Ontario

Book 19

Advanced Traffic Management Systems

Ontario Traffic Manual

December 2007

Ontario Traffic Manual

Foreword

The purpose of the Ontario Traffic Manual (OTM) is to provide information and guidance for transportation practitioners and to promote uniformity of treatment in the design, application and operation of traffic control devices and systems across Ontario. Further purposes of the OTM are to provide a set of guidelines consistent with the intent of the *Highway Traffic Act* and to provide a basis for road authorities to generate or update their own guidelines and standards.

The OTM is made up of a number of Books, which are being generated over a period of time, and for which a process of continuous updating is planned. Through the updating process, it is proposed that the OTM will become more comprehensive and representative by including many traffic control devices and applications specific to municipal use. Some of the Books of the OTM are new, while others incorporate updated material from the Ontario Manual of Uniform Traffic Control Devices (MUTCD) and the King's Highway Guide Signing Policy Manual (KHGSPM).

The Ontario Traffic Manual is directed to its primary users, traffic practitioners. The OTM incorporates current best practices in the Province of Ontario. The interpretations, recommendations and guidelines in the Ontario Traffic Manual are intended to provide an understanding of traffic operations and they cover a broad range of traffic situations encountered in practice. They are based on many factors which may determine the specific design and operational effectiveness of traffic control systems. However, no manual can cover all contingencies or all cases encountered in the field. Therefore, field experience and knowledge of application are essential in deciding what to do in the absence of specific direction from the Manual itself, and in overriding any recommendations in this Manual.

The traffic practitioner's fundamental responsibility is to exercise engineering judgement and experience on technical matters in the best interests of the public and workers. Guidelines are provided in the OTM to assist in making those judgements, but they should not be used as a substitute for judgement.

Design, application and operational guidelines and procedures should be used with judicious care and proper consideration of the prevailing circumstances. In some designs, applications, or operational features, the traffic practitioner's judgement is to meet or exceed a guideline while in others a guideline might not be met for sound reasons, such as space availability, yet still produce a design or operation which may be judged to be safe. Every effort should be made to stay as close to the guidelines as possible in situations like these, to document reasons for departures from them, and to maintain consistency of design so as not to violate driver expectations.

Custodial Office

Inquiries about amendments, suggestions or comments regarding the Ontario Traffic Manual may be directed to:

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A user response form is provided at the end of Book 1. Inquiries regarding the purchase and distribution of the OTM Books and the Master Sign Library (MSL) may be directed to the custodial office identified above, or to the OTM Committee's current publishing agent.

Inquiries specific to Book 19 (Advanced Traffic Management Systems) can be directed to the Lead Office for this book as shown below:

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1. Introduction

1.1 Background

For many years, the two primary traffic manuals used in Ontario were the Ontario Manual of Uniform Traffic Control Devices (MUTCD) and the King's Highway Guide Signing Policy Manual (KHGSPM). In recent years, the Ministry of Transportation Ontario (MTO) has been moving away from direct service delivery, towards a role of service management with service delivery provided by others, including the private sector and municipalities. As a result, traffic management and the design and implementation of traffic control devices are becoming the direct responsibility of a greater number of governing road authorities or their agents. This includes new players in the field with varying degrees of knowledge and expertise. This new direction has prompted the need to move away from the reference manuals of the past, towards a more comprehensive user's manual.

1.2 Purpose and Scope

Book 19 (Advanced Traffic Management Systems) is one of a series of volumes that makes up the Ontario Traffic Manual (OTM). Book 19 should be read in conjunction with Book 1 (Introduction to the Ontario Traffic Manual) and its appendices, which contain essential information on the fundamental principles and policies behind the design and application of traffic control signs, signals, markings and delineation devices. Applicable Ontario experience has also been provided to illustrate current practices within the Province of Ontario.

This Ontario Traffic Manual, Book 19, provides information about the planning, design, installation and operation of ATMS and incorporates relevant operational guidelines and technical standards. It is intended for use by both the experienced practitioner as well as the newcomer to the field. Book 19 therefore presents a greater amount of information with respect to practical guidance, engineering principles and application details than contained within previous manuals. The book explains not just the "what to do" aspects, but also the "why", in terms that will lead the reader to think carefully about relevant considerations and the choices to be made, in order to reach the best decision for the given circumstance. Book 19 serves as a practical and useful user manual instead of purely a reference manual and is available for use by the traffic and transportation community within Ontario, North America and the world.

It is assumed that the readers of the OTM have a basic understanding of traffic engineering principles.

1.3 History of ATMS in Canada

Canada is a leader in Advanced Traffic Management Systems (ATMS) with many pioneering efforts that have taken place in Ontario and across the country. The world's first computerized traffic signal management system commenced operation in Toronto in 1959. Freeway traffic management systems (FTMS) also have a history in Toronto with the first implementation of the COMPASS system (FTMS) initiated in 1975 in the Queen Elizabeth Way (QEW) corridor through Mississauga. Since then, COMPASS has been expanded to several key highway corridors where it now manages over 190 centreline kilometres of freeway including the QEW in Mississauga and Burlington, Highway 401 across Toronto and Highway 417 in Ottawa. Based on the successes of these initial installations, ATMS deployment has expanded across the country. Today, ATMS continues to be a major focus in managing the nation's transportation networks with systems being deployed throughout the country.

Highlights of some of the more significant ATMS achievements in Ontario are listed below:

1959 World's 1st experiment in computerized traffic control for the City of Toronto

1964 World's 1st full-scale traffic signal system using digital computer technology for the City of Toronto

1975 Field tests of real-time control of traffic signals in the City of Toronto

1975 COMPASS freeway traffic management system (FTMS) for the QEW in Mississauga

1976 Canada's second centralized traffic signal system in the City of Ottawa

1978 World's 1st second-generation traffic signal system in the City of Toronto

1982 Computerized traffic signal control available for smaller municipalities

1985 Canada's 1st corridor management system (COMPASS) implemented on the QEW in Burlington, Ontario

1990 Canada's first PC-based centralized traffic signal system implemented in the City of Ottawa

1991 COMPASS on Highway 401 in Toronto, North America's 1st freeway traffic management system (COMPASS) to utilize an all fibre optic communications system and amber-coloured LED variable message signs

1992 First SCOOT demonstration in City of Toronto

1994 Start of operation of the City of Toronto's RESCU FTMS system on the Gardiner Expressway, Lake Shore Boulevard and Don Valley Parkway

1995 SCOOT system in Toronto, now 3rd largest installation in the world

1995 Combo smartcard implemented for the public transportation system in Burlington, Ontario

1996 Ministry of Transportation Ontario as partner in the AURORA consortium of U.S., Canadian and European highway agencies, promotes collaborative research, development and deployment of advanced road weather information systems (ARWIS)

1996 Use of CCTV cameras in City of Ottawa to monitor arterial roads and supplement traffic signal management

1997 World's 1st all-electronic open road tolling system, fully accessible to general public – 407 Express Toll Route (407 ETR)

1999 Total conversion of Toronto SCOOT to version 7 software and decommissioning of original SCOOT computer systems

2003 Implementation of cellular communications (GSM/GPRS) for City of Ottawa's traffic signal system

2003 Operation of Canada's 1st Queue Warning System (QWS) along General Brock Parkway (previously known as Highway 405) and QEW on the approaches to the U.S. international border in the Niagara Region

2004 Operation of an incident detection and Advance Warning Sign (AWS) System for the High Occupancy Vehicle Bypass Tunnel at the Highway 404/401 Interchange

2007 Operation of a QWS along Highway 402 on the approaches to the U.S. international border in Sarnia

The concepts and objectives of ATMSs are introduced and discussed throughout this document under the following five categories:

- Information Collection
- Surface Street Control
- Highway Control
- Regional Traffic Control
- Traffic Information Dissemination
- Special Applications

Detailed descriptions of each category are provided in Section 2 of this document.

