

These signals are demodulated from the new cable control channel (see Figure 4-5), and include both CMS control and new ramp parameter commands (and possible camera chain switching commands) from the Concurrent system. They are combined with command packets from the camera control using simple time multiplexing (store and forward packet switching) and then sent to one of the 3 optional media for output along the designated corridor.

4.5.1.8.4 MOE and Status Return:

The ramp MOE’s (occupancy, traffic volume, flow rate, time, status), and loop MOE’s (volume, occupancy, speed) are passed through from the corridor node link to the DFOC. While this is shown as passing through the multiplexer / demultiplexer, little needs to be done beyond packet relay from the remote sensors to the cable. Again, this data could arrive from any one of the three possible media, also at a nominal 56 KB rate (although data throughput would be much less due to the burst nature of the reports).

4.5.1.8.5 Communications Protocols

There are cost-effective parts available which will completely handle a Carrier-Sense-Multiple-Access / Collision-Detection (CSMA/CD) fiber access for multiple devices on the same fiber with little additional intelligence required (i.e. no separate CPU). It is envisioned that the Control Processor will be fabricated using a COTS single-board computer (possibly VME-Bus) assembly and add-on COTS I/O cards. This processor could easily handle the set-up of the CSMA/CD LSI chip, which would then take care of all transmission and reception from the fiber. The Intel standard CSMA/CD controllers are available in several configurations. No custom hardware should be necessary, but semi-custom (modified) software will certainly be required.

A single fiber in the bundle can be used to carry ALL status and MOE information from the remote intelligent controllers. These controllers would simply send a packet when data were available at their predefined collection rates. The CSMA/CD protocol would allow each remote to determine if it had been interfered with and needed to retransmit the packet. At the junction box, outgoing commands are multiplexed in the same manner on the bidirectional cable transceiver. This scheme is a form of optical LAN access which has equal applicability to leased lines or coaxial cable.

For packet radio, a modified type of access protocol would be required. Packet radio, operating at 9600 bps, could support all communication within an extended 6 mile range. The packet radio mechanism uses not only collision avoidance (i.e., listen before transmit), but also reverse acknowledgment of received data. Some modification of the AX.25 protocol could be performed to enhance throughput and connectivity, but is easily avoided with multiple-session packet Terminal Node Controllers (TNC's) located at junction nodes.

Spread spectrum protocols generally work better with a poll-response type of approach. To use this type of radio, a frame time would have to be enforced by the junction control processor (on a 10-20 second basis). Polls to all remote detection stations would be generated and the responses collected and relayed to the cable modulator. This approach is less desirable due to the larger amount of custom software development that would be required. It could be needed to support larger bandwidths (up to 250,000 bps), however, than packet radio (using the available UHF frequencies and 9600 bps speeds) can accommodate.

4.5.1.9 Inductive Loop / Other Detectors

Figure 4-14 shows a representative loop detection station node. All optional communication mechanisms are also shown for completeness. Again, only 1 of the 3 will be required in the final system (which will most likely be the fiber interface). For interim quick deployment, the optional leased line or wireless modes are also to be considered.

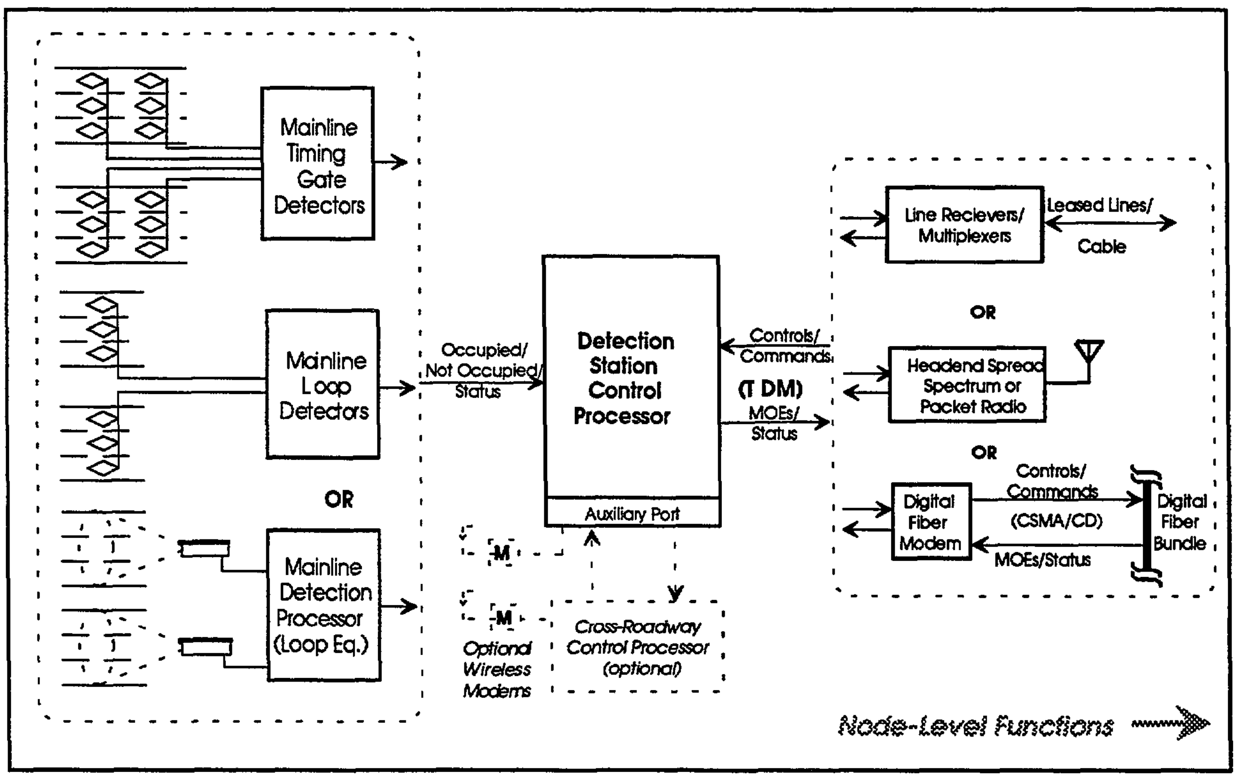

Figure 4-14. Detection Station Node Detail

This architecture is for a simple loop set from both sides of the roadway where there is no nearby ramp controller or camera. There does not need to be a co-located speed trap. If the site supports a speed trap, an additional set of loop drivers will be required to cover an 8 lane highway. For a speed trap, the processor should be programmed to also supply normal MOE's from a single set of loops (either set remotely commandable to compensate for temporary faults) along with the speed information.

Note that provision has also been made to replace some loop detectors with an equivalent system should it be necessary in certain locations due to roadway condition or other factors. The control processor should be able to handle raw loop on/off or processed data from the other detector types.

4.5.1.10 Ramp Controllers

Figure 4-15 shows the architecture within a cabinet housing a ramp control station node. This architecture is similar to that for a detection station node, but some additional I/O capabilities are required for lamp drivers, and less loop measurement capacity is required.

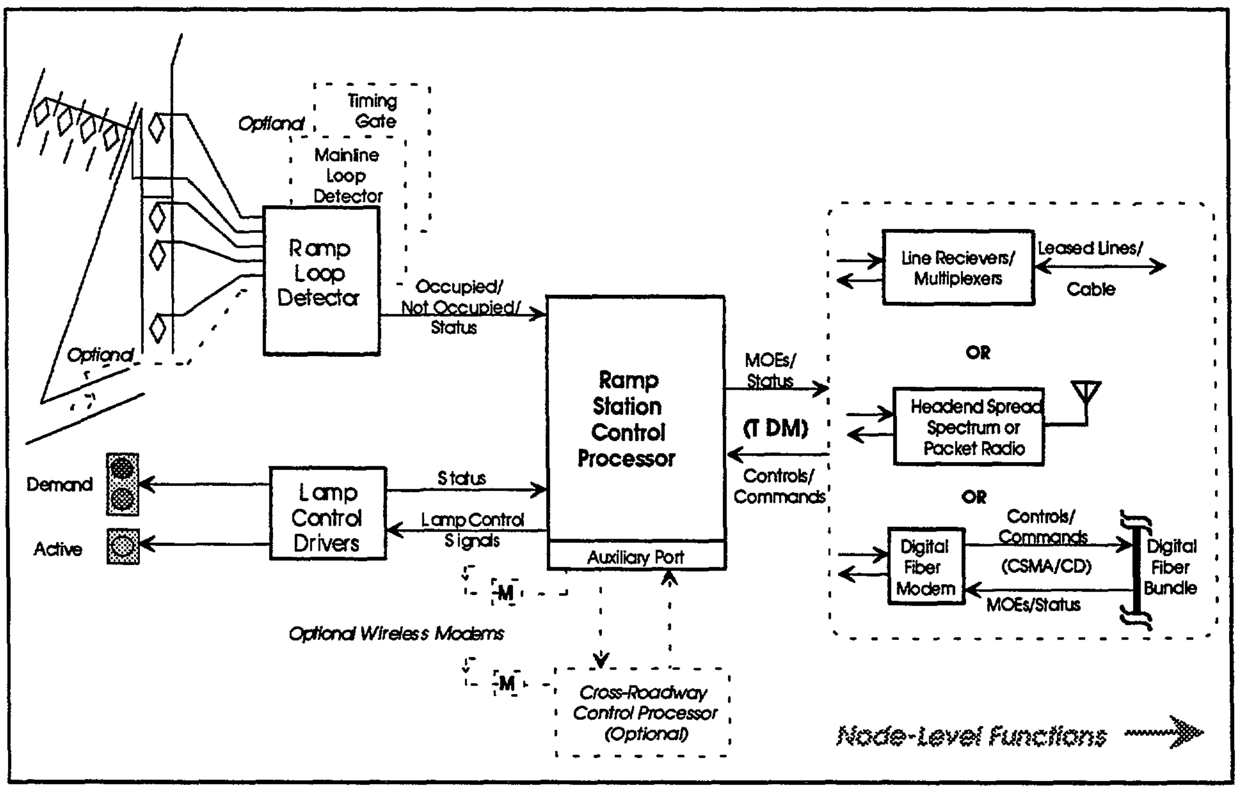

Figure 4-15. Ramp Control Station Node Detail

Additionally, since ramps are located on both sides of the roadway, and the cable/fiber will be on one side only, a wireless method is shown for passing information to and from a nearby cabinet located on the LAN. This is obviously not needed for the radio connection or a leased line. The wireless modems are simply UHF radios (such as a Motorola unit) with integral data modem. They require very little power (less than 100 milliwatts typically), so could be unlicensed if they are in the proper spectrum. However, since MDOT has a license for several UHF and VHF frequencies, it would be better to use that allocation to assure relative immunity from interference. With low power and a simple antenna (a quarter wave length of wire at the side of a cabinet would work), a single frequency could be used for all inter-cabinet cross-roadway connections.

The radios are shown under the assumption that it is cheaper to buy, install, and maintain them over a 15 year time span than it is to trench under the roadway to run a fiber / wireline extension to the backbone.

Some detail is omitted from the diagram for clarity in the use of the optional wireless modems. The fiber digital modem may require special control from a processor for setup. To avoid extra processors, it is best to provide an auxiliary port on the processor used for ramp control and detection nodes to accept input from a cross-roadway wireless modem. The processor would be responsible for receiving information for its own function as well as that of the cross-roadway "cousin". It would be responsible for multiplexing the received data onto the single fiber interface along with its own. This is also less costly than having separate fiber transceivers for each function. The detailed architecture is shown in Figure 4-16.

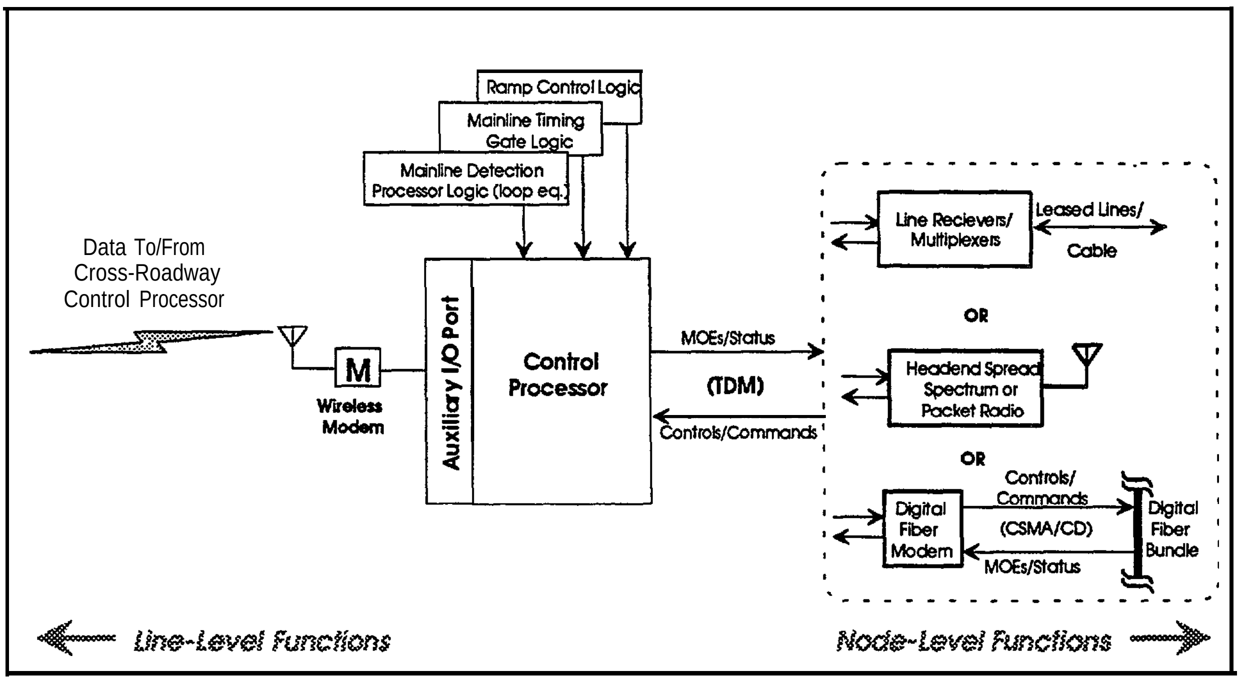

Figure 4-16. Cross-Roadway Wireless Communications Detail

4.5.1.11 CCTV Video Surveillance

This node is different than the other types since the wide video bandwidth required dictates the use of a fiber, cable, specialized wireless connection. Figure 4-17 illustrates a CCTV video / camera control node architecture. For this reason, it is assumed that the cabinet containing the control processor will be located on the fiber LAN or contain the wireless communications equipment for the video/camera control link. However, there is no reason why there cannot be a ramp controller on the opposite roadway side that uses the facilities of the control processor.