2. Advanced Traffic Management Systems Overview

Intelligent Transportation Systems (ITS) is the application of technology to better manage the transportation network. More specifically, the Intelligent Transportation Systems Society of Canada (ITS Canada) has defined ITS as:

"*the application of advanced and emerging technologies (computers, sensors, control, communications, and electronic devices) in transportation to save lives, time, money, energy and the environment.*"

The goal of ITS in road transport is to achieve improvements in mobility, safety, and the productivity of the transportation system through the integrated application of advanced monitoring, communications, computer, display, and control process technologies, both in the vehicle and on the road. Under the umbrella of ITS, Advanced Traffic Management Systems (ATMS) have proven to be one of the most successful components in accomplishing these objectives. This section provides an overview of the types of systems and functionality that can be provided through Advanced Traffic Management Systems.

Under the ITS Architecture for Canada, Traffic Management is one of the eight user-service bundles. The primary focus of OTM Book 19 is the Traffic Control user service contained within this bundle. For more information on the ITS Architecture for Canada and the related user services, the reader is referred to Transport Canada's website (www.its-sti.gc.ca/Architecture/).

2.1 Information Collection

Strategic traffic management and control requires information about the operational state and characteristics of traffic flow. The parameters most relevant to ATMS include:

- *Traffic Flow or Volume* – the number of vehicles passing a point per unit of time;
- *Vehicle Speed* – the distance travelled by a vehicle per unit of time, usually expressed in km/h;
- *Traffic Density* – the number of vehicles occupying a road lane per unit of length at a given point in time;
- *Occupancy* – similar to traffic density, usually expressed as a percentage representing the percentage of time a detection zone on the road is occupied;
- *Incident* – an unplanned event that occurs within a roadway (on the travelled portion, shoulder or roadside) that impacts the capacity of the roadway. Relevant details of an incident include date/time, location, direction of travel, type of impact, class of collision (fatal, personal injury, property damage), weather condition, road surface condition, number of vehicles involved, number of lanes blocked, etc.; and
- *Weather Conditions* – relevant details on current weather conditions, such as wind speed, humidity, temperature, visibility, etc.

To measure these parameters, many different types of detectors/sensors are available, including roadway sensors and vehicle probes. Part of the challenge of information collection is to gather information that is both accurate and relevant for traffic management purposes, and current enough to be useful.

2.1.1 Roadway Sensors

Roadway sensors can be divided into several categories: embedded or intrusive (i.e., embedded in the pavement), non-intrusive (i.e., installed off the pavement), and environmental. The following is a list of the more commonly used sensors:

Embedded (Intrusive) Detectors

- *Inductive Loop* – An Inductive Loop Detector consists of a copper wire embedded in the road surface in the shape of a loop (e.g., square, rectangular, diamond, etc.). Passing an electrical current through the copper wire induces a magnetic field in the vicinity of the loop. Typically, a loop will consist of three to five “turns” of copper wire in the ground. Connecting the loop to a roadside cabinet through a lead-in cable allows electronic equipment to monitor the magnetic field and changes in inductance as a vehicle passes over the loop.
- *Magnetometer* – Magnetic detectors are little pencil-shaped/cylindrical probes, placed vertically in or beneath the road surface. They measure changes in the earth’s magnetic field as a vehicle passes over them.

Non-Intrusive Detectors

- *Radar* – Radar detectors actively emit radio wave signals and can register vehicular presence and speed, depending upon the characteristics of the signal returned to them by the moving vehicles. Currently, there are two types of radar detectors: Doppler, which measure the change of frequency between the transmitted and received signals, and Time of Flight, which measure the difference in time between when the signal is transmitted and received.

- *Infrared* – Infrared detectors send out invisible infrared radiation pointed at the road surface. By comparing the radiation reflected from a passing vehicle with the radiation from the road surface, the sensor can detect the presence of a vehicle.

- *Ultrasonic* – Ultrasonic detectors emit continuous (Doppler) or short interval (Pulsed) signals directed to the road surface. The Doppler detector measures the shifts in frequency of signals reflected by passing vehicles to detect and determine their speeds. The Pulsed detector measures the time taken by reflected signals to return to the sensor.

- *Acoustic* – Acoustic detectors use microphones and signal processing technology to listen for sounds made by passing vehicles to determine the presence of a vehicle.

- *Video Image Processing (VIP)* – Video image processing utilizes images provided by video cameras installed near the roadway. "Machine Vision" algorithms are combined with computerized pattern recognition software to detect passing vehicles.

- *Closed Circuit Television (CCTV) Cameras* – CCTV cameras are used to monitor traffic flow conditions and verify traffic congestion and incidents. Typically, CCTV cameras provide visual images to aid operations centre personnel in determining and verifying causes of congestion, such as collisions, vehicle breakdown, load spills, construction/maintenance activities, police/fire operations, or just heavier than normal traffic.

Environmental Sensors

- *Atmospheric Sensors* – measure a variety of weather-related data, including wind speed and direction, air temperature, humidity, precipitation occurrence/accumulation and visibility. Video images can also be utilized to confirm conditions (e.g., precipitation, visibility, etc.).

- *Road Surface Sensors* – measure road surface temperature as well as ascertain a variety of information with respect to the road surface such as wet or dry, presence of chemicals (e.g., anti-icing, de-icing, etc.), presence of snow, ice or frost, etc.

- *Sub-surface Sensors* – measure the temperature at different depths in the substrate directly below the roadway.

2.1.2 Probe-Based Sensors

Probe-based sensors measure the movement of a percentage of the vehicles in the traffic stream in order to assemble real-time traffic information. Probe-based monitoring can be a very effective method of data collection for wide area monitoring where large geographic areas are involved. Probe-based sensors typically provide measurements on link speeds, link travel times, and origin and destination of vehicles travelling through the transportation system. The following is a list of the more commonly used probe-based sensors:

- *Vehicle Probes* – Vehicles equipped with on-board units that allow the time and location of the vehicle to be tracked using Automatic Vehicle Identification (AVI) or Automatic Vehicle Location (AVL) devices. Examples of commonly used devices include Global Positioning Systems (GPS) for AVL such as those used for monitoring of commercial vehicle fleets and E-ZPass transponders for AVI purposes, used throughout the Northeastern United States for electronic toll collection purposes. Cellular telephones can also be used for this purpose where the handset is located using either GPS or through information collected via the cellular transmission towers.

- *Mobile Reports* – Traditionally, emergency telephones (i.e., call boxes) installed along roadside facilitates have been used to report traffic problems to a traffic operations centre. However, with the proliferation of cellular telephones in recent years, the use of call boxes has significantly reduced. Instead, mobile reporting from patrol vehicles and private citizen calls through toll-free hotlines has become a valuable resource for quick detection of incidents and collection of traffic and incident information. This system has the advantage of low start-up cost and two-way communications between the caller and the response agency. It can, however, cause a high volume of calls when a major incident occurs. Also, it is sometimes difficult to verify the location of an incident when calls are received from private callers.
- *Designated Spotters* – Designated vehicles can be utilized to act as vehicle probes and/or as spotters for traffic incidents. These vehicles can be select vehicles from a government agency fleet (e.g., road maintenance, service patrol, etc.) or vehicles of regular commuters.

2.2 Surface Street Control

Surface Street Control refers to the monitoring, control and management of traffic operations on municipal streets and arterials. The primary application of ITS within Surface Street Control is the management of signalized intersection control and the assignment of right-of-way for all users of the transportation network including vehicles (e.g., passenger cars, trucks, transit vehicles, emergency response vehicles, maintenance vehicles, etc.), cyclists and pedestrians. This section describes surface street control systems from a network perspective addressing signal coordination techniques, system types and vehicle priority systems. A range of traffic signal control systems are represented ranging from static pre-timed control systems to fully traffic-responsive systems that dynamically adjust control plans and strategies based on current traffic conditions and priority requests. For a more detailed discussion on the operational aspects of traffic signals (e.g., signal phasing, timing, vehicle actuation, etc.), the reader is referred to OTM Book 12 (Traffic Signals). The remainder of the traffic signal information in this book refers to the operation of groups of signals in systems.

The major objectives of Surface Street Control Systems are to:

- Maximize the capacity of the existing road network through the optimization of traffic signal operation;
- Improve safety for all road users, including vehicles, cyclists and pedestrians;
- Reduce delays, stops and fuel consumption associated with the operation of traffic signals for all road users;
- Monitor the operation of traffic signal equipment and report malfunctions to minimize equipment "down time" and maximize maintenance efficiency; and
- Monitor traffic conditions and collect real-time traffic data.

A typical Surface Street Control System consists of intersection control equipment (i.e., intersection controller, signal heads, etc.), detection equipment (i.e., vehicle detector, pedestrian detector, bicycle detector, etc.), communications network and a computer system to provide central control and monitoring functions of the field equipment.

Multiple Surface Street Control Systems in a region should be capable of sharing data with each other electronically. The objective of this information exchange is to allow adjacent jurisdictions to provide area-wide signal coordination along major corridors and road networks regardless of jurisdictional boundaries.

The primary objective of a traffic signal is to safely assign right-of-way to vehicles, cyclists and pedestrians all competing for the use of the same road space at intersecting roadways. Typically, this is achieved using intersection control equipment with right-of-way assigned, based on the presence of vehicles, pedestrians and bicycles. Priorities between road users and vehicle types can vary, and for this reason many traffic signal systems offer a method of providing priority service to accommodate transit vehicles, emergency response vehicles and operation of at-grade rail crossings located in close proximity to signalized intersections. Both local and centralized methods of priority control are available.

A secondary application of ITS within Surface Street Control is lane management, which involves the restriction of specific lanes of a roadway to designated vehicle types, direction of travel or other purposes. It involves the use of lane control signs (LCSs) and a central control and monitoring system. Lane management systems are commonly used for reversible lane operation on urban arterials as well as bridges and tunnels, for high occupancy vehicle (HOV) / high occupancy toll (HOT) lane management, and have also been applied for traffic management purposes through construction zones. Typically, they are applied to traffic bottlenecks where roadway expansion is difficult due to right-of-way or cost restrictions. Their primary objective is to maximize the capacity of existing roadway infrastructure for specific vehicles or to alter a direction of travel.

2.3 Highway Control

Highway Control uses roadside equipment and communications to monitor traffic conditions on the highway network for traffic management, incident detection and management, ramp metering and access control. Typically, it is applied to high-volume, access-controlled highways located within or in close proximity to large population centres.

Highway control employs monitoring techniques and adaptive control strategies to maximize the efficiency of traffic movement and better manage traffic congestion.

It is widely recognized that the occurrence of an incident and the resultant blockage of travel lanes and/or shoulders has a dramatic effect on the capacity of the roadway. It therefore follows that the faster an incident can be cleared the less impact it will have on the operation of the highway network. Incident management refers to the timely detection of incidents and the dissemination of relevant information to emergency response agencies, maintenance personnel, traffic management staff and motorists in order to minimize the duration and impact of the incident on the transportation network.

Ramp metering and access control is the application of control devices such as traffic signals, signing and gates to regulate the rate of vehicles entering the freeway. In general, the primary focus of ramp metering and access control is to reduce congestion and the associated delays on the mainline, with the objective of balancing demand and capacity of the freeway.

2.4 Regional Traffic Control

Regional Traffic Control enhances the Surface Street Control and Highway Control by adding the communications links and integrated control strategies that enable integrated inter-jurisdictional traffic management. Regional traffic control can be applied to a freeway/arterial corridor consisting of a freeway, arterial road or combination of both. A typical Regional Traffic Control System consists of traditional traffic control such as regulation, warning and guidance of traffic, as well as freeway management activities such as vehicle monitoring, incident detection and management, provision of motorist assistance and traffic information dissemination. The major objectives of Regional Traffic Control Systems are to:

- Monitor traffic flow and other environmental conditions on the freeway/arterial corridor;
- Reduce delays and collision risks due to non-recurrent congestion through rapid detection and appropriate management of incidents;
- Determine and identify actions to alleviate recurrent congestion;
- Disseminate information to motorists about the freeway/arterial corridor condition to improve safety and mobility, and enable diversion; and
- Maintain the freeway/arterial corridor at an operating level by efficient implementation of traffic control strategies (including ramp metering, active/passive diversions, etc.).

While the objectives and functions of different Regional Traffic Control Systems may be similar, each system is a unique combination of subsystems, policies and procedures, and agency interfaces that reflect the location-specific requirements of the freeway/arterial corridor and its geographic area.

2.5 Traffic Information Dissemination

Knowledge of traffic and roadway conditions provides travellers advance warning of unusual conditions ahead and allows drivers the opportunity to alter their route or the timing of their trip. Traffic Information Dissemination addresses the ways by which timely and accurate traffic information is conveyed through the media, via traveller access devices such as the internet, personal digital assistants, phone, e-mail, pagers, in-vehicle devices, etc., or through the use of roadway equipment such as dynamic message signs. It also addresses the equipment and interfaces that provide information from a traffic operations centre to other operations centres (e.g., transit management centre, emergency service dispatch centre, etc.) or other agencies, for wider dissemination (e.g., media, information service providers, etc.).

Considerable research has been done over the past 30 years relating to human factors issues associated with the dissemination of traffic information through dynamic message signs. Although technologies have changed and will continue to change in the future, this research has identified several fundamental factors that influence the effectiveness of dynamic sign displays, independent of the technology used. These factors should govern the size, location, display characteristics and message content of sign displays.

The effectiveness or usage of signs depends on the following factors:

- *Conspicuity* – Does the sign attract attention given the environment in which it is placed?
- *Legibility* – At what distance can drivers read the sign?
- *Information Load* – Do drivers have sufficient time to read the entire message without unduly diverting their attention from the driving task?

- *Comprehension* – Do drivers understand the meaning of the message and any symbols or abbreviations used?

- *Driver Response* – Do drivers make the desired action as a result of reading the sign?

Additional information about these factors and how they affect sign design and the driver's ability to safely navigate within the traffic stream may be found in OTM Book 1b (Sign Design Principles), and in OTM Book 2 (Sign Design, Fabrication and Patterns). It should be noted that although the basic design principles apply to all signs, some of the specific information and comments presented in Book 1b are only applicable to static signing.

For additional information on dynamic message signs, human factors, and how they affect sign design, the reader should refer to OTM Book 10 (Dynamic Message Signs).

2.6 Special Applications

In addition to the ITS applications discussed above, there are several special applications for ATMSs that are discussed in further detail in Section 5. These are as follows:

- *Tunnel/Bridge Management* – due to the unique characteristics and physical constraints of bridges and tunnels, ATMS applications specific to these facilities are discussed separately. These applications include:

  – High Wind Warning System – to provide warning to motorists of the presence of high winds and any traffic management response plan in effect;

  – Swing Bridge Warning System – to provide advanced warning to motorists when a swing bridge is closed to vehicular traffic, providing the opportunity to divert to an alternate route;

  – Overheight/Overweight Detection – to detect the presence of overheight/overweight vehicles and provide motorists warning in order to prevent damage to a tunnel or overpass;

  – Noxious Fume Detection – to detect the build-up of noxious fumes from vehicle exhaust inside a tunnel and implement appropriate response plans; and

  – Lane Management – to close one or more lanes with use of signals, gates, etc.

- *Smart Work Zones* – to provide motorists with information on construction, speed management and/or detours with the objective of improving motorist and worker safety.

- *Queue Warning at Border Approaches* – to detect slow-moving traffic and provide motorists advance warning of queue conditions.

- *Rural Application* – to implement ATMS in rural areas that focus on the improvement of safety and minimizing the impact of environmental conditions.

- *Enforcement* – to utilize ATMS-related technologies to monitor compliance and help enforce traffic regulations.