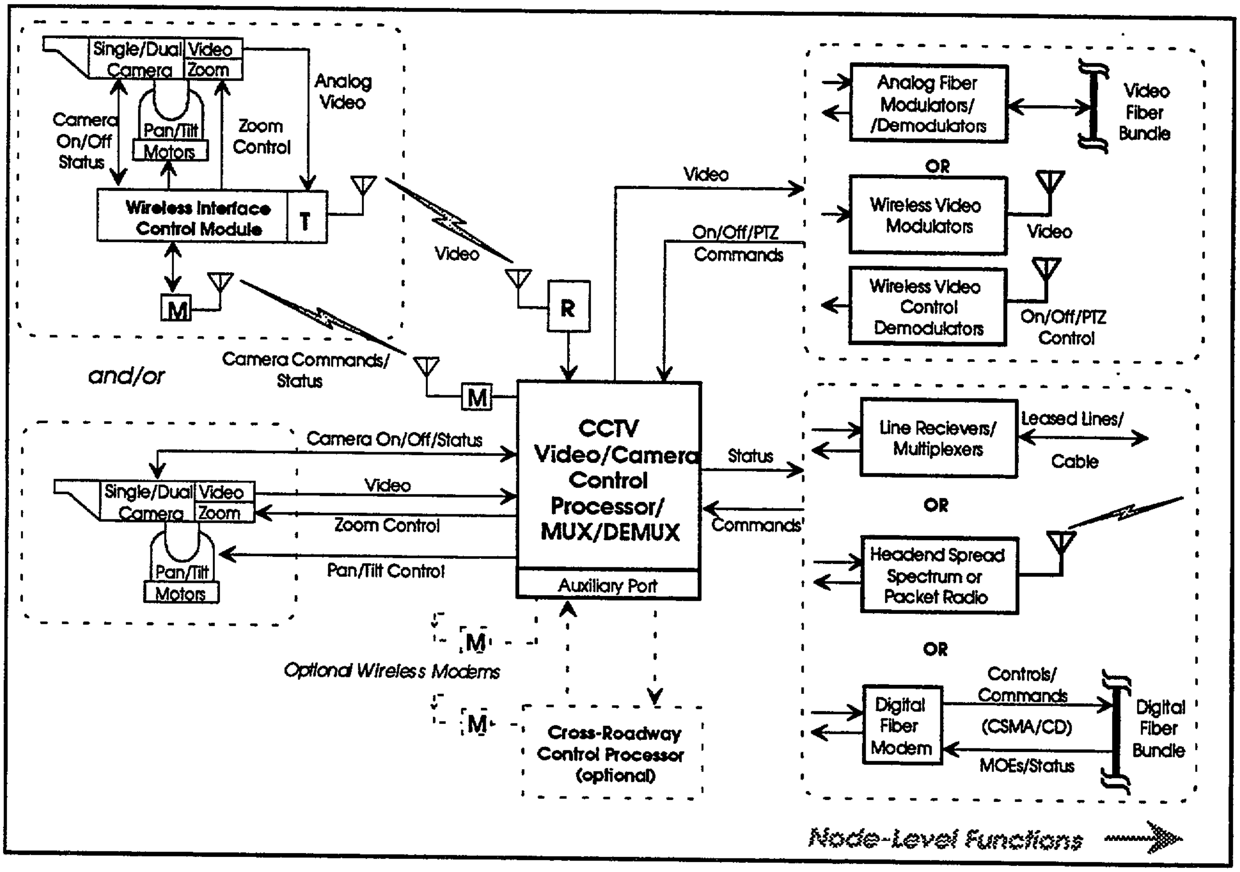

Figure 4-17. CCTV Video / Camera Control Node Detail

Provisions have been made for wireless modem and video modulator usage to link the control cabinet to the camera assembly in lieu of trenching and laying control lines and video cable. COTS wireless video transmitters (unlicensed) are available to handle the video transfer. A standard wireless modem of the type used for cross-highway links will also be required to transfer the camera PTZ commands and receive status from the remote side unless supplied with the wireless video link. If not, camera control will most likely require a special interface card to isolate the various PTZ commands from the digital data stream and route them to the proper control mechanism. A separate processor should not be required -- a control sequencer type of ASIC design will probably suffice.

If the camera is "hard wired" to the control cabinet, then separate lines will be run from the control processor I/O card for control of the PTZ functions as well as receipt of status. Video transfer will require a coax cable (to carry the baseband video signal) to the video-fiber modulator. The control processor interface software will be slightly different depending on the camera control interface type.

It should also be noted, although it is not shown in the figure, that multiple cameras could be handled by a single cabinet junction when they are located in close proximity to each other (such as on more than one side of freeway interchanges). In this case, one of the multi-channel video multiplexers will be required ahead of the video-fiber modulator and multiple camera command ports will be required from the control processor. Control processor software must be designed in a modular manner to support the decoding and routing of commands to multiple camera addresses from the common DFOC control port.

4.5.1.12 CMS / HAR Interface

The interface and control architecture for a CMS or HAR link is almost the same as that for a camera PTZ control link. There is no video interface, but the command / response interface is generically the same as shown in Figure 4-9, replacing the camera with the CMS or HAR control module. Control processor software can also be common as long as it is concerned only with command address recognition and speed buffering (i.e., packet switching) to a serial interface type. It is also conceivable that a single common control processor could handle either multiple cameras, or cameras and a CMS or HAR command / response port The function could also be combined with a ramp or loop interface.

4.5.2 Representative Control Processor Architecture

4.5.2.1 Processor and I/O Hardware

The control processor needed to satisfy the Baseline Architecture requirements should be selected for its capacity for growth potential as well as the availability of off-the-shelf modular CPU and peripheral cards. It is highly recommended that a modular chassis (e.g., VME-bus and standard card format) architecture be used. The NEMA 170 types of systems are evolving toward this standard, and interfaces from the 170 to VME configurations currently exist. However, use of a 170-type controller is probably not cost effective since growth and processing capacities are marginal in current configurations. Multiple vendors support the 680x0 VME standard, to which the NEMA 170 6800 CPU software is readily convertible. Allen Bradley has VME configuration processors and I/O cards. Many other vendors also have these, and it is probable that traffic-type operations (such as lamp drivers) and certainly fiber or cable LAN interface modules are readily available.

Figure 4- 18 shows a representative recommended internal control processor architecture. The figure shows all required modules for the Early Deployment architecture

implementation. Since a VME bus is used, many other peripheral cards for varying functions needed in the future are also easily added when required.

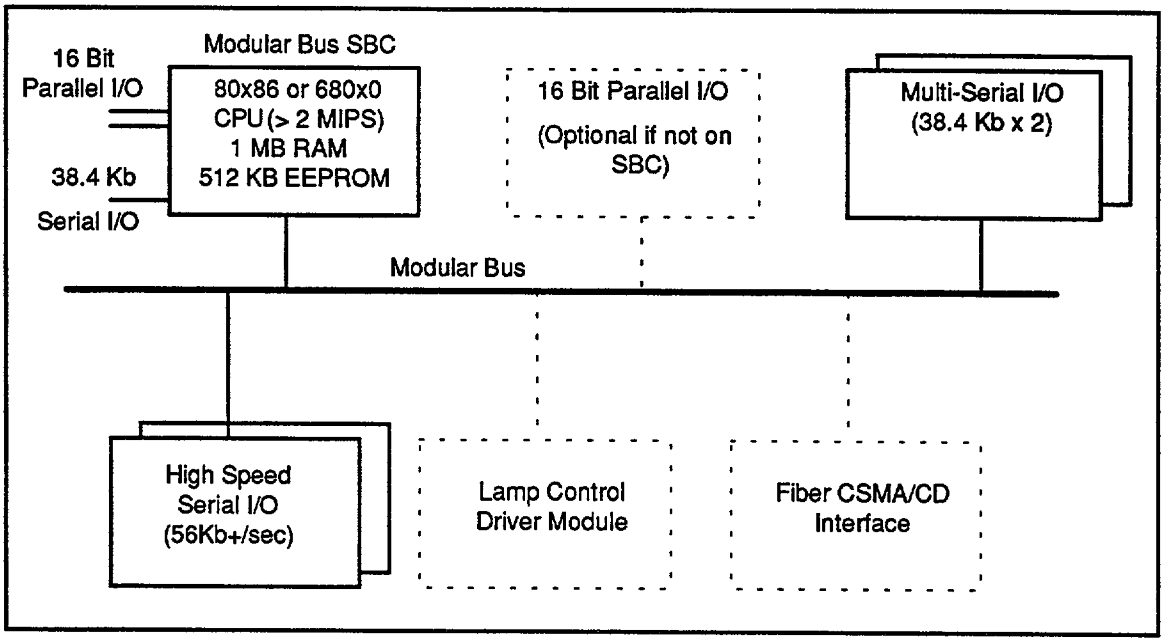

Figure 4-18. Representative Modular Control Processor Architecture

This type of architecture can be used to satisfy the requirements for Junction Nodes, Detection Nodes, Ramp Control Nodes, and Video nodes. Not all peripheral cards are required in all applications. A brief synopsis of each module follows:

4.5.2.2 Modular Single Board Computer (SBC) Module:

A large variety of modular chassis (e.g., VME-bus compatible) SBC's are currently available using both the Intel 80x86 types of processors and the Motorola 680x0 processor types. The 680x0 is preferred for commercial applications because of its compatible interface to the VME standard and upward compatibility with the current NEMA 6800 standard processor type. Abundant vendors for C compilers and 680x0 assemblers exist.

The selected SBC should have a minimum of 2 Million Instructions per Second (MIPS) throughput (easily satisfied by even the slowest 68000 board), 1 Megabyte of on-board RAM (expandable to at least 4 MB), and a minimum of 512 K bytes of Flash EEPROM for program and constant / parameter storage for non-volatility and unattended operation / automatic restart on power fault.

In addition, the board should have a general asynchronous serial I/O port with a speed rating of 1200 to 19,200 bps for connection of a local diagnostic console. A few bits of parallel I/O for general control and/or loop detector inputs should also be provided. A minimum of 16 bits is recommended, although an external (possibly multi-function) VME card could also provide these functions if not available on a cost-effective SBC. For future supportability and easy card interchange / upgrade, it is probably best to avoid dense, multi-function VME cards in favor of more modular systems which can be upgraded or repaired using "mix and match" techniques with full interchangeability from different vendors. This will also assure MDOT of easy repair / replacement in the future without the need to repeat their custom development efforts for new replacement parts when a sole-source vendor goes out of business.

The board should support full VME Direct Memory Access and control functions for high speed transfer from one port to another. Multiple DMA channels are required for simultaneous transfer of data for at least 4 ports. This is used for data packet switching and multiplexing / demultiplexing, particularly at the Junction Node (or possibly LAN hubs). Finally, the board should support at least 2 programmable counter/timers (3 is standard) for implementing a "real time" clock and other temporary timing loops for various functions.

4.5.2.3 16 to 24 Bit Parallel I/O:

This card would be used for handling inputs from standard loop detectors if used. It is required only if the SBC does not have at least 16 bits of parallel I/O. Each bit should be software configurable as either input or output, although if the majority are fixed at inputs with only a few outputs, that is sufficient.

4.5.2.4 Multi-Serial I/O:

This should be a general-purpose synchronous / asynchronous (USART or DUSART) serial I/O module with at least 2 ports on the same card. Both ports should provide, as a minimum, RS-232 drivers and receivers with RS-422 (balanced) provided as either a hardware strap option or software configurable item. Each port should have a set of RS-232 style control signals (RTS / CTS, DSR, DTR) and possibly also RING for potential use in dial-up line applications. Each port should support from 75 bps to 38.4 Kbps as a software configurable option.

These serial I/O cards (up to 2 should be provided for in the architecture) are used for the following:

- Radio Interface (spread-spectrum or packet) option,
- Leased line demodulator / demux option,
- Auxiliary Cross-Roadway wireless Modem port,
- Loop detector substitute (e.g., Autoscope, vision sensor,) input ports,
- Camera commands / status port for wireless node to camera link.

Full DMA capability is optional, but interrupt capability is mandatory.

4.5.2.5 High Speed Serial I/O:

These cards are similar to the multi-port serial I/O cards except they should have full DMA control capability. They are used only in the junction node for Camera demodulator input and Control / MOE / Status modem I/O at speeds of 56 Kbps. Up to 2 cards should be provided for in the architecture.

4.5.2.6 Lamp Control Driver Module:

This card is used only in the ramp controller applications for driving the red / green lamps. It is not necessary if an external solid-state **or** electromechanical switch which accepts TTL inputs is used, since the generic parallel I/O card can easily produce the required control signals.

4.5.2.7 Fiber CSMA/CD Interface:

This card will contain the fiber-optic LAN control logic (and also possibly the actual fiber modulator / demodulator logic). The LAN protocol must use a Carrier-Sense-Multiple-Access / Collision Detection scheme in order to multiplex multiple nodes on the same physical fiber. An LSI chip, such as the Intel 82592, is capable of several megabits of throughput and provides nearly all control and buffering necessary, as long as DMA is available from the processor to/from memory. It is intended that the processor configure this chip during initialization (configuration is quite complex due to the many options available). Any other equivalent function LAN control LSI chip would also be acceptable.

The card is needed only when a fiber-optic LAN architecture is used (in lieu of the packet radio or spread spectrum radio options).

4.5.3 Software Functions

There are many real-time operating systems available for use with VME bus types of processors. The Early Deployment tasks to be performed do not necessarily require a sophisticated Operating System (OS). They could all be easily implemented with a simple “activity loop polling” scheme in the software working from interrupt or DMA queue indicators to determine what action to take next. This simple approach saves on some types of costs but often results in higher software development costs than if a standard COTS operating system is selected. This must be carefully traded before making a final decision. Any COTS OS selected should be mature and likely to remain on the market for many years to come, support C and assembler programming, full debugging tools, and preemptive multi-tasking for future growth.

Whether or not an OS is used, the software functions should still be partitioned into tasks. A modular approach must be used to enhance re-usability and also flexibility in implementing multiple functions within a single control processor. The best way to specify the functions required in the software is on a task basis for each node type, as will be done in subsequent subsections.

4.5.3.1 Junction Node

The control processor at the junction node is primarily concerned with switching data from one port to another. It will require a store-and-forward packet switch type of software protocol. This is most easily implemented by defining a task to handle each exchange. DMA transfers should be used and a modular protocol interpreter (to determine packet start / end or to format new packets) should be provided.

The following major tasks are defined:

a. Receive and process ramp control and status requests. Inputs come from the cable demodulator. The software must interpret each command received, determine that it is valid, and then format and queue it for transfer per the output option (Fiber, Radio, or Leased Line driver). The actual output of the data is a separate task This task is also responsible for recognizing Video Chain switching commands that may arrive in the input stream and sending them to the local switcher.

b. Camera control PTZ command processing. Inputs come from the Camera Control cable demodulator. The software must interpret the input data, determine it is valid, and then format and queue it for transfer per the output option (Fiber, Radio, or Leased line). This is similar to task (a) except for the different format and different interrupt port. The same software should be usable beyond the input data interpretation differences.

c. Output commands to remote device. This task is responsible for managing and coordinating the time-division output of data that arrives from tasks (a) and (b). It contains the specific drivers necessary for the selected output option (Fiber, Radio, or Leased line). This is little more than a queue management task and device driver.

d. Input of MOE and Status information from remote devices. This task is responsible for accepting the returned data packets from remote devices, verifying them, reformatting where required, and queuing them for output via the Cable Modulator back to the DFOC. Input protocol will vary depending on the selected option (Fiber, Radio, or Leased Line).

e. Output Remote Responses to DFOC. This task handles the protocol necessary to output CMS responses, MOE's, and Status information back to the DFOC via the Cable Modulator. It must also multiplex local processor status (including video chain switcher command acknowledgment) with the data stream received from the remote devices. Speed buffering and storage is provided to match potentially higher (megabit) burst rates from fiber to the slower 56KB steady stream to the DFOC.

4.5.3.2 Detection Node

The control processor in the detection node shares some common functions with the junction node. It also has additional required capabilities. The following major tasks are defined:

a. Receive control commands. Inputs come from the Fiber / Radio / Leased Line interface (as applicable) and consist of BIT status requests, node configuration change commands such as addresses of associated linked controllers), commands to a (possibly linked) cross-roadway ramp controller, and synchronization information to control sorting of detector derived MOE's. The commands must be validated by the software and then acted upon.

   Control commands change the internal software configuration and operation. These should be stored in some sort of non-volatile (e.g., Flash EEPROM) for power fail recovery purposes. There should also be an acknowledgment of the command queued for output back to the DFOC.

   Commands addressed to the cross-roadway controller should be queued for output to the auxiliary port.