3. Planning for ATMS

A structured approach to the planning of ATMS deployment is important in order to rationalize ATMS relative to other competing transportation investment options, and to ensure the quality, integrity and accountability of the program. The planning process is equally relevant to agencies embarking on a new ATMS program as well as agencies expanding existing systems. The planning process starts with a review of traffic conditions leading to a statement of needs and objectives. Candidate system strategies are assessed and prioritized in consideration of these objectives to yield a definition of system requirements and project scope. Systems are defined at the component level based upon a review of the current state of enabling technologies and future technology trends.

This section provides a logical approach to guide the reader through the various planning steps for the implementation of advanced traffic management systems. The planning process will ensure that projects are implemented cost-effectively, meet established needs and priorities, and take into consideration budgetary constraints as well as other funding concerns and/or opportunities.

3.1 Identification of Existing Conditions

Advanced Traffic Management Systems are often developed to help mediate recurrent and non-recurrent congestion problems as well as to reduce the frequency of collisions. In order to determine if an ATMS is the correct solution for a particular problem, it is necessary to accurately define the problem. There are a number of methods of defining congestion and collision characteristics, all of which require collection of a significant amount of field data. A thorough description of roadway geometry, operating characteristics and incidents is required. This information will help to determine the need for an ATMS, help the agency develop operational strategies, and assist in the selection of the appropriate type and location of ATMS components.

3.1.1 Description of Roadway Geometry

A description of existing physical road network conditions is an important component to the development of an ATMS, as there are different traffic management strategies that can be implemented on different classes of roads. In addition, geometric layout and physical location of intersections/interchanges can impact the choice of strategies that will be deployed. Therefore, a detailed description of the study area is required. The description should include:

- Location of alternate routes and their capacities;
- Number of lanes and their capacities (including turning lanes if applicable);
- Horizontal and vertical alignment;
- Number, type, location and spacing of interchanges/intersections;
- Width and type of shoulders;
- Median characteristics (divided, undivided and type of barrier);
- Number and type of overpass/underpass structures;
- Location of existing traffic system installations (including communications and power facilities);
- Current width of right-of-way (ROW), and potential limitations to expand the ROW (if required or planned);

- Identification of rural versus urban environment; and
- Coverage and type of roadway lighting.

The description of roadway geometry can be documented in tabular format and supplemented with schematic drawings. This inventory of the physical attributes of the roadway will facilitate the development of a concept plan with preliminary equipment layout, assist with the definition of installation requirements and related costs, and highlight any potential impediments to installation. It may also assist in defining the limits and scope of the deployment.

3.1.2 Operating Characteristics

Traffic Characteristics

Traffic volume is fundamental data necessary for capacity calculations and growth forecasting. Traffic volume profiles by roadway link and by time of day are necessary to assess traffic volume/capacity relationships and peak-hour loading. It is important to distinguish traffic volume profiles to reflect commuter, seasonal and recreational travel patterns. Relevant information includes vehicle classification counts, vehicle occupancy, speed profiles, volume profiles and, where applicable, intersection turning movement counts. This information is typically documented in tabular spreadsheet or database format.

Traffic volume generated by special events or venues such as entertainment complexes, parades and sporting events is also of interest. These generators can introduce a large volume of traffic onto the surrounding network in a concentrated time period. A special event is not necessarily limited to a particular facility. Large events such as parades can directly impact a large portion of the road network, including full or partial closures, and generate special traffic volume characteristics over concentrated (several hours) or extended (several days) periods of time. Typically, a traffic management plan is developed for these types of events, and this information should be included in the summary of current conditions.

Levels of Congestion

For both urban freeway and arterial networks, congestion is a recurrent feature that is prevalent during weekday peak periods. It is associated with the traditional patterns of travel to work in the morning and home again in the evening.

From the perspective of the motorist, longer and more variable travel times, and lower operating speeds are indicators of congestion. For system design purposes, there are two types of traffic volume parameters that best illustrate the severity of recurrent congestion. These are the design hour volume (DHV) and the peak hour (AM/PM) volumes. The DHV is defined as the 30th highest hourly volume experienced during the year and is calculated using observed data. The peak hour volumes are normally derived from a relatively small sample of observations obtained over the peak traffic periods of a day. This information is typically documented in tabular spreadsheet or database format.

Current DHV data is generally a more realistic reflection of the peak hour traffic volume than the observed peak hour volumes. This is because the data used to calculate the DHV is often based on the distribution of observed hourly traffic volumes over a longer period of time than those observed to determine the peak hour volumes. Normally, peak hour volumes represent a one-hour volume based on data taken over several days, and therefore can be more easily influenced by such factors as weather, incidents, construction, etc.

3.1.3 Incidents

When incidents temporarily reduce roadway capacity, the resulting non-recurrent congestion increases driver delays and frustration, and decreases safety. An incident is defined as an event occurring on the road which reduces roadway capacity and causes, or may potentially be a cause of, traffic disruption. Incident rates and collision frequencies are developed over a significant period of time in order to be statistically significant. Incident location, severity and duration information is of particular use. This information is typically interpreted from police records and documented in tabular spreadsheet or database format, and can be graphically represented using schematics of the road network.

Incident Type

There are five main classes of traffic incidents: vehicle collisions, vehicle breakdown, debris, fire/ emergency, and other traffic incidents. It is necessary to determine the frequency of each type of incident. The following is a brief description of these classes:

Vehicle Collisions

These are significant incidents that may involve vehicles colliding with other vehicles, pedestrians, trains, road furniture, trees, bridge structures or other physical features. The incident may be classified as either non-injury (property damage), injury or fatal. Minor collisions can be moved to off-highway Collision Reporting Centres by drivers or tow trucks. Police assistance is required at major incidents to manage traffic flows and to complete the necessary procedures. Emergency services requested would normally include towing, ambulance and/or fire services. These incidents may result in a lane and/ or road closure. In the event of an incident, the ATMS Traffic Operation Centre can assume a key response management role, providing information to response agencies, implementing area-wide traffic management/diversion strategies, and providing media relations and traveller information.

The frequency and rate of collisions must be reviewed by type, severity, roadway section, time of day, vehicle type, etc. This information can be subjected to off-line analysis in order to help identify problem locations or circumstances. Analysis must also discriminate between personal injury and property damage collisions. In addition to qualitative social impacts, the collision analysis can serve to calculate the economic impacts of collisions.

Vehicle collision frequencies and rates are typically calculated using data available from police reports prepared by the police officer attending a collision site, or by motorists at Collision Reporting Centres. Self-reported collision data from motorists is considered to be of dubious accuracy. It is important to note that not all collisions are reported. According to MTO[1], police collision data typically do not reflect about 20% of injuries requiring hospitalization and up to 50% of injuries not requiring hospitalization. Furthermore, it is estimated that 60% of reportable property-damage-only collisions are not reported. Existing ATMS are a useful source of incident data, which can be used to help define a correlation between total collisions and police collision data.

Vehicle collision rates are generally calculated for defined roadway links based on the number of collisions per million vehicle-kilometres or at an intersection based on collisions per million entering vehicles. While collision rates have been traditionally used to evaluate the need for operational improvements, including ATMS applications, MTO[2] recommends using "collision frequency" (usually collisions/year, or collisions/km/year) instead of the aforementioned "collision rate" to evaluate the

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1 *The Science of Highway Safety – Network Evaluation and Safety Conscious Procedures*, MTO Traffic Office, Traffic Safety Management Section, 1999.

2 *Ibid.*

relative safety of a road. Research indicates that the relationship between expected collision frequency and traffic flow is usually not linear. Therefore, for example, doubling the vehicle kilometres of travel does not double the number of collisions. As a result of this non-linearity, using the collision rate to measure safety can be misleading, if "safety" is to be used as a tool to evaluate the need to implement an ATMS.