   Commands addressed to nodes other than this one or the associated cross-roadway controller should be discarded.

b. Calculation of MOE's Depending on the configuration of the node, several sub-tasks could be defined The software is responsible for collecting inputs from the loop detector (or alternate loop equivalent) devices at nominal 10 millisecond intervals, determining vehicle presence or non-presence, and accumulating volume and occupancy, using the same algorithm as currently implemented in the Concurrent mainframe for processing CCU inputs from the loop RCU's. This data must be accumulated on a lane-by-lane basis for reporting back

   When a tuning gate is implemented in the node, the software shall calculate the average speed of traffic flow using the same algorithm as in the Concurrent system. Alternatively, speed shah be derived based upon vehicle classification and adjustments received from the Concurrent mainframe for adjacent nodes when a single loop arrangement exists at the node.

   Provisions should be made to clear all internal counters upon command of the Concurrent control program.

c. Reporting of MOE's and Algorithm Reset. The merged / calculated volume, occupancy, and speed shah be queued for output to the (Fiber, Radio, or Leased Line as applicable) port at the interval configured in the program ROM or the interval commanded from the headend Concurrent control program. This data will be sent at a nominal rate of once each 20 seconds for fusion with previous node data.

Since the Concurrent contains the logic to “smooth” and “average” the collected MOE’s at the 20 second interval into larger 1 minute intervals, it should not be necessary to perform any filtering of data at the node. Once a set of MOE’s is calculated, the counters should be reset to zero and the software will start all over again.

d. Accept responses from auxiliary node. The software must accept inputs from the Cross-roadway node via the auxiliary port for combination with its own responses and queuing for output back to the DFOC.

e. Output queue handling. The software must time-division multiplex the outputs resulting from tasks a, c, and d, format them, and output them to the selected communication medium (Fiber, Radio, or Leased Line). The appropriate device drivers and data protocol formatting should be implemented independently to preserve as much device-independence as possible. This is primarily a store-and-forward message switch task.

The software must also format and output the commands received for the Cross-roadway node to the auxiliary port.

f. Built-in test. The software shall detect on-line faults in the control processor (as evidenced by erroneous operation of any control port) and report them along with the MOE’s to the DFOC.

The software shall support the capability to perform an “off-line” self test (and a startup self test) of processor logic and interface logic that more rigorously tests each subsystem and reports the results so that faults may be isolated down to the lowest LRU (or group). Consideration should also be given to diagnostics that will isolate parts down to the lowest SRU, although this may be something that is loaded and run only in the shop environment.

4.5.3.3 Ramp Control Node

The control processor in the ramp control node shares many common functions with the detection node. It also has additional required capabilities for ramp metering. The following major tasks are defined:

a. Receive control commands. Inputs come from the Fiber / Radio / Leased Line interface (as applicable) and consist of BIT status requests, node configuration change commands (such as addresses of associated linked controllers, metering on/off control or time-of-day segment for metering, or red/green timing sequence changes), commands to a (possibly linked) cross-roadway ramp controller, and synchronization information to control reporting of the ramp’s loop detector derived MOE’s. The commands must be validated by the software and then acted upon.

Control commands change the internal software configuration and operation. These should be stored in some sort of non-volatile (e.g., Flash EEPROM) for power fail recovery purposes. There should also be an acknowledgment of the command queued for output back to the DFOC.

Commands addressed to the cross-roadway controller should be queued for output to the Auxiliary port.

Commands addressed to nodes other than this one or the associated cross-roadway controller should be discarded.

b. <u>Calculation of MOE's</u>. The software should calculate MOE's based on the ramp loop inputs whether or not ramp control is in progress. The software is responsible for collecting inputs from the loop detector (or alternate loop equivalent) devices at nominal 10 millisecond intervals, determining vehicle presence or non-presence at each of the Queue, Presence, and Passage loops, and accumulating the following, using the same algorithm as currently implemented in the Concurrent mainframe for processing CCU inputs from the ramp RCU's. This data must be accumulated on a lane-by-lane basis for reporting back in the event there is more than one entrance lane on a given ramp:

1. Ramp occupancy
2. Ramp queue and demand
3. Ramp traffic volume (vehicles per minute)
4. Metering rate (i.e., vehicles per minute, vehicles per hour)
5. Detected metering violations (if metering in progress)

Provisions should be made to clear all internal counters upon command of the Concurrent control program.

c. <u>Reporting: of MOE's.</u> The merged / calculated ramp volume and occupancy shall be queued for output to the (Fiber, Radio, or Leased Line as applicable) port at the interval configured in the program ROM or the interval commanded from the headend Concurrent control program. This data will be sent at a nominal rate of once each 20 seconds for fusion with previous node data. Exact interface with the Concurrent algorithm is will be determined.

Unlike the detection nodes, the Concurrent probably does not contain logic to "smooth" and "average" the collected MOE's at the 20 second interval into larger 1 minute intervals. The software should continue to update the current MOE's with newly recorded inputs, smoothing the data from one 20 second (or other, depending on configuration) to the next. The number of 20 second intervals to be used in the smoothing algorithm is will be determined, but should be a minimum of 2 and probably a maximum of 5 minute's worth. Detected violations should be cleared after each reporting period, but the data maintained so that a violation in progress at the reporting interval is not lost, but instead reported during the next interval. Traffic data will also be collected on an hourly basis and then archived for each 24-hour period.

d. Accept responses from Auxiliary node. The software must accept inputs from the Cross-roadway node via the Auxiliary port for combination with its own responses and queuing for output back to the DFOC.

e. Output queue handling. The software must time-division multiplex the outputs resulting from tasks a, c, and d, format them, and output them to the selected communication medium (Fiber, Radio, or Leased Line). The appropriate device drivers and data protocol formatting should be implemented independently to preserve as much device-independence as possible. This is primarily a store-and-forward message switch task.

   The software must also format and output the commands received for the Cross-roadway node to the Auxiliary port.

f. Built-in test. The software shall detect on-line faults in the control processor (as evidenced by erroneous operation of any control port) and report them along with the MOE's to the DFOC.

   The software shall support the capability to perform an "off-line" self test (and a startup self test) of processor logic and interface logic that more rigorously tests each subsystem and reports the results so that faults may be isolated down to the lowest LRU (or group). Consideration should also be given to diagnostics that will isolate parts down to the lowest SRU, although this may be something that is loaded and run only in the shop environment.

g. Meter ramp. The software shall provide the control signals to the red/green signal lamps independently for each lane in a multi-lane entrance ramp (or simultaneously to both, dependent on configuration). These signals shall be provided only during time-of-day intervals pre-set in the configuration PROM or upon command of the Concurrent control program at the DFOC.

   Prior to starting metering or upon termination of metering, the software should hold the signals at a steady state of "green" for 30 seconds. When metering is not in progress, the signal lamps should both be dark (off).

   The software shall support vehicle entrance rates from 4 to 15 vehicles per minute with the metering algorithm, using demand and passage detection points to aid in red/greed signal switching.

The software should be initially configured to release a vehicle each 4 seconds in the absence of other commands from the DFOC during initial deployment. This results in a 15 vehicle per minute metering rate.

4.5.3.4 Video Node

The control Processor in the video node has the fewest required functions of all node types since it is not involved in processing the video signal and it is assumed a video node is located on the LAN and thus does not need to be concerned with remote radio operation across the freeway. It is possible that a ramp control node may use the video node's LAN hookup, however. Additionally, provision is made for use of a wireless interface to the PTZ camera interface.

a. Receive control commands. Inputs come from the Fiber / Radio / Leased Line interface (as applicable) and consist of BIT status requests, node configuration change commands (such as addresses of associated linked controllers), commands to a (possibly linked) cross-roadway ramp controller, and Pan / Tilt / Zoom commands to be sent to the camera. The commands must be validated by the software and then acted upon.

Control commands change the internal software configuration and operation. These should be stored in some sort of non-volatile (e.g., Flash EEPROM) for power fail recovery purposes. There should also be an acknowledgment of the command queued for output back to the DFOC.

Commands addressed to the cross-roadway controller should be queued for output to the Auxiliary port

Commands addressed to this node's camera control mechanism must be passed to the camera controller. The method of doing this, and the ports used will vary depending on whether the camera is linked via wireless or wired connections. The commands should be queued to a generic output device handler to minimize software differences.

Commands addressed to nodes other than this one or the associated cross-roadway controller should be discarded.

b. Reporting of status. The software should acknowledge all commands sent to the camera PTZ mechanism. The software should also report internal node status periodically so that the health of the node may be monitored by the DFOC processor to enable fault detection as soon as possible. The software should send a status report back to the DFOC at least once each 5 minutes, even if no control or other commands have been received. Since responses from an auxiliary node are handled transparently back to the DFOC, the presence or absence of such a node has no bearing on this requirement.

c. Accent responses from Auxiliary node. The software must accept inputs from the Cross-roadway node via the Auxiliary port for combination with its own responses and queuing for output back to the DFOC.

d. Output queue handling. The software must time-division multiplex the outputs resulting from tasks a, b, and c, format them, and output them to the selected communication medium (Fiber, Radio, or Leased Line). The appropriate device drivers and data protocol formatting should be implemented independently to preserve as much device-independence as possible. This is primarily a store-and-forward message switch task.

The software must format and output the commands received for the Cross-roadway node to the Auxiliary port.

The software must format commands for the camera PTZ mechanism received from the DFOC and output them to the camera control. Both wireless communication (with status return) and wired communication (possibly via different ports) must be supported. Note that translation of the DFOC camera control device into a different form or content may be required to accommodate new camera control logic. This translation is the responsibility of the node control processor.

e. Built-in test. The software shall detect on-line faults in the control processor (as evidenced by erroneous operation of any control port) and report them to the DFOC as soon as they are detected. Once a fault is detected, there is no need to continuously send the status to the DFOC at an interval more frequent than specified above for normal status reports.

The software shah support the capability to perform an “off-line” self test (and a startup self test) of processor logic and interface logic that more rigorously tests each subsystem and reports the results so that faults may be isolated down to the lowest LRU (or group). Consideration should also be given to diagnostics that will isolate parts down to the lowest SRU, although this may be something that is loaded and run only in the shop environment.

4.5.3.5 CMS/HAR Interface

The functions of the CMS/HAR interface node are nearly identical to those for the video node when the camera control port’s interface is replaced by the CMS or HAR controller.

The control processor software in a CMS or HAR interface node shall “transparently” (without modifying the commands or responses) switch the packets to and from the attached CMS or HAR. This may be done using either a regular port (such as the camera port equivalent) or the auxiliary port.

Self test requirements and support for a cross-roadway ramp node also apply.

4.5.4 DFOC Headend Software Modifications

Software modifications will be required to the headend computer equipment. It is hoped that the scope of these modifications has been minimized through the careful interface design. The following sections discuss only the nature of the changes, not the specific changes, since the internals of each computer are not specifically known at this time. Most of the information herein is based on discussions with of MDOT.

4.5.4.1 Vicon VPS-1300

The Vicon video switcher should require no special modifications other than possible table modifications to accommodate additional camera inputs and additional monitor outputs.

4.5.4.2 Camera Control PC

The current video and camera control should not require modifications beyond possibly enabling additional camera addresses, by simple table updates.

4.5.4.3 Vultron CMS Controller

The Vultron CMS controller should not require any modifications beyond adding new CMS addresses to its internal tables. An interface protocol will need to be investigated to remotely control the controller through the integrated user interface.

4.5.4.4 Concurrent 3280MPS

It has been confirmed with MDOT personnel that there should be no problem with merging new detector inputs at the 20 second data fusion point in its processing. It is estimated that all that will be required is to expand some working arrays which hold the data (and also store it on disk) along with the associated array index limits. A new task to perform this function as the data is received from remote nodes is required.

a. Serial I/O handling. A new serial I/O handler is required to manage data input and output via the new control / status return interface. The standard Concurrent common serial port protocol driver will most likely be capable of handling the actual device-level interface.

b. Detector failure to report and reported faults. A new software task to handle faults and also internally generated fault indications when detection nodes fail to report new information (detected when the data is needed for merging) will be required.

A new software task to format and display these faults (or merge the reports in with the existing fault reporting subsystem) will be required.

c. Operator Interface. The existing operator interface will require modification to accept commands for ramp overrides, node configuration changes, and commands for node off-line self test for the new node types. This capability goes beyond the current operator interface, but should be compatible with it.

d. Graphic Display Subsystem interface. The Concurrent sends volume, occupancy, and speed on a 1 minute update basis to the GDS (without the GDS requesting it). The scope of this data must be increased to include the newly instrumented sections of roadway.

The Concurrent also polls the GDS at 250 millisecond intervals to receive and transfer incident and construction information from one GDS station to another. If any of the GDS systems are displaying a metered ramp detailed view, the Concurrent also sends information about the state of the loops and metering lamps. A new subroutine will be required in the Concurrent to "simulate" generation of the passage and metering data based on the last reported volume, occupancy, and passage information to the mainframe from the remote "intelligent" ramp controller. The computations will produce an "average" vehicle entry rate and generate the required sequence of queue, presence, and passage indications synchronized to the fixed lamp on/off cycle time. This will provide a graphical display of the vehicle moving along the ramp in synchronized with the lamps, as it now does in real-time. The graphical display essentially is the equivalent of the statistical numbers, but is easier for an operator to "get a feel" for the actual flow rate.

4.5.4.5 Graphic Display Subsystem

The Graphic Display Subsystem interface will remain the same except additional volume, occupancy, and speed, and ramp control information must be sent on the 1 minute update basis. It is hoped that the GDS map displays are table driven so that minimal software (just table) updates are required to add the new corridors. Based upon the current map coverage, significant changes to the GDS database will be required to cover the entire Metropolitan Detroit freeway and trunkline network..

Adding new ramp controller detailed views is also a database modification task. There are probably existing ramp views that can be copied and modified to include the new ramps. The internal tables of ramps will need to be updated. Software modifications should be minimal provided that sufficient software documentation is available for the current system.

The low-level interface from the Concurrent for the ramp metering view should remain the same, although a new concurrent subroutine will be generating the data.

4.5.5 Interface Data Definitions

Table 4-21 lists each of the interfaces and the top-level data types that are passed on them.

Table 4-21. Deployment Interfaces

From	To	Data Types	Comm Method
MTC/DFOC Headend			
3280MPS	Junction Nodes (Detection, Ramp, and Video Nodes)	Ramp Parameters Status Requests Node Configuration Commands	56Kb Cable Modulator (multiplexed with CMS data)
Vultron CMS Controller	New CMSs	CMS Control / Configuration Data (via "modem" port)	56Kb Cable Modulator/ RF -trunked radio
Camera Control PC	Video Nodes	Camera Pan/Tilt/Zoom Commands	Camera 18.1 MHz Cable Modulator wireless FM
I-94 Junction Nodes (Detection, Ramp, and Video Nodes)	3280MPS	Detector: Volume, Occupancy, Speed, Time, Node Status Ramp: Volume, Occupancy, Flow Rate, Time, Node Status Video: Camera and Node Status	56Kb Cable Demodulator (Multiplexed with CMS return data) or fiber or wireless
Video Node	VICON VPS-1300	NTSC Video	Blonder-Tongue Cable Video Demod.
CMS	Vultron CMS Controller	CMS Status Responses (via "modem" port)	56Kb Cable Demodulator/ RF -trunked radio
Junction Node			
Video Node	Cable Video Modulators	NTSC Video from Camera(s)	Fiber Bundle or Leased Lines to Cable Conversion
Detection, Ramp, Video Nodes	Headend	MOE's, Node Status	Fiber, Radio, or Leased line to 56Kb Cable Modulator
Camera Control Demod	Video Nodes	Pan/Tilt/Zoom commands	Cable Demod to Fiber, Radio, or Leased Line Conversion
Node & CMS Command Demodulator	Detection, Ramp, Video Nodes	Ramp Parameters Status Requests Node Configuration Commands	56Kb Cable Demod to Fiber, Radio, or Leased Line Conversion
Detection Station Node			
DFOC Headend	Node Control Processor	Node Configuration Commands Self test Requests Time Synchronization Commands (Also Node Configuration Commands and self test requests to cross-roadway interfaced ramp controller)	Fiber, Radio, or Leased Line Demodulator

Volume Control Processor	DFOC Headend	Volume, Occupancy, and Speed MOE' s Node Status and Time Tags Node Off-line BIT Status (Also Node MOE' s and Status for cross-roadway interfaced ramp controller)	Fiber, Radio, or Leased Line Modulator
Loop Detector (or equivalent)	Node Control Processor	Loop Detect / No Detect Status	Wireline inside cabinet
		Ramp Controller Node	
DFOC Headend	Node Control Processor	Node Configuration Commands Self test Requests Time Synchronization Commands (Also Node Configuration Commands and self test requests to cross-roadway interfaced ramp controller)	Fiber, Radio, or Leased Line Demodulator
Node Control Processor	DFOC Headend	Volume, Occupancy, Flow Rate MOE' s Node Status and Time Tags Node Off-line BIT Status (Also Node MOE' s and Status for cross-roadway interfaced ramp controller)	Fiber, Radio, or Leased Line Demodulator
Loop Detector	Node Control Processor	Loop Detect/No Detect Status for ramp loops	Wireline inside cabinet
Node Control Processor	Lamp Control Drivers	Red / Green / Off signals	Wireline
		Video Node	
DOFC Headend	Node Control Processor	Node Configuration Commands Self Test Requests Time Synchronization Commands Camera Pan / Tilt / Zoom Commands Fiber Video Modulator On/Off (Also Node Configuration Commands and self test requests to cross-roadway interfaced ramp controller)	Fiber, Radio, or Leased Line Demodulator
Node Control Processor	DFOC Headend	Node Status and Time Tags Node Off-line BIT Status Camera / Modulator Command Acknowledgements (Also Node MOE' s and Status for cross-roadway interfaced ramp controller)	Fiber, Radio, or Leased Line Demodulator
Node Control Processor	Camera Control Logic	Pan, Tilt and Zoom Commands	Wireless modem or wireline
Camera Control Logic	Node Control Processor	Camera subsystem status	Wireless modem or wireline

Camera Video	DFOC Headend	NTSC Video	Fiber, Leased Line or wireless
CMS or HAR Node			
DFOC Headend	Node Control Processor	Node Configuration Commands Self test Requests Time Synchronization Commands (Also Node Configuration Commands and self test requests to cross-roadway interfaced ramp controller)	Fiber, Radio, or Leased Line Demodulator
Node Control Processor	DFOC Headend	Node Status and Time Tags Node Off-line BIT Status CMS and HAR subsystem Acknowledgements and status (Also Node MOE's and Status for cross-roadway interfaced ramp controller)	Fiber, Radio, or Leased Line Modulator
CMS or HAR	Node Control Processor	CMS or HAR Control Commands	Wireless modem or wireline
Node Control Processor	CMS or HAR	CMS or HAR Subsystem acknowledgements and status	Wireless modem or wireline

The following subsections define the format for data packets passed over the major interfaces in more detail. Note that camera control commands and CMS / HAR commands remain the same as they are now, but they will be "wrapped" in a packet with destination identified for routing over the selected communication system.

4.5.5.1 Headend to Remote Nodes

Commands to the remote nodes are already defined in the case of camera controls and CMS commands. It is intended that these be "wrapped" in some sort of digital envelope at the DFOC headend, which is then converted, if required, at junction nodes. Both CMS and CCTV camera controls carry their own node addressing information, which will have to be checked at each CMS / Video node. The general format is shown in Table 4-22 below:

Table 4-22. CCT / Camera / CMS Commands

Field	Number of Bits	Usage
Packet Header	16 Nominal	Identifies start of a new packet for synchronization
Data Identifier (Apply ONLY at Junction, Not Headend)	16 Nominal	Identifies the source of the data -- Camera Controller or CMS / HAR Controller. This is applied ONLY at junction nodes by the Control Processor there since these commands arrive over different cable channels from the headend.
Camera Information or CMS Command	Predefined	Identifies the camera address (8 bits) and the function (16 bits) as documented already at the DFOC -or- identifies the CMS and its function, as documented by Vultron
Packet Trailer	16 Nominal	Identifies end of a packet for synchronization

Commands from the 3280MPS to the Detection, Ramp, and Video Nodes should all be formatted into a standard packet which is easily distinguished from camera control packets. The general format is shown in Table 4-23. Note that 16 bit words are defined for nearly all entries. This should be done to make the software easier and memory access faster, even when only 8 bits are used. 16 bits is also the granularity of some types of LAN controllers.

Table 4-23. 3280MPS Commands

Field	Number of Bits	Usage
Packet Header	16 Nominal	Identifies start of a new packet for synchronization. Should be different than Packet Header used for Camera Control.
Packet ID	16 Nominal	Identifies the function of this packet (for example Set Node Time)
Node Address	16 Nominal	Identifies the node to which the command is addressed. Provision should be made for an "all call" or "all nodes" address (such as all ones except the LS bit)
Packet Word Count	16	Number of significant 16-bit words following this entry, excluding the check word
Control Information	Varies	Each control item (e.g., date, hour, minute, second) needed for the particular control function
Check Word	16	16- bit add-and-left-rotate (discard carry) checksum over all data in the packet following the packet header and excluding the check word itself.
Packet Trailer	16 Nominal	Identifies end of a packet for synchronization

4.5.5.2 Remote Nodes to Headend

The format of the packets from the remote nodes to the headend are similar to those from the headend to the nodes. The data is different, of course. The node control processors will generate the packets. The junction control processor may strip off certain information in the case of the CMS responses to maintain compatibility with current formats. The Demux at the headend may also have to strip off some identifying information in order to present the CMS Controller with the exact format of a response as it would get from a direct wireline modem hookup. Table 4-24 illustrates this.

Table 4-24. CMS Responses

Field	Number of Bits	Usage
Packet Header	16 Nominal	Identifies start of a new packet for synchronization (strip at headend demux)
Data Identifier	16 Nominal	Identifies the data as CMS / HAR Controller response. This must also be stripped by the headend demux after it is used to route the received data.
CMS Response	Predefined	Identifies the CMS response function as documented by Vultron
Packet Trailer	16 Nominal	Identifies end of a packet for synchronization (junction node before sending to headend demux)

BIT responses and node MOE' s and status must be packetized by the node controllers. The format is similar to that for the 3280 MPS headend commands, as shown in Table 4- **25.**

Table 4-25. Node Controller Responses

Field	Number of Bits	Usage
Packet Header	16 Nominal	Identifies start of a new packet for synchronization. Should be different than Packet Header used for CMS Responses.
Packet ID	16 Nominal	Identifies the function of this packet (for example, Detector MOE Report)
Node Address	16 Nominal	Identifies the node from which the response is sent
Packet Word Count	16	Number of significant 16-bit words following this entry, excluding the check word
Control Information	Varies	Each item (e.g., volume, occupancy, speed, minute, second, node status) needed for the particular response
Check Word	16	16-bit add-and-left-rotate (discard carry) checksum over all data in the packet following the packet header and excluding the scheck word itself.
Packet Trailer	16 Nominal	Identifies end of a packet for synchronization

4.5.5.3 Remote Video to Headend

Video will be standard NTSC carried via fiber analog modulators, cable analog modulators, or wireless video modulators. Leased line will require CODEC equipment to digitize the video and send it with reduced (T1 carrier -- 1.5 MHz) bandwidth. Formats will depend on the CODEC vendor.

4.6 Initial Deployment Architecture

This section describes the system requirements and architecture descriptions for the Initial Deployment option. The Initial Deployment option emphasizes timely traffic system expansion improvements which provide increased visibility to both MDOT and the motoring public. The objective of the Initial Deployment architecture is to expand current DFOU traffic management capabilities to a priority corridor without changing current system operations, while preserving compatibility with future deployment capabilities.

The Initial Deployment architecture is a subset of the Baseline System Architecture and is designed as a modular corridor component. This approach expands the capabilities of the current system, with the corridor infrastructure design being a component of the new system The architecture primarily uses existing equipment to provide traffic surveillance monitoring and control. Maximum use of all existing equipment is made with SCANDI RF cable system junction conversions and modulation to take advantage of the current cable system network to the DFOC. Other alternative communication options may be considered for connectivity between the new corridor and the DFOC.

4.6.1 Initial Deployment Architecture Functions

The system shall interface with existing equipment through currently available channel and processing capacities. In general, new subsystem equipment and components will provide capabilities to communicate with both the existing and new systems through industry-standard interfaces (i.e., NEMA, EIA, CCITT, SAE, ANSI, VME, SCSI, NTSC, etc.). The current infrastructure and equipment will be maintained as the primary system for the Initial Deployment corridor. Current DFOC operator interfaces will be augmented (where needed) to manage traffic operations capabilities for the new corridor (i.e., network status displays, ramp control, etc.). The new system shall perform the following primary functions to support freeway operations in the metropolitan Detroit area.

- Perform Traffic Network Surveillance and Control
- Display and Control Changeable Messages
- Display Traffic Network Status
- Perform System Malfunction Monitoring

Subsequent deployment phases shall utilize the existing system to the maximum extent possible for continued operations in concert with new system and subsystem equipment. DFOU operation of both systems shall be integrated to minimize differences in operator interface(s) and tasks. As new freeway corridors are instrumented and brought on-line, corresponding operator interfaces shall also be integrated and reflect the additional system capabilities. Specific functional processes are identified as follows:

4.6.1.1 Perform Mainline Flow Surveillance

The system shall provide the capability to perform mainline traffic flow surveillance for the Initial Deployment corridor.

4.6.1.1.1 Perform Vehicle Detection

The system shall have the capability to capture vehicle presence counts and detection time differentials (speed traps) for passenger cars; commercial vehicles; transit vehicles; motorcycles; and other roadway vehicles.

1. Vehicle detection points (stations) along the mainline corridor(s) shall be separated by roadway distances of minimum l/3 mile increments plus or minus 10%. If roadway characteristics in certain areas preclude using this increment tolerance, the next available location shall be selected.
2. Vehicle detection stations shah be located immediately upstream of mainline entrance ramps in accordance with MDOT standards. These stations shall provide traffic flow data to determine ramp metering activation and metering rates.
3. Vehicle detection points (stations) for mainline entrance and exit ramps shall conform to MDOT standards for ramp queue, demand, and passage locations, merge occupancy, and corresponding mainline locations to detect and calculate upstream demand and downstream capacity.
4. System vehicle detection accuracy shall be within 10% of actual vehicle counts. Performance is based upon MDOT metering activation/deactivation threshold levels.

4.6.1.1.2 Calculate Corridor MOEs

The system shall compute mainline corridor MOEs (min. average occupancy, total volume, and average speed) for each detection station from the vehicle detection data.

4.6.1.1.3 Manage Corridor MOEs

The system shall maintain traffic flow MOE's in an integrated freeway network status database. This information shah be made available for use with other traffic operations functions (i.e., area-wide traffic coordination, work zone management, traffic demand management and flow prediction, incident management, and traffic and travel information dissemination).

4.6.1.1.4 Display Corridor MOEs

Mainline corridor MOE data shall be made available for freeway network status displays, entrance ramp status displays, information management, and other DFO activities.

4.6.1.1.5 Perform Video Surveillance

The system shall capture NTSC broadcast quality color or black and white TV video images at identified locations along mainline freeway corridors and communicate images and control data to the DFOC for traffic flow assessments and incident verification by DFOU personnel for up to 24-hour surveillance.

4.6.1.1.5.1 Collect Video Images

The system shall collect NTSC broadcast quality video images (color; black and white) of designated freeway corridors for display on the MDTS DFOC video monitors Image characteristics shall include the following:

1. Full color (daylight)/low light black and white (dawn/dusk/night) capability: 0.1 lux (1.0x10-2 FC)
2. Automatic/manual bright/low light compensation and transition
3. Image resolution (minimum): 500 lines horizontal, 400 lines vertical
4. Image zoom/telephoto: Minimum effective zoom/telephoto of the video image shall be 25-150 mm @ f1.2, with manual focus, remotely controlled.
5. TV video image resolution and modulation shall be compatible with NTSC TV standard.
6. TV video image modulation shall be compatible with current DFOC TV monitors.

4.6.1.1.5.2 Video Image Control

The system shall provide remote video image viewing control from the DFOC. Control functions shall include the following:

1. Remote control viewing direction (i.e., horizontal pan and vertical tilt) and image quality (i.e., focus, color, zoom, intensity, etc.) adjustments shall be provided.
2. Video camera platforms shall provide pan-tilt mounting surfaces. Specifications for the pan-tilt platforms shall be:
   Rotation: Pan: 0 to 355 degrees
   Tilt: +/-90 degrees horizontal.
   speed: 3 to 11 degrees/second
3. Pan and tilt stops to prevent over rotation.
4. Platform mounting shall allow for attachments to poles, buildings, on/under bridges, or other roadway fixtures.
5. Deployed cameras shall be mounted in locations which provide effective viewing of the freeway segment under surveillance. Viewing height shall be a minimum of 40 ft above the roadway surface and minimize occlusion effects of roadway overpasses and curves.

4.6.1.1.5.3 Display Video Images

The system shall capture video images for viewing and display at the DFOC (and other locations) through the current video monitors. The system shall provide operator control to monitor video images collected from any field camera to a designated video monitor in the DFOC.

4.6.1.2 Perform Mainline Flow Control

The system shall control mainline traffic flow through traffic flow diversion techniques (e.g., message signing).

4.6.1.2.1 Display and Control Changeable Messages

The system shall provide a variable roadway signing capability which supports display and radio transmission of traffic diversion/status information for traffic alerts and routing of traffic flow onto alternate mainline or trunkline corridors. Corridor and status-specific messages shall be developed using MDOT-approved criteria and stored in a message database for use with the CMS or HAR (or AHAR) systems.

Dissemination of traveler information for Initial Deployment shall be consistent with current capabilities. CMS/HAR placement included in the Initial Deployment program shall be consistent with MDOT criteria and offer diversion and information delivery opportunities on existing MDOT mainlines and trunklines.

4.6.1.3 Display Traffic Network Status

The system shall provide traffic data collected from the Initial Deployment corridor to the current SCANDI (with modifications) and the GDS for traffic status displays. This data shall include mainline traffic MOEs and system status.

4.6.1.4 Perform System Malfunction Monitoring

The system shall monitor operational performance and system/subsystem status operations through on-line interrogation, health checks, and operator-commanded requests. The system shall monitor detectable malfunctions in the Initial Deployment system and subsystems functions and components. These functions and components shall integrate diagnostic capabilities which identify abnormal operating states to the replaceable component level. Reports which indicate the status of functional parameters of the system or any malfunctioning subsystem component(s) shall be available through the SCANDI system. At a minimum, failures and malfunctions shall be reportable to the lowest replaceable component level (i.e., mainline detectors, ramp controllers, etc.). Failures and malfunctions shall also be reported on the system map display consistent with the existing GDS system.

4.6.1.4.1 Perform Routine Status Monitoring

The system shall monitor system operations for malfunctions or abnormal conditions, modes, or states through built-in test (BIT) during startup (power-on) and routinely during operations (background processing).

4.6.1.4.2 Determine System Malfunction

When a malfunction or component failure occurs, the system monitoring function shall determine the nature of the anomaly and isolate the level to the replaceable component level, generate a malfunction or failure message, and display an indicator at the MTC/DFOC to capture the operator's attention. The system shall provide the capability to interrogate and diagnose system/subsystem components locally on-site.