Vehicle Breakdown
Examples of vehicle breakdowns could include a vehicle that has a flat tire or has run out of gas and can involve the blockage of the shoulder or a travel lane. Typically, in these circumstances, an emergency response vehicle or tow truck would respond and use flashing lights to warn approaching motorists that there are vehicles broken down or parked within the roadway. However, freeway shoulder blockages and lane-blocking events on some arterials are considered a low priority to police and other emergency response services. Road operations dispatch centres typically keep records of these types of incidents.

Provincial highways in Ontario are maintained by Area Maintenance Contractors (AMC) within their given geographical areas. The AMC emergency response vehicles and/or tow trucks would be involved in the removal of vehicles from the travelled portion of the roadway. With vehicles which are more difficult to tow, such as overturned trucks and loaded vehicles, heavy-duty tow trucks with adequate uprighting, lifting and recovery capability may be required to assist in incident clearance. Locating specialty equipment, transporting it to the site and undertaking clean-up activities can significantly increase the duration of the incident and any associated lane closure.

Debris
Major emergencies/disasters may create a large amount of debris or materials spilled on the roadway which must be cleared as part of the response and recovery process. In general, MTO's AMCs would be involved in the removal of debris on provincial highways. The trend is to use an automated debris recovery system that allows removal of debris from the roadway without stopping or having personnel working outside the vehicle.

For incidents involving dangerous goods spills, the Ministry of the Environment and Fire Services are to be notified. Specialized dangerous goods contractors may have to be mobilized to effect the necessary clean-up and disposal of toxic or hazardous materials.

Fire/Emergency
This level of incident often requires that emergency services secure the incident scene for safety purposes. As a result, these incidents result in the possibility of partial or total road closure. Typically, all emergency services (police, fire, ambulance) would be involved. Secondary traffic measures would be activated with traffic management required on the adjacent arterial road network. These response activities are normally directed by the police service. Road operations dispatch centres typically keep records on these types of incidents.

The standard practice is to stage the fire-fighting vehicles behind (upstream) the incident in order to block lanes for the safety of the incident scene and the emergency responders. This is done in such a manner that facilitates traffic movement around or through the incident scene and minimizes the number of lanes closed. The practice of fighting fires from the side, however, may result in additional lanes being closed, or the possibility of total closures.

Other Incidents
Other incidents that affect traffic can include severe weather conditions, community evacuations, emergency road maintenance, and any situation or event, excluding vehicle breakdown or collisions. There are times when police officers responding to an incident of this type may not be directly involved with the situation but would assist by providing specialist services. A good example of this type of incident is when animals are present on the roadway, having strayed from adjacent properties. Road operations dispatch centres typically keep records on these types of incidents.

Incident Duration

Incident duration is defined as the time from the occurrence of the incident to the clearance of the incident from the roadway. It is incorporated into economic analyses to calculate the delay experienced by motorists. If known, this duration should include the time between the occurrence of the incident and detection of the incident. It is difficult to establish the time of incident occurrence without CCTV (closed-circuit television) monitoring in place.

Impact Duration

Impact duration is defined as the time from the occurrence of the incident to the clearance of the obstruction and return to normal traffic conditions. It is used for calculating the time that an ATMS operator would be involved with the incident, and therefore, important in the calculation of operator loading.

Each of these measurement categories is to be considered in conjunction with various stages of an incident as follows:

- Incident-to-detection
- Detection-to-response
- Response-to-clearance
- Recovery (i.e., restoration of normal operating conditions).

Reducing the duration of these stages improves safety by reducing secondary incidents, reducing vehicle delays and results in savings in vehicle operating costs as well as reductions in harmful emissions.

Typical Impacts of Incidents

The severity or degree of incident impact should be quantified, which is often, but not necessarily tied to the duration of the incident. It should be noted that adjacent arterial roads experience additional flows as motorists divert around the incident (on either a freeway or arterial). Also, during incidents, "rubbernecking" is a common occurrence, and as a result, the traffic lanes in both directions of travel can experience capacity reductions. "Rubbernecking" can result in secondary incidents of varying severity within the affected roadway lanes and on adjacent roadways.

Three levels of impacts are discussed here.

Minor Impact Incidents
Minor incidents are primarily comprised of vehicle breakdowns, debris, as well as other traffic incidents and minor vehicle collisions. Typically, they consist of shoulder closures which result in capacity reductions in adjacent lanes.

Major Impact Incidents
Major incidents are comprised of vehicle collisions, debris involving dangerous goods spills, other traffic incidents and fire/emergency incidents. They consist of non-injury, injury and fatal collisions, and typically involve lane closures and an emergency response team involving several agencies. A small number of major incidents can result in full closure of the roadway with motorists being diverted onto other

freeways and the adjacent arterial road network. Major incidents have a large impact on motorists, particularly if they occur during or before the peak periods.

Headline Impact Incidents
Headline incidents are normally comprised of vehicle collisions, debris involving dangerous goods spills, other traffic incidents and fire/emergency incidents. These typically involve fatalities, heavy vehicles and major spills. In many cases, these incidents result in a full road closure, but always result in significant delays to motorists upstream of the incident, and those on the adjacent parallel arterial roads that act as the diversion route. Headline incidents tend to attract a significant amount of media attention.

3.1.4 Ontario Experience

The collection of data on existing conditions can be cumbersome, and can often experience delays. Some typical hurdles that have been experienced in Ontario include:

- Mapping which is out of date, or incomplete;
- Traffic volume data which is incomplete, out of date, or has been collected on different sections in different years, or in different times of the year;
- Collision data which is incomplete and/or includes significant errors;
- A significant drop in reportable collisions from one year to the next – this can be attributed to major changes in the process for collision reports, such as an increase in the property damage dollar value threshold for "reportable collisions"; and
- A non-typical traffic pattern resulting from road construction activity.

Ontario experience also indicates that it can be helpful to involve representatives of emergency services at the data collection stage of the planning process, to provide an opportunity for them to contribute their observations on problem areas and the reasons or causes behind them.

3.2 Prediction of Future Traffic Conditions

In order to plan a new ATMS or expansion to an existing ATMS, agencies need to be able to define criteria that trigger deployment. There are two primary criteria that can be used. These are level of service and collision experience. These two criteria are performance indicators that reflect the traffic safety and flow for a particular highway section.

3.2.1 Level of Service

The level of service of a roadway facility is typically expressed in terms of the Volume-Capacity (V/C) ratio. A V/C ratio is listed in the Highway Capacity Manual (HCM) as one of the performance measures that characterize traffic flow on a roadway section. A V/C ratio approaching 1 (one) for any particular roadway link indicates a problem area and likely a breakdown in traffic flow. Using the HCM, the capacity of different roadway sections can be determined. It should be noted that the capacity of a roadway section will drop due to the occurrence of incidents and/or the associated effects of "rubbernecking".

In order to predict the level of service for future traffic conditions, the following data is required:

- Number and geometry of lanes on the section of roadway; and
- Projected traffic volumes for the horizon year.

This information is typically documented in tabular spreadsheet or database format, and can be graphically represented using schematics of the road network. The number of lanes on a section of roadway may be confirmed by consulting the capital works program of the operating authority. If there are no plans for the section of roadway, the number of lanes will remain unchanged from current conditions.

If rehabilitation work is planned, there will be lane reductions for the duration of the project. If a widening is planned, there will likely be lane reductions during the project, followed by the opening of additional lanes. If there are plans to rehabilitate and/or widen the roadway, the designer should consider the implementation of an ATMS to assist with traffic management in work zones in order to improve safety and optimize traffic throughput. Furthermore, the cost of implementation of ATMS infrastructure (e.g., ductwork, pole bases and cabinet bases) is greatly reduced when implemented as part of a broader roadwork initiative.