4.6.2 Initial Deployment Architecture Description

For integration of the new corridor, the inputs and outputs of the three relatively independent subsystems, (i.e., video monitor/camera, CMS, and traffic surveillance and control), must be isolated for independent communications and routing control; however, Time-Division Multiplexing (TDM) of the various controls and status will accomplish the modulation required to interface with the current RF cable system. Selection of where TDM is performed is based primarily on implementation cost and minimizing impacts to existing resources. Candidate locations for TDM include the I-75/I-94 cable junction and the DFOC headend.

To support the Initial Deployment program extension, the existing CCU/RCU communications system shall be augmented, but not replaced, to accommodate the additional surveillance and control coverage. Direct extension of the CCU and RCU channel implementation will not be a requirement, and is discouraged due to potential command/response delay problems that could result in propagation delays or other communications-related problems when the physical cable/ communications path is extended beyond the current system bounds.

The top-level Initial Deployment architecture is shown in Figure 4-19 This shows the roadway infrastructure-based components, the DFOC-based components, and their interconnections. Although the headend RF cable equipment is at the DFOC, it has been split out separately to emphasize changes and additions required to implement the Initial Deployment corridor functions.

4.6.2.1 Current Subsystems Modifications and Additions

The Initial Deployment program shall require equipment modifications and additions to provide traffic surveillance and control and information dissemination capabilities on the priority corridor. The following paragraphs describe these modifications and additions in more detail.

General Hardware Modifications. Addition of the corridor surveillance shall require a minimum of hardware changes to the MTC, being limited to augmentation of the existing hardware and addition of new communications interfaces to it.

General Software Modifications. Additions to the current system shall not require extensive changes to existing software. Software shall be developed to interface additional inductive loop (or equivalent) sensors, ramp controllers, video cameras, and CMS and HAR resources to provide, as a minimum, the same capabilities in the current system.

The existing Graphic Display Subsystem (GDS) software and database shall be expanded to include the new freeway segment in its map display capabilities.

Note that when intelligent remote ramp controllers are used (as opposed to central control of the ramp activities on a 250 ms basis), it may not be possible to provide the low-level vehicle passage and ramp signal on/off information for real-time display, and that this capability, when weighed against communications and other costs, may not provide much value-added benefits. If low-level operations are needed, monitoring of vehicle passage may be obtained through CCTV. If the ramp display capability is important for diagnosis of incidents and system faults, generation of the necessary GDS inputs at 250 ms intervals for a specified ramp may be provided by software simulation on the Concurrent central computer, based on the ramp flow volume, metering rate, queue and demand information received from the ramp controller during the last reporting interval.

4.6.2.1.1 Sensor Requirements

Additional sensors to monitor traffic volume and occupancy shall be compatible with existing inductive loop resources. The sensors shall cover all lanes of the freeway in both directions. The sensors shall be capable of sensing all vehicle types from motorcycles to multiple-trailer trucks traveling at speeds from 0 to 100 mph. The sensors shah provide reliable detection under all environmental conditions possible in southeast Michigan including rain, snow, ice, fog (with visibility greater than 25 feet) and clear conditions at air temperatures from -20 to +120 degrees Fahrenheit.

4.6.2.1.2 Sensor Processing

Local processing of sensor information shah be provided in the roadway infrastructure to yield total volume, average occupancy, and average speed (using “timing gates”, where required) at a minimum interval of 10 seconds and a maximum interval of 20 seconds. The resulting data shall preserve individual lane information consistent with current system formats. The data shah contain all required information, including time tagging, so that it is usable (possibly after conversion / combination) by the existing 3280MPS algorithms to provide data fusion into 1 minute periods at 20 second intervals.

Status of the remote sensor subsystems shall be provided at the same interval as the sensor information to enable fault isolation to the field replaceable unit (Line Replaceable Unit {LRU}) level. The subsystems shall be capable of maintaining and outputting additional status information, upon request, to isolate malfunctions and faults to the lowest circuit card / shop replaceable unit (SRU).

4.6.2.1.3 Changeable Message Sign Processing

Any new CMS resources added to the system shall be compatible with the existing CMS monitor and control subsystem Software changes to the CMS control system to incorporate the new CMS shah be limited to database updates necessary to bring the new CMS on-line.

4.6.2.1.4 Video Surveillance

Full-motion video shall be provided at those locations designated for surveillance. The infrastructure shall accommodate a 6 MHz video bandwidth using standard NTSC video. The video signal(s) shah be routed to the MDOT DFOC at the nearest junction point to the new equipment using spare existing cable capacity wherever possible.

4.6.2.1.5 Communications

Communications between corridor processing and the DFOC shall be designed to provide the following capabilities:

a. Sufficient communications bandwidth capability shah be designed into the Initial Deployment corridor to provide full-motion N’I’SC video signals and bi-directional data transfer.

b. Communications facilities shah be provided for one-way video transfer to the DFOC, remote camera Pan-Tilt-Zoom (PTZ) and camera switching, communication with processed (volume, occupancy, speed, status) inputs from mainline detectors on a 10 second (minimum) interval, and control / status collection from Changeable Message Signs (CMSs).

c. Sufficient processing capacity shall be available for control of Highway Advisory Radio (HAR) transmitters.

The Initial Deployment shall not require more than 50 percent of the design communications capacity. The remainder is reserved for future expansion. Alternative temporary communication facilities, such as wireless radio or leased lines, may be considered to enable earlier deployment,

When a communications "backbone" media is embedded on one side of a roadway, the use of short-distance wireless communication from equipment cabinets located on the backbone side to equipment cabinets located on the opposite side of the roadway shall be weighed against the life-cycle cost (ICC) of trenching across the freeway for the installation of fixed wire / fiber link required to reach the backbone. Similarly, the life cycle costs of using wireless communication methods from video cameras to a nearby cabinet shall be weighed against the installation of fixed lines for both video signal return and camera PTZ controls.

Because pre-processing of sensor inputs and autonomous operation of ramp controllers is specified, the communication bandwidth for these functions will be quite low and well within the capability of UHF (or VHF) packet or spread-spectrum radios, CMS communications could also be handled within this bandwidth or the current CMSS. The primary communication difficulty is with the full-motion video. Even using compression techniques, a minimum of 1.5 MHz bandwidth (T1 Carrier) is currently required.

Commercially-available means for communicating with cameras using short-distance wireless radio is available. Further evaluation of these means are required based upon system requirements and cost considerations. It is also possible to avoid costly trenching operations between ramp controllers on the opposite side of a roadway to the communications backbone cable or fiber using wireless radio.

4.6.2.1.7 DFOC / MTC Headend

Figure 4-20 shows the DFOC headend interfaces. At the DFOC, video inputs will use the existing blonder-tongue (B-T) demodulator / Vicon Switcher and video control architecture. It is envisioned that additional B-T video demodulator(s) will be required for the additional corridor cameras. The Vicon equipment currently provides a sufficient number of spare ports for camera video inputs and monitor outputs.

Similarly, the camera controllers will remain common with the current camera control system. Some modifications may be required to the PC database to accommodate new cameras and addressing, but there should be adequate spare margin for Initial Deployment camera additions. The same cable frequency modulator will be used as for all other cameras, operating at a frequency of 18.1 MHz with a 56KB data rate.

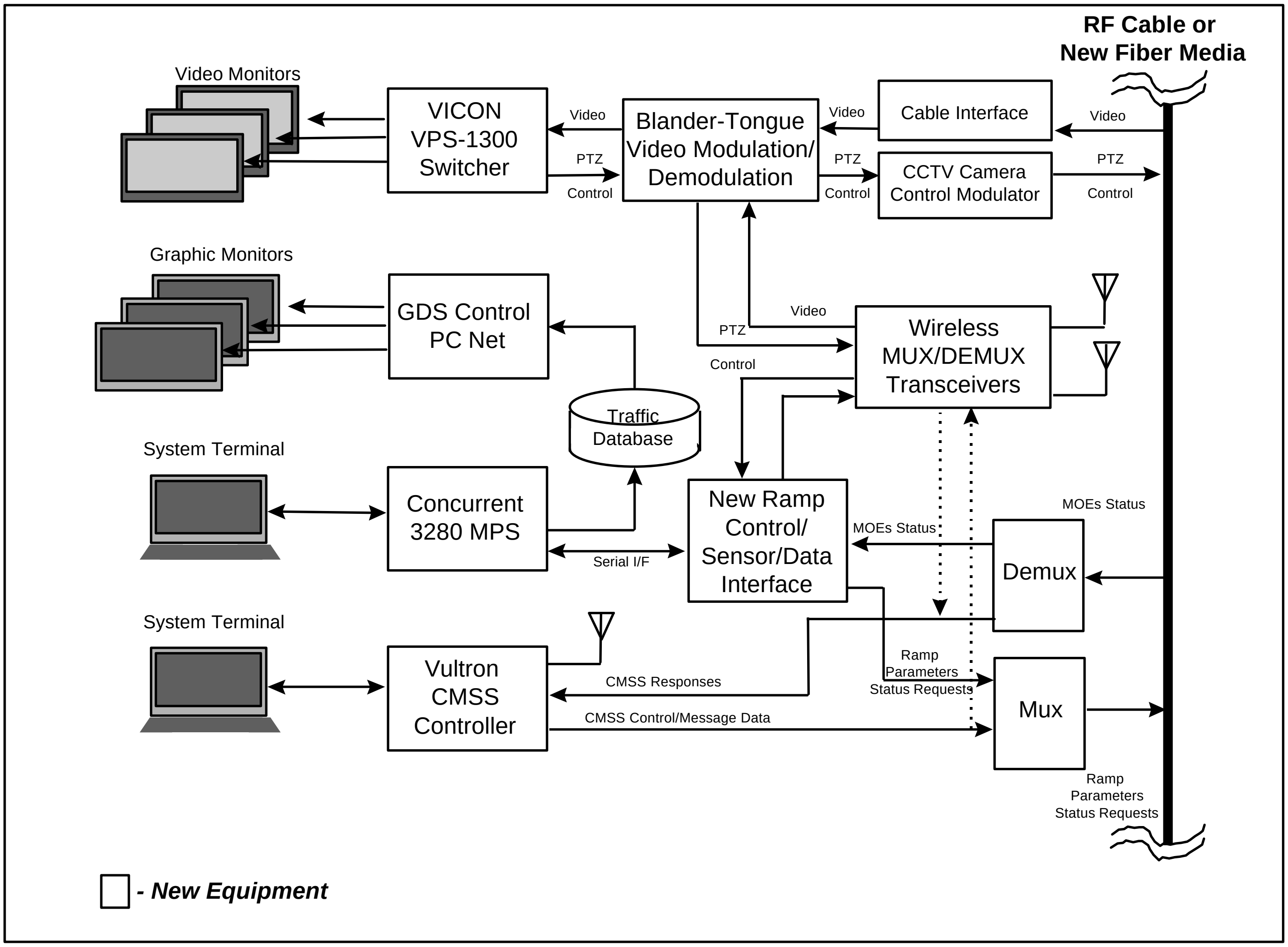

Figure 4-19. Initial Deployment MTC/DFOCHeadend Detail

The details of the new Vultron CMS controller interfaces are not known at this time, but it is believed that the standard “modem” type of interface can be used as for existing wireline-connected CMS facilities. To conserve cable resources, however, this infrequent control information will be multiplexed in a straightforward manner with the (also infrequent) new ramp control parameter overrides and ramp / loop status requests. The multiplexing may be as simple as controlling the Clear-to-send (CTS) line(s) going back to the Vultron CMS controller and new Concurrent serial interface to assure that only one device is sending data at a time with a digital selector used to route the appropriate input to the output. Responses coming back from the remote CMS controllers will be routed to the Vultron CMS controller by a demultiplexing process based on a simple algorithm such as received data parity. The throughput of the 56KB RF cable modem should be adequate to satisfy the currently-programmed response requirements of the Vultron software operating on a 2400 bps wireline modem.

Since the remote ramp controllers and loop controllers contain intelligent processing, they do not need to be polled to return the ramp MOE’ s (occupancy, queue, and demand, flow volume, metering rate, time, status) or the loop MOE’ s (volume, occupancy, speed). The remote controllers are expected to send this data at their pre-set rates once commanded "on" without further polling. Commands to the ramp controllers to change metering rates or activate / deactivate metering may also be sent. The capability to poll the controllers for additional status (primarily faults) is also provided.

Two additional narrow band 56KB cable frequency interface devices (or a single dual-frequency modem) may be required, as shown in Figure 4-20.

4.6.2.1.8 I-94 Junction

Figure 4-21 shows the internal detail for the "junction box" located in the I-94 / I-75 area. The equipment is required to convert between any of 3 possible communications media to the existing cable media.

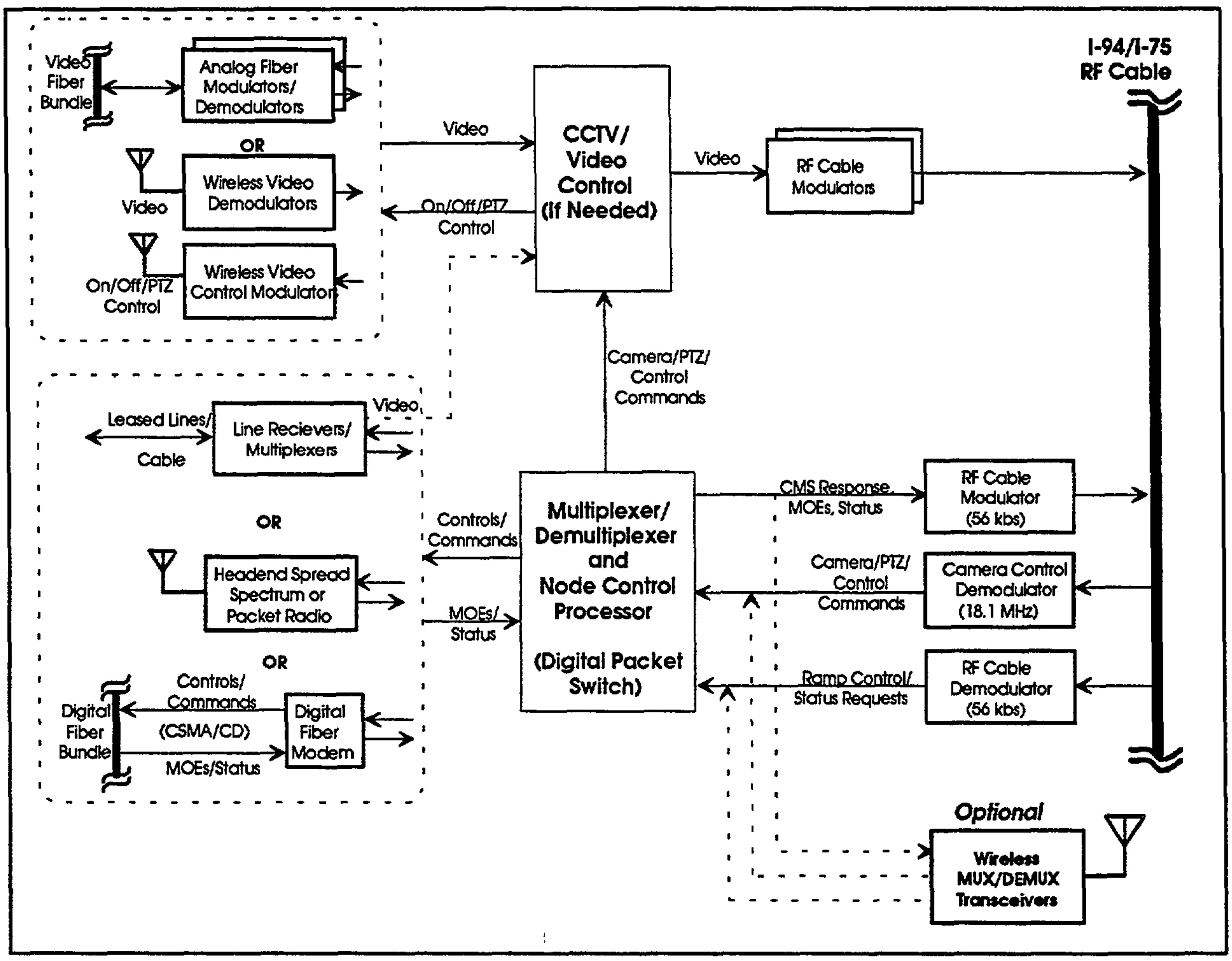

Figure 4-21. Initial Deployment I-75/I-94 Junction Detail

Camera video will require either fiber-optic transmission line from remote I-75 locations, wireless video transmission, or leased cable facilities. If trenching must be performed to install cable, the additional cost to use fiber-optic bundles is negligible.

Note that the architecture in this document is for Initial Deployment only, and omits the normal fiber LAN architecture details. In particular, a fiber "backbone" is normally installed. There are then "spurs" that connect with this backbone (Star configuration) at hub locations. The "spurs" then run on a separate fiber bundle (or even wireline cable) to somewhere between 8 and 15 nodes. This type of architecture usually has a hub every 4 or 5 miles along the fiber backbone so that a smaller number of nodes will be impacted should there be a break in the spur (or in the event a cabinet is damaged by maintenance crews knocking it over, as sometimes happens).

For the Initial Deployment architecture, since the entire run is only about the length of a single spur, it is proposed to dispense with the expense of a backbone / hub architecture and simply run the fiber from the I-94 junction to all nodes for the (approximately) 6 mile run. However, the fiber backbone cable (if used) should be installed in the conduit alongside the spur cable during initial installation, even though it will not be used until the ATMS system is extended beyond the Initial Deployment corridor.

Since remote sensors, CMS, and ramp controllers require a much smaller bandwidth, the option exists to use wireless media such as spread-spectrum radios or packet radios as well as leased (or switched) voice-grade wirelines. This is reflected in the figure, where options exist for bringing in data (or sending data) via radio, leased line, or a fiber digital modem (if fiber is used for the video).

4.6.2.1.8.1 Video Signal Return

When fiber-optic cable is available, the most cost-effective use is to allocate one fiber of a bundle for each camera chain (more than 1 camera can be in a chain) with standard COTS analog modulation / demodulation equipment. This avoids costly digitization and/or multiplexing of the signal. A camera chain consists of one or more cameras whose modulator and camera are all capable of being switched off or on via remote command. Only 1 modulator at a time (using simple LED's) may be carried on the fiber. Note that COTS equipment is available which will multiplex 4 or more NTSC video signals on a single fiber. This is useful for co-located cameras, and would be an exception to the "single camera chain, single fiber" approach. The group of cameras would then be treated as a single camera for switching on or off the chain.

Multiple fibers in a bundle are used to accommodate multiple camera chains for simultaneous viewing of several locations. This technique will cover 99% of the real-time surveillance requirements where incidents statistically happen frequently at only 1 location on a chain and infrequently at others. The high-incident location would normally be selected for viewing with the others switched in or out as indicated by the received MOE's from the field sensors. This switching could even be done automatically on a round-robin basis to present (for example) 10 seconds of a given camera view before switching to the next camera on the chain. This would, however, require significantly more software modifications than a simple operator-commanded switch mechanism. It would also result in a fraction of a second of "black" on the monitor before the next camera were switched on, which could be aesthetically disturbing.

Demodulated video, either from the fiber or leased cable, is presented to a video chain switcher, if required, prior to being sent to a standard cable modulator for frequency-division multiplexing on the existing cable. The video switcher is required only if there are fewer cable video channels available than there are camera chains on the fibers. At the switcher, a second level switching occurs to select the chain to be sent back to the DFOC. While this should not be needed for the Initial Deployment implementation, it is shown for future expansion of video coverage. Control for the secondary switcher will be time multiplexed with other control functions at the DFOC.

4.6.2.1.8.2 Camera Control:

The camera PTZ control that is currently sent on the 18.1 MHz digital channel from the DFOC will be demodulated at the junction box and input to a 2-way multiplexer (effectively a packet switch). The control commands occur infrequently, and can easily be combined with ramp control and status requests.

4.6.2.1.8.3 CMS Control and Status Requests:

These signals are demodulated from the new cable control channel (if used) and include both CMS control where applicable and possible camera chain switching commands from the Concurrent system. They are combined with command packets from the camera control using simple time multiplexing (store and forward packet switching) and then sent to one of the 3 optional media for output along the Initial Deployment corridor.

4.6.2.1.8.4 MOE and Status Return:

Mainline MOE's (volume, occupancy, speed) are passed through from the link directly to an additional 56Kb cable modulator for relay to the DFOC. While this is shown as passing through the multiplexer / demultiplexer, little needs to be done beyond packet relay from the remote sensors to the cable. Again, this data could arrive from any one of the three possible media, also at a nominal 56 KB rate (although data throughput would be much less due to the burst nature of the reports).

4.6.2.1.8.5 Communications Protocols:

There are cost-effective parts available which will completely handle a Carrier-Sense-Multiple-Access / Collision-Detection (CSMA/CD) fiber access for multiple devices on the same fiber with little additional intelligence required (i.e. no separate CPU). It is envisioned that the Control Processor will be fabricated using a COTS single-board computer (possibly VME-Bus) assembly and add-on COTS I/O cards. This processor could easily handle the set-up of the CSMA/CD LSI chip, which would then take care of all transmission and reception from the fiber. The Intel standard CSMA/CD controllers are available in several configurations. No custom hardware should be necessary, but semi-custom (modified) software will certainly be required

A single fiber in the bundle can be used to carry ALL status and MOE information from the remote intelligent controllers. These controllers would simply send a packet when data were available at their predefined collection rates. The CSMA/CD protocol would allow each remote to determine if it had been interfered with and needed to retransmit the packet. At the junction box, outgoing commands are multiplexed in the same manner on the bidirectional cable transceiver. This scheme is a form of optical LAN access which has equal applicability to leased lines or coaxial cable.

For packet radio, a modified type of access protocol would be required. Packet radio, operating at 9600 bps, could support all communication for the junction link. The packet radio mechanism uses not only collision avoidance (i.e., listen before transmit), but also reverse acknowledgment of received data. Some modification of the AX.25 protocol could be performed to enhance throughput and connectivity, but is easily avoided with multiple-session packet Terminal Node Controllers (TNC's) located at the junction.

Spread spectrum protocols generally work better with a poll-response type of approach. To use this type of radio, a frame time would have to be enforced by the junction control processor (on a 10-20 second basis). Polls to all remote detection stations would be generated and the responses collected and relayed to the cable modulator. This approach is less desirable due to the larger amount of custom software development that would be required. It could be needed to support larger bandwidths (up to 250,000 bps), however, than packet radio (using the available UHF frequencies and 9600 bps speeds) can accommodate.

4.6.2.1.9 Inductive Loop / Other Detectors

Figure 4-22 shows a representative mainline detection station node. All optional communication mechanisms are also shown for completeness. Again, only 1 of the 3 will be required in the final system. For initial deployment, wireless modes shall be used.

This architecture is for a simple detector set from both sides of the roadway where there is no nearby ramp controller or camera. There does not need to be a co-located speed trap. If the site supports a speed trap, an additional set of loop drivers will be required to cover an 8 lane highway, if loops are to be used. For a speed trap, the processor should be programmed to also supply normal MOE's from a single set of loops (either set remotely commandable to compensate for temporary faults) along with the speed information.

Note that provision has also been made to replace some loop detectors with an equivalent system should it be necessary in certain locations due to roadway condition or other factors. The control processor should be able to handle raw loop on/off or processed data from the other detector types.

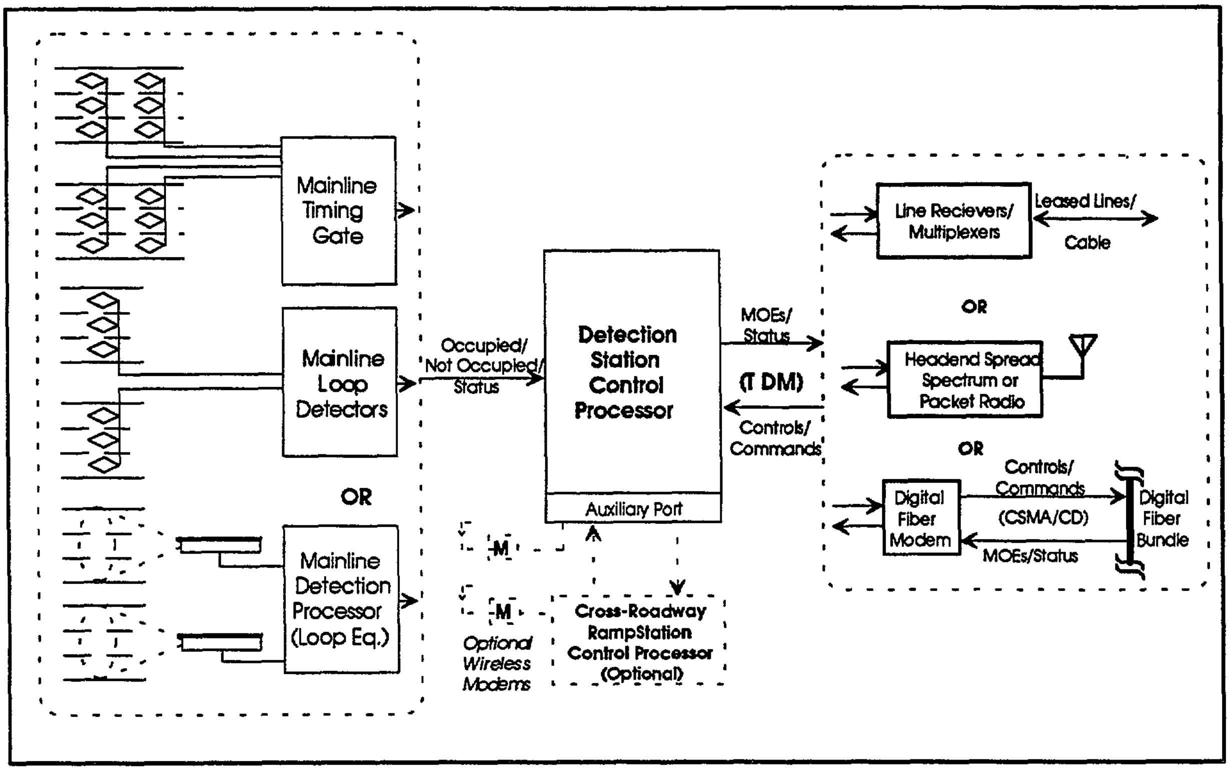

Figure 4-22. Initial Deployment Detection Station Node Detail

4.6.2.1.10 CCTV Video Surveillance

This node is different than the other types since the wide video bandwidth required dictates the use of a fiber, cable, specialized wireless connection. Figure 4-23 illustrates a CCTV video / camera control node architecture. For this reason, it is assumed that the cabinet containing the control processor will be located on the fiber LAN or contain the wireless communications equipment for the video/camera control link. However, there is no reason why there cannot be a detector controller on the opposite roadway side that uses the facilities of the control processor.

Provisions have been made for wireless modem and video modulator usage to link the control cabinet to the camera assembly in lieu of trenching and laying control lines and video cable. COTS wireless video transmitters (unlicensed) are available to handle the video transfer. A standard wireless modem of the type used for cross-highway links will also be required to transfer the camera PTZ commands and receive status from the remote side unless supplied with the wireless video link. If not, camera control will most likely require a special interface card to isolate the various PTZ commands from the digital data stream and route them to the proper control mechanism. A separate processor should not be required -- a control sequencer type of ASIC design will probably suffice.

If the camera is "hard wired" to the control cabinet, then separate lines will be run from the control processor I/O card for control of the PTZ functions as well as receipt of status.

Video transfer will require a coax cable (to carry the baseband video signal) to the video-fiber modulator. The control processor interface software will be slightly different depending on the camera control interface type.

It should also be noted, although it is not shown in the figure, that multiple cameras could be handled by a single cabinet junction when they are located in close proximity to each other (such as on more than one side of freeway interchanges). In this case, one of the multi-channel video multiplexers will be required ahead of the video-fiber modulator and multiple camera command ports will be required from the control processor. Control processor software must be designed in a modular manner to support the decoding and routing of commands to multiple camera addresses from the common DFOC control port.

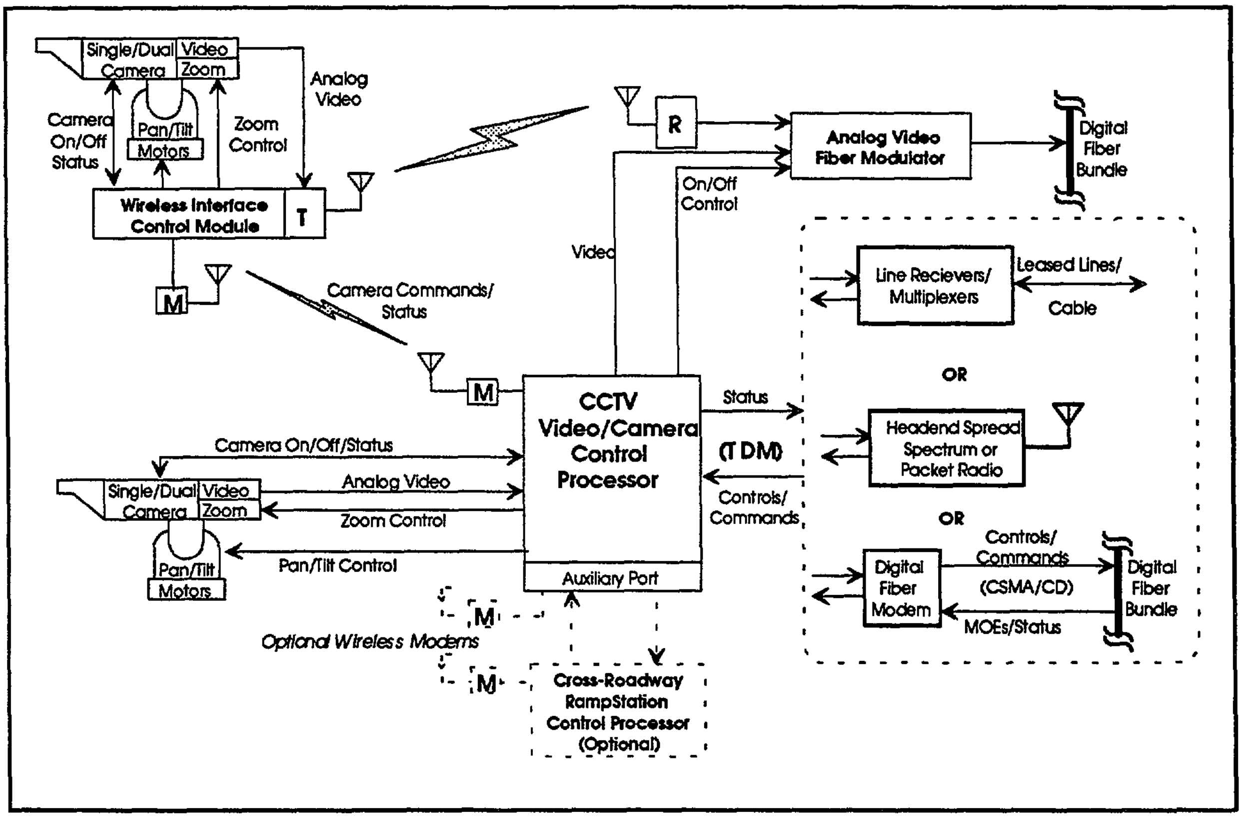

Figure 4-23. Initial Deployment CCTV Video / Camera Control Node Detail

4.6.2.1.11 CMS / HAR Interface

The interface and control architecture for a CMS or HAR link is almost the same as that for a camera PTZ control link. There is no video interface, but the command / response interface is generically the same as shown in Figure 4-23, replacing the camera with the CMS or HAR control module. Control processor software can also be common as long as it is concerned only with command address recognition and speed buffering (i.e., packet switching) to a serial interface type. It is also conceivable that a single common control processor could handle either multiple cameras, or cameras and a CMS or HAR command / response port. The function could also be combined with a detector station controller.