Traffic volume growth rates can be assessed using historical trends in DHV, peak hour and annual average daily traffic (AADT) volumes. The operating agency usually has a transportation planning section already performing traffic volume projections. This information will provide general background growth rates. The designer should also investigate plans for the development of significant traffic generators, such as large commercial developments, entertainment complexes and sports facilities that might significantly increase traffic volumes at specific locations. These types of facilities are usually required to submit a "traffic impact study" to the local planning authority, and the contents of these studies will provide valuable input into future traffic projections, including capacity constraints, peak periods and peak spreading.

Traffic flow theory indicates that there is a direct relationship between traffic flow and speed. This relationship illustrates that as traffic volume increases, traffic density increases reducing spacing between vehicles. As density increases, traffic flow also increases. Traffic, however, will reduce speed as density reaches a critical point which negatively impacts traffic flow. The result is that there is an optimum speed at which traffic flow or the capacity of a facility is maximized. Currently, there is research underway which examines this speed/flow curve to estimate the operational speed at which the capacity of a roadway facility is maximized. The ultimate goal is to be able to predict the degradation of traffic operations (i.e., congestion) on a roadway or the probability of an incident due to congestion before it occurs.

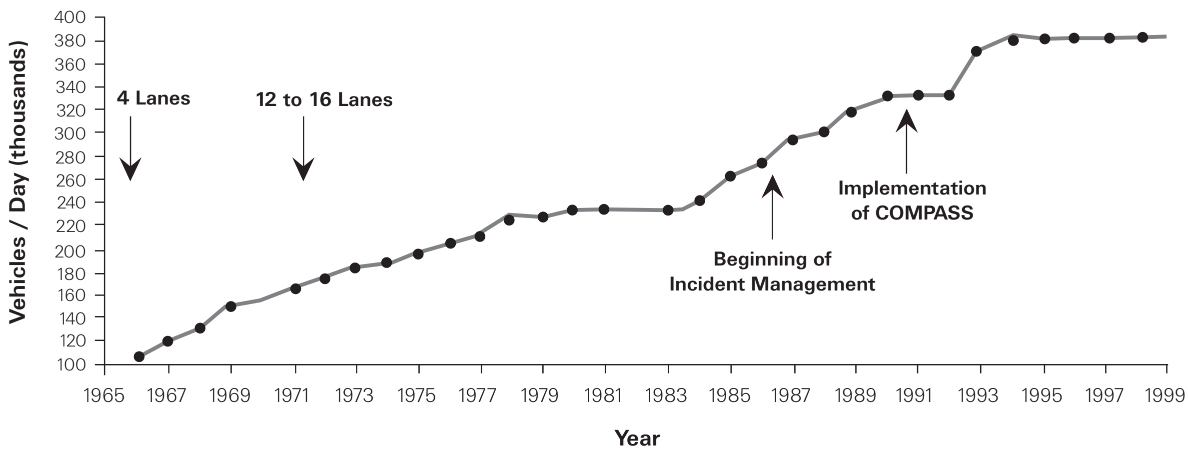
3.2.2 Collision Experience

Trends in historical, year-by-year, average collision frequencies or collision rates will form the basis for projecting future collisions and identify potential safety concerns. A review of the data on a section-by-section basis will also identify key roadway sections where collisions have been relatively high. It is also important to examine the historical trends in collision frequency, either at a point (interchange or intersection) in collisions/year, or on a section, in collisions/km/year. The economic impacts and costs of collisions can be extracted from an analysis undertaken by the MTO entitled *The Social Cost of Motor Vehicle Collisions in Ontario* (1994).

3.2.3 Ontario Experience

Anticipating future traffic conditions can be a challenging undertaking, particularly when dealing with regionally-oriented traffic flows. In completing this task, experience on similar projects in Ontario indicates that the following should be considered:

Figure 1 – Historical Traffic Growth on Highway 401 at Keele Street



- Emergency services representatives can be a valuable resource in identifying potential safety deficient locations and providing input on projected future conditions; and

- Planned regional attractions and growth considerations outside of the subject jurisdiction should be incorporated into the forecasting exercise.

It should also be recognized that traffic growth is subject to the impact of regional economic activities and development and can fluctuate as regional economic activity varies. As an example, historical AADT data for Highway 401 at Keele Street in Toronto, illustrated in Figure 1, shows how traffic growth has varied over the past 45 years with distinct low growth periods 1981-1983 and 1990-1992. These periods coincide with periods of slow economic activity in Ontario.

3.3 Identification of Needs and Problems, Existing and Future

Sections 3.1 and 3.2 identified the processes used to identify current and future roadway geometry, operating conditions (including volumes and congestion) and incident profiles. It is necessary to review this information to determine if there are concerns with the current and future operations of the roadway that need to be rectified.

The following sections identify a number of categories for system measures of effectiveness.

3.3.1 Geometric Constraints

On a section-by-section basis, the subject roadway may be evaluated for a number of Measures of Effectiveness (MOEs) related to roadway geometry. For example, lack of shoulders impacts the ability of the network to handle incidents, as any incident (regardless of the duration) will result in a lane closure, limiting roadway capacity for passing traffic and reducing the accessibility of the incident scene to emergency response vehicles.

The ATMS planning process must take into consideration and reflect any plans for future geometric improvements. In some cases, geometric improvements may be difficult to implement, as many mature roadway sites are constrained by right-of-way limitations, topography, environmental considerations, etc. In these circumstances, ATMS may be used to mitigate the operational impacts of the existing geometric constraints.

3.3.2 Network Operating Conditions

Similarly, on a section-by-section basis, the subject roadway may be evaluated using the measures identified to quantify the existing and future operating conditions.

A V/C ratio of approximately 0.85 or higher describes a roadway that is nearing, or is at capacity. At this V/C ratio, vehicles are spaced at approximately six car lengths, leaving little room for vehicles to manoeuvre. With traffic flow so close to capacity, the traffic stream has no ability to accommodate any minor fluctuation in traffic demand or even the most minor of disruptions. In these circumstances, any disruption or minor increase in traffic can propagate serious capacity breakdown and extensive queuing, both within the capacity-deficient section as well as for a significant distance upstream.

Identification of an acceptable peak-hour speed can be used as a secondary MOE. A peak hour speed of approximately 40% of the posted limit is generally considered the speed at which drivers become increasingly frustrated.

An important consideration is the availability of the adjacent arterial road network to accommodate diverted traffic. If the arterial network has insufficient capacity, is discontinuous, or otherwise unable to accommodate a significant amount of diverted traffic, the duration and subsequent impacts of major and headline incidents may be exacerbated. These constraints to the transportation system are worth noting.

Where there are multiple candidate routes for ATMS deployment, either as an initial installation or as a system expansion, these measures may be used to assist in establishing priorities.

3.3.3 Incidents

As with the network operating conditions, measures used to quantify existing and future incident profiles may be used as MOEs. Useful MOEs include:

- Collision frequency (collisions/year or collisions/km/year);
- Collision rate (collisions per million vehicle-kilometres or collisions per million entering vehicles);
- Collision severity (frequency of collisions by severity [fatal, injury or property damage only]); and
- Incident duration (number of lane closure hours, incident detection time, emergency response vehicle response time, incident clearance time, etc.)

While collision-rate data is typically published, it is the incident rate that impacts traffic. As a result, it is important to draw a relationship, or correlation, between incident rates and collision rates, drawing upon the experience of various operating ATMS with similar characteristics.

3.3.4 Environmental Concerns

The impacts of congestion on the environment should be considered. To the extent that recurring and non-recurring congestion can be mitigated, fuel consumption and vehicle emissions are minimized. In the U.S., many corridor congestion management programs have applied Federal Environmental Protection Agency funding.

3.3.5 Stakeholder Input

Consultation with stakeholders, including public, commercial vehicle operators, road maintenance authorities, other provincial or municipal traffic authorities, police and emergency services, transit operators, etc., can reveal additional existing or anticipated problems related to the performance of the transportation system.

3.3.6 Other Factors

It may be appropriate to incorporate other government systems or objectives. For example, the effectiveness of local emergency response plans, and the coordination of the road system with air and water transportation systems, could be evaluated to determine if there are any shortcomings that might benefit from ATMS deployment.