4.6.2.2 Representative Control Processor Architecture

4.6.2.2.1 Processor and I/O Hardware

The control processor needed to satisfy Initial Deployment and future MDOT requirements should be selected for its capacity for growth potential as well as the availability of off-the-shelf modular CPU and peripheral cards. It is highly recommended that a modular chassis (e.g., VME-bus and standard card format) architecture be used. The NEMA 170 types of systems are evolving toward this standard, and interfaces from the 170 to VME configurations currently exist. However, use of a 170-type controller is probably not cost effective since growth and processing capacities are marginal in current configurations. Multiple vendors support the 680x0 VME standard, to which the NEMA 170 6800 CPU software is readily convertible. Allen Bradley has VME configuration processors and I/O cards. Many other vendors also have these, and it is probable that traffic-type operations (such as lamp drivers) and certainly fiber or cable LAN interface modules are readily available.

Figure 4-24 shows a representative recommended internal control processor architecture. The figure shows all required modules for the Initial Deployment architecture implementation. Since a VME bus is used, many other peripheral cards for varying functions needed in the future are also easily added when required.

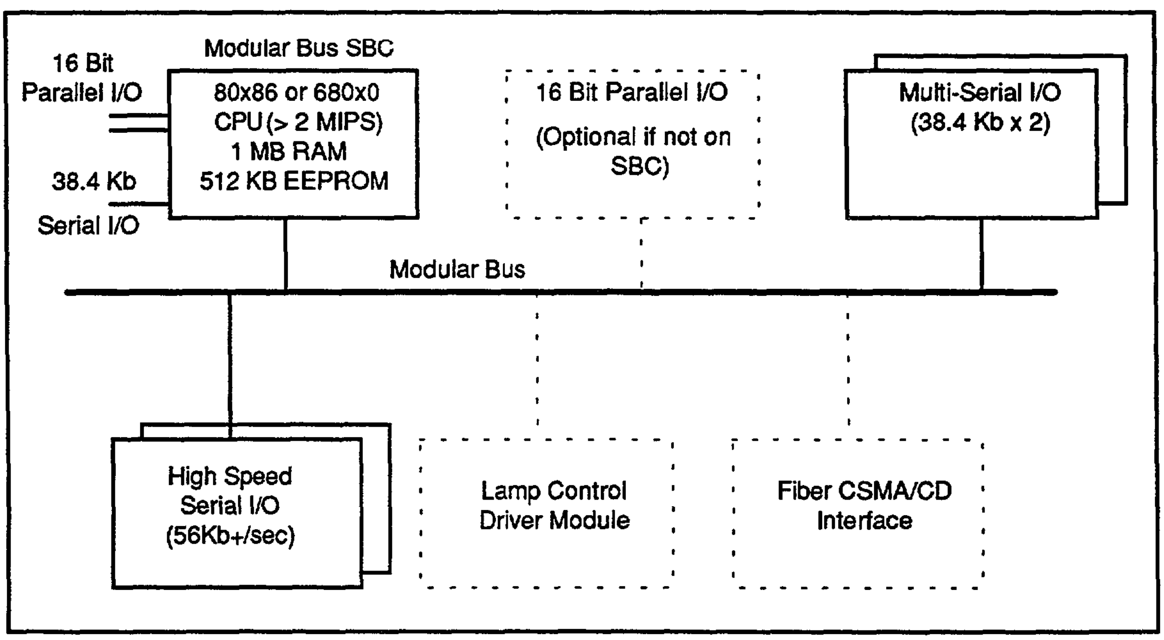

Figure 4-24. Representative Modular Control Processor Architecture

This type of architecture can be used to satisfy the requirements for the Junction, Detection Nodes, and Video nodes. Not all peripheral cards are required in all applications. A brief synopsis of each module follows:

4.6.2.2.2 Modular Single Board Computer (SBC) Module:

A large variety of modular chassis (e.g., VME-bus compatible) SBC's are currently available using both the Intel 80x86 types of processors and the Motorola 680x0 processor types. The 680x0 is preferred for commercial applications because of its compatible interface to the VME standard and upward compatibility with the current NEMA 6800 standard processor type. Abundant vendors for C compilers and 680x0 assemblers exist.

The selected SBC should have a minimum of 2 Million Instructions per Second (MIPS) throughput (easily satisfied by even the slowest 68000 board), 1 Megabyte of on-board RAM (expandable to at least 4 MB), and a minimum of 512 K bytes of Flash EEPROM for program and constant /parameter storage for non-volatility and unattended operation / automatic restart on power fault.

In addition, the board should have a general asynchronous serial I/O port with a speed rating of 1200 to 19,200 bps for connection of a local diagnostic console. A few bits of parallel I/O for general control and/or loop detector inputs should also be provided. A minimum of 16 bits is recommended, although an external (possibly multi-function) VME card could also provide these functions if not available on a cost-effective SBC. For future supportability and easy card interchange / upgrade, it is probably best to avoid dense, multi-function VME cards in favor of more modular systems which can be upgraded or repaired using "mix and match" techniques with full interchangeability from different vendors. This will also assure MDOT of easy repair / replacement in the future without the need to repeat their custom development efforts for new replacement parts when a sole-source vendor goes out of business.

The board should support full VME Direct Memory Access and control functions for high speed transfer from one port to another. Multiple DMA channels are required for simultaneous transfer of data for at least 4 ports. This is used for data packet switching and multiplexing / demultiplexing, particularly at the Junction Node (or possibly LAN hubs). Finally, the board should support at least 2 programmable counter/timers (3 is standard) for implementing a "real time" clock and other temporary timing loops for various functions.

4.6.2.2.3 16 to 24 Bit Parallel I/O:

This card would be used for handling inputs from standard loop detectors. It is required only if the SBC does not have at least 16 bits of parallel I/O. Each bit should be software configurable as either input or output, although if the majority are fixed at inputs with only a few outputs, that is sufficient.

4.6.2.2.4 Multi-Serial I/O:

This should be a general-purpose synchronous / asynchronous (USART or DUSART) serial I/O module with at least 2 ports on the same card. Both ports should provide, as a minimum, RS-232 drivers and receivers with RS-422 (balanced) provided as either a hardware strap option or software configurable item. Each port should have a set of RS-232 style control signals (RTS / CTS, DSR, DTR) and possibly also RING for potential use in dial-up line applications. Each port should support from 75 bps to 38.4 Kbps as a software configurable option.

These serial I/O cards (up to 2 should be provided for in the architecture) are used for the following:

- Radio Interface (spread-spectrum or packet) option,
- Leased line demodulator / demux option,
- Auxiliary Cross-Roadway wireless Modem port,
- Loop detector substitute (e.g., Autoscope) input ports,
- Camera commands / status port for wireless node to camera link.

Full DMA capability is optional, but interrupt capability is mandatory.

4.6.2.2.5 High Speed Serial I/O:

These cards are similar to the multi-port serial I/O cards except they should have full DMA control capability. They are used only in the junction for Camera demodulator input and Control / MOE / Status modem I/O at speeds of 56 Kbps. Up to 2 cards should be provided for in the architecture.

4.6.2.2.6 Fiber CSMA/CD Interface:

This card will contain the fiber-optic LAN control logic (and also possibly the actual fiber modulator / demodulator logic). The LAN protocol must use a Carrier-Sense-Multiple-Access / Collision Detection scheme in order to multiplex multiple nodes on the same physical fiber. An LSI chip, such as the Intel 82592, is capable of several megabits of throughput and provides nearly all control and buffering necessary, as long as DMA is available from the processor to/from memory. It is intended that the processor configure this chip during initialization (configuration is quite complex due to the many options available). Any other equivalent function LAN control LSI chip would also be acceptable.

The card is needed only when a fiber-optic LAN architecture is used (in lieu of the packet radio or spread spectrum radio options).

4.6.2.3 Software Functions

There are many real-time operating systems available for use with VME bus types of processors. Initial Deployment tasks to be performed do not necessarily require a sophisticated OS. They could all be easily implemented with a simple "activity loop polling" scheme in the software working from interrupt or DMA queue indicators to determine what action to take next. This simple approach saves on some types of costs but often results in higher software development costs than if a standard COTS operating system is selected. This must be carefully traded before making a final decision. Any COTS OS selected should be mature and likely to remain on the market for many years to come, support C and assembler programming, full debugging tools, and preemptive multi-tasking for future growth.

Whether or not an OS is used, the software functions should still be partitioned into tasks. A modular approach must be used to enhance re-usability and also flexibility in implementing multiple functions within a single control processor. The best way to specify the functions required in the software is on a task basis for each node type, as will be done in subsequent subsections.

4.6.2.3.1 Junction Node

The control processor at the junction node is primarily concerned with switching data from one port to another. It will require a store-and-forward packet switch type of software protocol. This is most easily implemented by defining a task to handle each exchange. DMA transfers should be used and a modular protocol interpreter (to determine packet start / end or to format new packets) should be provided.

The following major tasks are defined:

a. Receive and process MOE and status requests. Inputs come from the cable demodulator. The software must interpret each command received, determine that it is valid, and then format and queue it for transfer per the output option (Fiber, Radio, or Leased Line driver). The actual output of the data is a separate task. This task is also responsible for recognizing Video Chain switching commands that may arrive in the input stream and sending them to the local switcher.

b. Camera control PTZ command processing. Inputs come from the Camera Control cable demodulator. The software must interpret the input data, determine it is valid, and then format and queue it for transfer per the output option (Fiber, Radio, or Leased line). This is similar to task (a) except for the different format and different interrupt port. The same software should be usable beyond the input data interpretation differences.

c. Output commands to remote devices. This task is responsible for managing and coordinating the time-division output of data that arrives from tasks (a) and (b). It contains the specific drivers necessary for the selected output option (Fiber, Radio, or Leased line). This is little more than a queue management task and device driver.

d. Input of MOE and Status information from remote devices. This task is responsible for accepting the returned data packets from remote devices, verifying them, reformatting where required, and queuing them for output via the Cable Modulator back to the DFOC. Input protocol will vary depending on the selected option (Fiber, Radio, or Leased Line).

e. Output Remote Responses to DFOC. This task handles the protocol necessary **to** output CMS responses, MOE's, and Status information back to the DFOC via the Cable Modulator. It must also multiplex local processor status (including video chain switcher command acknowledgment) with the data stream received from the remote devices. Speed buffering and storage is provided to match potentially higher (megabit) burst rates from fiber to the slower 56KB steady stream to the DFOC.

4.6.2.3.2 Detection Node

The control processor in the detection node shares some common functions with the junction node. It also has additional required capabilities. The following major tasks are defined:

a. Receive control commands. Inputs come from the Fiber / Radio / Leased Line interface (as applicable) and consist of BIT status requests, node configuration change commands such as addresses of associated linked controllers), commands to a (possibly linked) cross-roadway ramp controller, and synchronization information to control sorting of detector derived MOE's. The commands must be validated by the software and then acted upon.

Control commands change the internal software configuration and operation. These should be stored in some sort of non-volatile (e.g., Flash EEPROM) for power fail recovery purposes. There should also be an acknowledgment of the command queued for output back to the DFOC.

Commands addressed to the cross-roadway controller should be queued for output to the auxiliary port.

Commands addressed to nodes other than this one or the associated cross-roadway controller should be discarded.

b. Calculation of MOE's. Depending on the configuration of the node, several sub-tasks could be defined. The software is responsible for collecting inputs from the loop detector (or alternate loop equivalent) devices at nominal 10 millisecond intervals, determining vehicle presence or non-presence, and accumulating volume and occupancy, using the same algorithm as currently implemented in the Concurrent mainframe for processing CCU inputs from the loop RCU's. This data must be accumulated on a lane-by-lane basis for reporting back

When a timing gate is implemented in the node, the software shall calculate the average speed of traffic flow using the same algorithm as in the Concurrent system Alternatively, speed shah be derived based upon vehicle classification and adjustments received from the Concurrent mainframe for adjacent nodes when a single loop arrangement exists at the node.

Provisions should be made to clear all internal counters upon command of the Concurrent control program.

c. Reporting of MOE's and Algorithm Reset. The merged / calculated volume, occupancy, and speed shall be queued for output to the (Fiber, Radio, or Leased Line as applicable) port at the interval configured in the program ROM or the interval commanded from the headend Concurrent control program. This data will be sent at a nominal rate of once each 20 seconds for fusion with previous node data.

Since the Concurrent contains the logic to "smooth" and "average" the collected MOE's at the 20 second interval into larger 1 minute intervals, it should not be necessary to perform any filtering of data at the node. Once a set of MOE's is calculated, the counters should be reset to zero and the software will start all over again.

d. Accept responses from auxiliary node. The software must accept inputs from the Cross-roadway node via the auxiliary port for combination with its own responses and queuing for output back to the DFOC.

e. Output queue handling. The software must time-division multiplex the outputs resulting from tasks a, c, and d, format them, and output them to the selected communication medium (Fiber, Radio, or Leased Line). The appropriate device drivers and data protocol formatting should be implemented independently to preserve as much device-independence as possible. This is primarily a store-and-forward message switch task.

The software must also format and output the commands received for the Cross-roadway node to the auxiliary port.

f. Built-in test. The software shah detect on-line faults in the control processor (as evidenced by erroneous operation of any control port) and report them along with the MOE's to the DFOC.

The software shall support the capability to perform an "off-line" self test (and a startup self test) of processor logic and interface logic that more rigorously tests each subsystem and reports the results so that faults may be isolated down to the lowest

LRU (or group). Consideration should also be given to diagnostics that will isolate parts down to the lowest SRU, although this may be something that is loaded and run only in the shop environment.

4.6.2.3.3 Video Node

The control processor in the video node has the fewest required functions of all node types since it is not involved in processing the video signal and it is assumed a video node is located on the LAN and thus does not need to be concerned with remote radio operation across the freeway. It is possible that a ramp control node may use the video node's LAN hookup, however. Additionally, provision is made for use of a wireless interface to the PTZ camera interface.

a. Receive control commands. Inputs come from the Fiber / Radio / Leased Line interface (as applicable) and consist of BIT status requests, node configuration change commands (such as addresses of associated linked controllers), commands to a (Possibly linked) cross-roadway ramp controller, and Pan / Tilt / Zoom commands to be sent to the camera. The commands must be validated by the software and then acted upon.

Control commands change the internal software configuration and operation. These should be stored in some sort of non-volatile (e.g., Flash EEPROM) for power fail recovery purposes. There should also be an acknowledgment of the command queued for output back to the DFOC.

Commands addressed to the cross-roadway controller should be queued for output to the Aux port.

Commands addressed to this node's camera control mechanism must be passed to the camera controller. The method of doing this, and the ports used will vary depending on whether the camera is linked via wireless or wired connections. The commands should be queued to a generic output device handler to minimize software differences.

Commands addressed to nodes other than this one or the associated cross-roadway controller should be discarded.

b. Reporting of status. The software should acknowledge all commands sent to the camera PTZ mechanism. The software should also report internal node status periodically so that the health of the node may be monitored by the DFOC processor to enable fault detection as soon as possible. The software should send a status report back to the DFOC at least once each 5 minutes (), even if no control or other commands have been received. Since responses from an auxiliary node are handled transparently back to the DFOC, the presence or absence of such a node has no bearing on this requirement.

c. Accept responses from Aux node. The software must accept inputs from the Cross-roadway node via the Aux port for combination with its own responses and queuing for output back to the DFOC.

d. Output queue handling. The software must time-division multiplex the outputs resulting from tasks a, b, and c, format them, and output them to the selected communication medium (Fiber, Radio, or Leased Line). The appropriate device drivers and data protocol formatting should be implemented independently to preserve as much device-independence as possible. This is primarily a store-and-forward message switch task.

The software must format and output the commands received for the Cross-roadway node to the Aux port.

The software must format commands for the camera PTZ mechanism received from the DFOC and output them to the camera control. Both wireless communication (with status return) and wired communication (possibly via different ports) must be supported. Note that translation of the DFOC camera control device into a different form or content may be required to accommodate new camera control logic. This translation is the responsibility of the node control processor.

e. Built-in test. The software shall detect on-line faults in the control processor (as evidenced by erroneous operation of any control port) and report them to the DFOC as soon as they are detected. Once a fault is detected, there is no need to continuously send the status to the DFOC at an interval more frequent than specified above for normal status reports.

The software shall support the capability to perform an “off-line” self test (and a startup self test) of processor logic and interface logic that more rigorously tests each subsystem and reports the results so that faults may be isolated down to the lowest LRU (or group). Consideration should also be given to diagnostics that will isolate parts down to the lowest SRU, although this may be something that is loaded and run only in the shop environment.

4.6.2.3.4 CMS/HAR Interface

The functions of the CMS/HAR interface node are nearly identical to those for the video node when the camera control port’s interface is replaced by the CMS or HAR controller.

The control processor software in a CMS or HAR interface node shall “transparently” . (without modifying the commands or responses) switch the packets to and from the attached CMS or HAR. This may be done using either a regular port (such as the camera port equivalent) or the auxiliary port.

4.6.2.4 DFOC Headend Software Modifications

Software modifications will be required to the headend computer equipment. It is hoped that the scope of these modifications has been minimized through the careful interface design. The following sections discuss only the nature of the changes, not the specific changes, since the internals of each computer are not specifically known at this time. Most of the information herein is based on discussions with of MDOT.

4.6.2.4.1 Vicon VPS-1300

The Vicon video switcher should require no special modifications other than possible table modifications to accommodate additional camera inputs and additional monitor outputs.

4.6.2.4.2 Camera Control PC

The current video and camera control should not require modifications beyond possibly enabling additional camera addresses, by simple table updates.

4.6.2.4.3 Vultron CMS Controller

The Vultron CMS controller should not require any modifications beyond adding new CMS addresses to its internal tables.

4.6.2.4.4 Concurrent 3280MPS

It has been confirmed with MDOT personnel that there should be no problem with merging new detector inputs at the 20 second data fusion point in its processing. It is estimated that all that will be required is to expand some working arrays which hold the data (and also store it on disk) along with the associated array index limits. A new **task to** perform this function as the data is received from remote nodes is required.

a. Serial I/O handling. A new serial I/O handler is required to manage data input and output via the new control / status return interface. The standard Concurrent common serial port protocol driver will most likely be capable of handling the actual device-level interface.

b. Detector failure to report and reported faults. A new software task to handle faults and also internally generated fault indications when detection nodes fail to report new information (detected when the data is needed for merging) will be required.

   A new software task to format and display these faults (or merge the reports in with the existing fault reporting subsystem) will be required.

c. Operator Interface. The existing operator interface will require modification to accept commands for ramp overrides, node configuration changes, and commands for node off-line self test for the new node types. This capability goes beyond the current operator interface, but should be compatible with it.

d. Graphic Display Subsystem interface. The Concurrent sends volume, occupancy, and speed on a 1 minute update basis to the GDS (without the GDS requesting it). The scope of this data must be increased to include the newly instrumented sections of roadway.

4.6.2.4.5 Graphic Display Subsystem

The Graphic Display Subsystem interface will remain the same except additional volume, occupancy, and speed, and ramp control information must be sent on the 1 minute update basis. It is hoped that the GDS map displays are table driven so that minimal software (just table) updates are required to add the new I-75 corridor (which now appears in “grey” on the map up to 8 Mile Road). If the instrumentation is extended beyond 8 Mile Road, it will not be covered by the current map, and far more significant changes to the GDS database will be required to include it.

Adding new ramp controller detailed views is also a database modification task. There are probably existing ramp views that can be copied and modified to include the new ramps. The internal tables of ramps will need to be updated. Software modifications should be minimal provided that sufficient software documentation of the existing system is available.

4.6.2.5 Interface Data Definitions

Table 4-26 lists each of the interfaces and the top-level data types that are passed on them.

Table 4-26. Initial Deployment Interfaces

From	To	Data Types	Comm Method
MTC/DFOC Headend			
3280 MPS	I-94 Junction (Detection, Ramp, and Video Nodes)	Ramp Parameters Status Requests Node Configuration Commands	56Kb Cable Modulator (multiplexed with CMS data)
Vultron CMS Controller	New CMS	CMS Control / Configuration Data (via “modem” port)	56Kb Cable Modulator
Camera Control PC	Video Nodes	Camera Pan/Tilt/Zoom Commands	Camera 18. MHz Cable Modulator
I-94 Junction (Detection, Ramp, and Video Nodes)	3280 MPS	Detector: Volume, Occupancy, Speed, Time, Node Status Ramp: Volume, Occupancy, Flow Rate, Time, Node Status Video: Camera and Node Status	56Kb Cable Demodulator (Multiplexed with CMS return data)
Video Node	VICON VPS-1300	NTSC Video	Blonder-Tongue Cable Video Demod.
CMS	Vultron CMS Controller	CMS Status Responses (via “modem” port)	56Kb Cable Demodulator

Junction			
Video Node	Cable Video Modulators	NTSC Video from Camera(s)	Fiber Bundle or Leased Lines to Cable Conversion
Detection, Video Nodes	Headend	MOE's, Node Status	Fiber, Radio, or Leased line to 56Kb Cable Modulator
Camera Control Demod	Video Nodes	Pan/Tilt/Zoom commands	Cable Demod to Fiber, Radio, or Leased Line Conversion
Node & CMS Command Demodulator	Detection, Video Nodes	Ramp Parameters Status Requests Node Configuration Commands	56Kb Cable Demod. To Fiber, Radio, or Leased Line Conversion
Detection Station Node			
DFOC Headend	Node Control Processor	Node Configration Commands Self test Requests Time Synchronization Commands (Also Node Configuration Commands and self test requests to cross-roadway interfaced ramp controller)	Fiber, Radio, or Leased Line Demodulator
Node Control Processor	DFOC Headend	Volume, Occupancy, and Speed MOE's Node Status and Time Tags Node Off-line BIT Status (Also Node MOE's and Status for cross-roadway interfaced ramp controller)	Fiber, Radio, or Leased Line Modulator
Loop Detector (or equivalent)	Node Control Processor	Loop Detect / No Detect Status	Wireline inside cabinet
Video Node			
DFOC Headend	Node Control Processor	Node Configuration Commands Self test Requests Time Synchronization Commands Camera Pan/Tilt/Zoom Commands Fiber Video Modulator On/Off (Also Node Configuration Commands and self test requests to cross-roadway interfaced ramp controller)	Fiber, Radio, or Leased Line Demodulator
Node Control Processor	DFOC Headend	Node Status and Time Tags Node Off-line BIT Status Camera/Modulator Command Acknowledgements (Also Node MOE's and Status for cross-roadway interfaced ramp controller)	Fiber, Radio, or Leased Line Modulator

Node Control Processor	Camera Control Logic	Pan, Tilt, and Zoom Commands	Wireless modem or wireline
Camera Control Logic	Node Control Processor	Camera subsystem status	Wireless modem or wireline
Camera Video	DFOC Headend	NTSC Video	Fiber, wireless, or Leased Line
CMS or HAR Node			
DFOC Headend	Node Control Processor	Node Configration Commands Self test Requests Time Synchronization Commands CMS or HAR Commands (Also Node Configuration Commands and self test requests to cross-roadway interfaced ramp controller)	Fiber, Radio, or Leased Line Demodulator
Node Control Processor	DFOC Headend	Node Status and Time Tags Node Off-line BIT Status CMS or HAR subsystem Acknowledgements and status (Also Node MOE’s and Status for cross-roadway interfaced ramp controller)	Fiber, Radio, or Leased Line Modulator
CMS or HAR	Node Control Processor	CMS or HAR Control Commands	Wireless modem or wireline
Node Control Processor	CMS or HAR	CMS or HAR Subsystem Acknowledgements and status	Wireless modem or wireline

The following subsections define the format for data packets passed over the major interfaces in more detail. Note that camera control commands and CMS / HAR commands remain the same as they are now, but they will be “wrapped” in a packet with destination identified for routing over the selected communication system.

4.6.2.5.1 Headend to Remote Nodes

Commands to the remote nodes are already defined in the case of camera controls and CMS commands. It is intended that these be “wrapped” in some sort of digital envelope at the DFOC headend, which is then converted, if required, at the junction. Both CMS and CCTV camera controls carry their own node addressing information, which will have to be checked at each CMS / Video node. The general format is shown in Table 4-27 below:

Table 4- 27. CCTV Camera / CMS Commands

Field	Number of Bits	Usage
Packet Header	16 Nominal	Identifies start of a new packet for synchronization.
Data Identifier (Apply ONLY at Junction, Not Headend)	16 Nominal	Identifies the source of the data – Camera Controller or CMS/HAR Controller. This is applied ONLY at the I-95/75 junction by the Control Processor there since these commands arrive over different cable channels from the headend.
Camera Information or CMS Command	Predefined	Identifies the camera address (8 bits) and the function (16 bits) as documented already at the DFOC -or- identifies the CMS and its function as documented by Vultron.
Packet Trailer	16 Nominal	Identifies end of a packet for synchronization

Commands from the 3280MPS to the Detection, Ramp, and Video Nodes should all be formatted into a standard packet which is easily distinguished from camera control packets. The general format is shown in Table 4-28. Note that 16 bit words are defined for nearly all entries. This should be done to make the software easier and memory access faster, even when only 8 bits are used. 16 bits is also the granularity of some types of LAN controllers.

Table 4-28. 3280MPS Commands

Field	Number of Bits	Usage
Packet Header	16 Nominal	Identifies start of a new packet for synchronization. Should be different than Packet Header used for Camera Control.
Packet ID	16 Nominal	Identifies the function of this packet (for example Set Node Time)
Node Address	16 Nominal	Identifies the node to which the command is addressed. Provision should be made for an "all call" or "all nodes" address (such as all ones except the LS bit)
Packet Word Count	16	Number of significant 16-bit words following this entry, excluding the check word
Control Information	Varies	Each control item (e.g., date, hour, minute, second) needed for the particular control function
Check Word	16	16- bit add-and-left-rotate (discard carry) checksum over all data in the packet following the packet header and excluding the check word itself.
Packet Trailer	16 Nominal	Identifies end of a packet for synchronization

4.6.2.5.2 Remote Nodes to Headend

The format of the packets from the remote nodes to the headend are similar to those from the headend to the nodes. The data is different, of course. The node control processors will generate the packets. The junction control processor may strip off certain information in the case of the CMS responses to maintain compatibility with current formats. The Demux at the headend may also have to strip off some identifying information in order to present the CMS Controller with the exact format of a response as it would get from a direct wireline modem hookup. Table 4-29 illustrates this.

Table 4-29. CMS Responses

Field	Number of Bits	Usage
Packet Header	16 Nominal	Identifies start of a new packet for synchronization (strip at headend demux)
Data Identifier	16 Nominal	Identifies the data as CMS / HAR Controller response. This must also be stripped by the headend demux after it is used to route the received data.
CMS Response	Predefined	Identifies the CMS response function as documented by Vultron
Packet Trailer	16 Nominal	Identifies end of a packet for synchronization (junction node before sending to headend demux)

BIT responses and node MOE' s and status must bepacketized by the node controllers. The format is similar to that for the 3280 MPS headend commands, as shown in Table 4- 30.

Table 4-30. Node Controller Responses

Field	Number of Bits	Usage
Packet Header	16 Nominal	Identifies start of a new packet for synchronization. Should be different than Packet Header used for CMS Responses.
Packet ID	16 Nominal	Identifies the function of this packet (for example, Detector MOE Report)
Node Address	16 Nominal	Identifies the node from which the response is sent
Packet Word Count	16	Number of significant 16-bit words following this entry, excluding the check word
Control Information	Varies	Each item (e.g., volume, occupancy, speed, minute, second, node status) needed for the particular response
Check Word	16	16-bit add-and-left-rotate (discard carry) checksum over all data in the packet following the packet header and excluding the check word itself.
Packet Trailer	16 Nominal	Identifies end of a packet for synchronization

4.6.2.5.3 Remote Video to Headend

Video will be standard NTSC carried via fiber analog modulators, cable analog modulators, or wireless video modulators. Leased line will require CODEC equipment to digitize the video and send it with reduced (T1 carrier -- 1.5 MHz) bandwidth. Formats will depend on the CODEC vendor.

Appendix A - Prohibition of Discrimination In State Contracts

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Appendix B - Acronyms

AHAR	Automatic Highway Advisory Radio
ANSI	American National Standards Institute
ATIS	Advanced Traffic Information System
ATMS	Advanced Traffic Management System
BBS	Bulletin Board System
CATV	Cable Television
CCITT	European standards association
CCTV	Closed Circuit Television
CMAQ	Congestion Management Air Quality
CMS	Changeable Message Sign
COTS	Commercial Off-The-Shelf
CPU	Central Processor Unit
CSMA/CD	Carrier Sense Multiple Access/Collision Detection
DFOC	Detroit Freeway Operations Center
DFOU	Detroit Freeway Operations Unit
DOS	Disk Operating System
EEPROM	Electrically Erasable Programmable Read Only Memory
EIA	Electronic Industries Association
EISA	Extended Industry Standard Architecture (computer bus standard)
EMI	Electromagnetic Interference
FC	Foot Candle (unit of light intensity)
FHWA	Federal Highway Administration
GDS	Graphic Display System
HAR	Highway Advisory Radio
HAZMAT	Hazardous Materials
ISA	Industry Standard Architecture (computer bus standard)
IVHS	Integrated Vehicle Highway Systems
Kbps	thousands of bits per second
KByte	thousands of bytes
MByte	millions of bytes
MDOT	Michigan Department of Transportation
MDTS	Metropolitan Detroit Transportation Svstem
MEP	Michigan Emergency Patrol
MIPS	Million Instructions per Second
MITS	Michigan Intelligent Transportation Systems
MITSC	Michigan Intelligent Transportation Systems Center
MOE	Measure of Effectiveness
MSP	Michigan State Police
NEMA	National Electrical Manufacturers Association

Appendix B - Acronyms (continued)

NTSC	National Television Standards Committee
PCS	Personal Communications Service
PDL	Program Design Language
RCOC	Road Commission for Oakland County
RCU	Remote Communication Unit
RDBS	Radio Data Broadcast System
RFI	Radio Frequency Interference
RFP	Request for Proposal
SAE	Society of Automotive Engineers
SCSI	Small Computer System Interface
SEMCOG	Southeast Michigan Council of Governments
TOC	Transportation Operation Center
TOD	Time of Day
VME	computer bus standard
lux	unit of light intensity
vph	vehicles per hour
vpm	vehicles per minute