3.3.7 Development of Consolidated Problem and Needs Statement

From the above-noted review of available traffic data and stakeholder consultations, the range of transportation system concerns has been identified. This information is most effective when consolidated and expressed in a concise format using quantifiable terms to produce an overall Needs Statement. In this way, it will be possible to determine if these problems can be alleviated with the introduction of the management, institutional and operational improvements typically associated with ATMS.

3.3.8 Ontario Experience

The Ministry of Transportation Ontario's *Ontario ITS Strategies Framework Study and Five Year COMPASS Implementation Plan* incorporates a needs analysis of the provincial freeway network in order to prioritize areas of deployment for the COMPASS ATMS Program. Each freeway link has been characterized in terms of geometrics, traffic operations and incidents based upon available data. Other considerations which were incorporated into the analysis included coordination with planned roadwork activities and proximity to existing ATMS installations.

Lessons learned in conducting the needs analysis for the *COMPASS Implementation Plan* indicated that the process benefits from:

- Learning from the experience of other jurisdictions;
- Including regional planning agencies in the identification of needs; and
- Involving police and emergency service agencies as early as possible.

3.4 Establishment of ATMS Goals and Objectives

Operating goals and objectives will arise out of the needs identified in the previous section. These goals will likely be aimed at providing transportation products and services that can have a positive societal impact by improving safety, supporting a higher quality of life, and increasing the attractiveness of a community for business. To this end, the following goals and objectives for ATMS deployment focus on increasing the level of performance of existing transportation products and services to meet the social and economic needs of the people of Ontario.

3.4.1 Increase Capacity and Operational Efficiency

By providing early detection and response to incidents and congestion, ATMS optimizes the use of the existing network capacity and reduces the need for building additional infrastructure. It also improves the ability to better manage traffic flows, reduce congestion and delay, and encourage a more balanced use of all modes of travel.

3.4.2 Increase Productivity for Commercial Vehicles

Increased operational efficiency results in improved and more consistent travel times for all users of the road network. For commercial carriers, this translates into reduced costs and improved productivity, and contributes to the overall industrial competitiveness of the region.

3.4.3 Improve Safety

ATMS applications provide the opportunity to reduce the occurrence of primary and secondary collisions by:

- Controlling conflicting traffic movements at intersections, freeway entrance ramps, etc.;
- Advising and controlling traffic movements on the approach to and through atypical conditions, such as incidents, work zones, inclement weather, and congestion; and
- Minimizing the duration of recurring and non-recurring congestion.

3.4.4 Increase Traveller Comfort and Convenience

ATMS applications provide the opportunity to disseminate information on current travel conditions on a region-wide scale. This helps travellers make informed decisions with respect to temporal, spatial, and modal shifts in trip patterns. As a result, the overall accessibility and convenience of the transport network is improved, with reduction in driver frustration.

3.4.5 Improve Public Transportation Services and Operations

Current traffic conditions information can be combined with transit service information to help facilitate appropriate pre-trip travel decisions. This can result in a shift of commuter travel patterns to public transportation where viable transit options exist.

3.4.6 Improve Cooperation Amongst Transportation Operators

The benefits associated with ATMS increase significantly as a region-wide level of deployment is achieved. Opportunities for cooperation in the delivery of regional ATMS services includes shared collection and use of data, multiple uses for field components, coordination of network operations, shared use of maintenance resources, and coordination of information services, all of which can improve system efficiencies and lower costs. These cooperative relationships should be pursued between government agencies, and with the private sector, to deliver ATMS services as effectively and efficiently as possible.

3.4.7 Reduce Environmental and Energy Impacts

ATMS systems smooth traffic flow, producing higher average network speeds and fewer stops. This provides a near-term benefit in terms of reduced fuel usage and emissions. Over the longer term, it is important that ATMS systems be considered as an integral component of a broader array of ITS elements and the transport planning process as a whole, in order to optimize the overall efficiency of the transport network. This holistic approach incorporates demand-management measures, and improves the attractiveness of transit options.

3.4.8 National Context

The ATMS goals stated above complement and support the goals outlined in Transport Canada's An *ITS Plan for Canada: En Route to Intelligent Mobility*. These include efforts to:

- Improve the safety of Canada's ground transportation system;
- Increase operational efficiency and capacity of the ground transportation system;
- Reduce energy and environmental costs associated with ground transportation;
- Enhance productivity and competitiveness;
- Improve the collection of information and data for policy making, planning, program management and evaluation, traffic operations, enforcement, and congestion monitoring;
- Enhance personal mobility, convenience and security of the ground transportation system;
- Create opportunities for Canadian companies in the global marketplace; and
- In general, create an environment in which the development and deployment of ITS will flourish in Canada.

Similarly, the U.S. Department of Transportation's National ITS Architecture provides the following goals:

- Increase capacity and operational efficiency;
- Enhance personal mobility;
- Reduce energy and environmental cost associated with traffic congestion;
- Improve safety;
- Enhance present and future productivity of individuals, organizations and the economy as a whole; and
- Create an environment in which the development and deployment of ITS can flourish.

The Ministry of Transportation Ontario's *ITS Strategies – Moving Forward with Intelligence* based its goals and objectives on those of Transport Canada's ITS Plan for Canada as well as the those articulated in the ITS Architecture for Canada.

3.4.9 Performance Monitoring

Performance monitoring of an ATMS helps to identify how well the system meets its goals and objectives and quantify the associated benefits. It is a key aspect of any deployment project and one which should be considered throughout the planning and design phases to ensure it can be undertaken easily and that both the 'before' and 'after' conditions are well documented. The guidelines presented in Transport Canada's Final Report on the "Development of a Project Evaluation Methodology Framework for Canadian Intelligent Transportation

Systems" presents typical measures for performance monitoring that are in keeping with the goals and objectives for ATMS deployment. These measures are summarized below:

- Safety
  - reduction on overall crash rate
  - reduction in fatal crashes
  - reduction in injury crashes
  - reduction in secondary crashes

- Mobility
  - reduction in travel time delay
  - reduction in travel time variability

- Efficiency and Productivity
  - increase in roadway throughput
  - cost savings for users
  - cost savings for agencies (emergency response, road maintenance, etc.)

- Energy and the Environment
  - decrease in vehicle emissions
  - decrease in vehicle energy consumption

- Security
  - reduction in acts of crime against motorists and property
  - reduction in response time to incidents (rural applications)

- Customer Satisfaction
  - increase in customer satisfaction.

3.4.10 Ontario Experience

The experience of Ontario transportation agencies in the planning and definition of ATMS applications suggests that it is important to:

- Keep the goals well-defined and realistic;

- Carefully estimate the lead time required to accomplish the established goals;

- Include all stakeholders in the goal definition process;

- Provide for education of the travelling public; and

- Provide performance monitoring to track progress against the defined goals.

3.5 Review of Network Requirements and Plans

In planning ATMS deployment, a number of considerations outside of the subject roadway need to be considered. These include the availability and jurisdiction of diversion routes, inter-agency and inter-jurisdictional coordination of construction projects, and network management responsibilities.

3.5.1 Coordination of Diversion Route Management

ATMS deployment may impact traffic flow and require use of diversion routes to manage traffic during construction. ATMS operation may also impact parallel routes as traffic management plans are put into effect that divert traffic to alternate routes in order to manage an incident or recurrent congestion. A collaborative effort is required with jurisdictions that are responsible for these diversion routes.

During ATMS deployment, this could include a review of any planned infrastructure improvements and schedules along diversion routes, and the coordination of ATMS construction activities with these infrastructure improvements. Temporary ATMS facilities can also be used to mitigate the impact of ATMS deployment. Information on construction activities (regardless of the responsible jurisdiction) can be disseminated to the motorist. For example, a Portable Variable Message Sign (PVMS) can be implemented upstream of a construction zone to warn motorists of lane restrictions ahead. This will improve work zone safety for both the workers and the motorists, as well as help to improve public relations with the travelling public.

Recommended diversion routes may include ATMS-monitored signalized arterial roadways. In this situation, coordination with the jurisdiction responsible for ATMS operation on these routes can be of benefit to the motorist. For example, during a major or headline incident, an upstream Dynamic Message Sign (DMS) may be used to warn motorists of the situation ahead. When ATMS operators inform the jurisdiction responsible for the arterial (diversion) traffic signals of the collision, they can implement timing strategies that will favour the arterial roadway to better manage the diverted traffic. Furthermore, the signal system jurisdiction could proactively develop signal timing plans to respond to a severe incident, or implement a traffic responsive/adaptive signal system that would automate this process.

Further coordination between jurisdictions may provide route management capabilities where the diversion routes are monitored by an ATMS. In route management, an alternate route is suggested based on calculated travel time estimates. Route management allows for a more balanced use of the available capacity on the two roadway sections. Information on route options can then be disseminated to the motorist. ATMS diversion routing schemes can be supported through the application of static trailblazer signage along the diversion routes.

Use of a simulation tool for the modelling of the roadway network, in an off-line mode or in real-time when available, can assist in scenario analysis and selection of the most effective response plan (i.e., diversion route) for implementation during construction activities or in response to incidents.

3.5.2 Ontario Experience

Through the period 1993 to 2000, the City of Toronto undertook a major reconstruction effort for the Gardiner Expressway and Lake Shore Boulevard Humber Bridges project on the Toronto waterfront. The project called for the successive demolition and reconstruction of six bridges in this major corridor which provides direct access to central Toronto from the west. In planning for the project, the City and the MTO worked together to establish an area-wide traffic plan which considered the impacts on the area's arterial network with use of off-line simulation tools to optimize the traffic response plans, and establish diversion routing between Lake Shore Boulevard and a parallel arterial, The Queensway. The result of the process was an ATMS deployment, which included traffic monitoring and advisory information to motorists as they approached routing decision points in the vicinity of the work zone.

The experience of various transport authorities emphasizes the need to have all stakeholders work together at each phase of the project to identify and manage diversion routing. Stakeholders include the various road authorities as well as transit agencies, emergency services, etc. Halton Region and Waterloo Region have recently embraced this approach in undertaking the development of region-wide emergency plans to provide a structured process in coordinating responses to natural disasters, evacuation scenarios, etc.

3.6 Selection of Appropriate Strategies

The traffic monitoring and detection function is one of the key building blocks upon which any ATMS is founded. It is imperative to obtain reliable and up-to-date information on prevailing conditions on the road network in order to competently influence future traffic behaviour and provide traveller information through traffic management strategies. Various automated and manual techniques are available to

Table 1 – ATMS Strategies

Strategy	Description	Requirements
Incident Management	Early detection and response to unscheduled events	• Incident detection/confirmation • Emergency response/motorist assistance • Pre-trip and en-route advisory
Congestion Management	Mitigating the impacts of recurring and non-recurring congestion	• Congestion monitoring • Pre-trip and en-route advisory • Lane metering • Ramp metering
Corridor Management	Balancing level of service among alternate parallel routes within a corridor	• Event and travel time monitoring • Pre-trip and en-route advisory
Network Management	Balancing level of service within the network as a function of current conditions	• Event and travel time monitoring • Pre-trip and en-route advisory
Travel Demand Management	Improving traffic flow by managing travel demand	• Congestion pricing • Ramp metering

assist in traffic monitoring and incident detection/confirmation activities, including vehicle detection systems and closed circuit television (CCTV) systems.

Various ATMS strategies are available to support the operator goals and objectives identified in Section 3.4. They can be broadly categorized into Incident, Congestion, Corridor, Network and Travel Demand Management strategies. Table 1 illustrates the application of these strategies.

The following sections provide an "ATMS toolbox" of options to suit a range of operator needs.

3.6.1 Incident Management

Incident Management strategies focus on maximizing the use of available roadway capacity and reducing the impact of non-recurring congestion resulting from incidents. They are designed to reduce the overall duration of an incident, thereby reducing the safety and capacity impacts of each stage of an incident as follows:

- Incident-to-detection time is minimized through the application of automatic incident detection, motorist call-in services, agency coordination (911 calls), and CCTV confirmation;
- Detection-to-response time is minimized through CCTV assessment of the incident, automated response plan generation, and optimized response agency communication;
- Response-to-clearance time is minimized through pre-determined response agency coordination; and
- Time to return to normal operating conditions is minimized through application of various congestion management and traveller information strategies.

Reducing the duration of these stages improves safety by reducing secondary incidents, results in savings in vehicle operating costs, and reduces the amount of harmful emissions.

Incident management strategies can be implemented on an automated or non-automated level. The automated incident management strategy implemented by an ATMS consists of three general steps:

- Incident detection
- Confirmation of the incident
- Implementation of response measures.

Following detection of an incident by the system, the system prompts the operator to confirm the incident. For incidents that are not detected by the system (e.g., the event is detected by motorist calls to 911, or by staff or police on the road, or by operator experience), the operator will enter the event details manually. With the increasing market penetration of cellular telephones and expanding CCTV deployment allowing operators to monitor more known trouble spots, many ATMS operators are increasingly relying on these other detection sources.

Upon incident confirmation, the system will automatically analyze all data gathered by the detection systems and the incident details provided by the operator, and determine suitable responses based on current roadway conditions. Modern incident management systems typically use an automated "logic-based" approach, or a combination of "logic-based" and "plan-based" approaches to formulate a suitable response to ensure safe and efficient flow of traffic throughout the network. Using non-automated approaches alone are not recommended due to the large volume of manual work required and the high risk of operator error.

The incident management response that the system implements is based on the traffic management strategies that are in place, and the availability of appropriate devices to control traffic or display information. The following sections describe devices and strategies that can be used to respond to an incident.

Traffic Information Dissemination

The provision of incident information and real-time traffic conditions through a variety of motorist communication modes is key to effective incident management. These communication modes are outlined in Section 4.5.

Detection and communication of unexpected adverse weather conditions, such as high winds on skyways, can also significantly improve safety. Advisory information may provide general or vehicle-specific advisories (e.g., wind advisories for large vehicles), and directions to alternate routes or safe temporary vehicle parking or storage facilities.

Surface Street Control System Integration

The ability to monitor on-street conditions in real time provides certain advantages when employed in combination with a surface street control system. Traffic Operation Centres use CCTV and real-time traffic data monitoring to allow an operator to manually adjust traffic signal control parameters to improve on-street operations. Alternatively, traffic-adaptive and traffic-responsive control systems may adjust automatically to accommodate the changing on-street conditions resulting from an incident. For incident management strategies involving diversion routes, the development and use of pre-planned incident response timing plans would be beneficial for coordinated arterial signal control during incidents.

Other incident response strategies include managing traffic flow into the freeway corridor both upstream and downstream of the incident location by altering ramp metering rates in an effort to better balance available capacity. On-road response may also be utilized by dispatching vehicles (e.g., blocker trucks), equipment (e.g., cones, portable variable message signs, etc.) and staff to manage traffic at the incident site and provide protection for emergency response personnel.

3.6.2 Congestion Management

Congestion Management strategies employ a variety of traffic management and control strategies to mitigate the negative impacts of recurring congestion. In so doing, these strategies optimize road capacity and improve road safety for general traffic and vehicles involved in maintenance and construction activities.

Traffic Information Dissemination

The provision of real-time and traffic conditions through a variety of communication modes is key to the effective management of a congested road network by providing motorists the opportunity to change their route or the timing of their trip. These communication modes are outlined in Section 4.5.

Lane Management

Lane management provides lane-specific information to motorists through the use of overhead-mounted lane control signs (LCS). They are typically used as part of a congestion management strategy by displaying information relating to lane availability. LCS displays include a downward pointing green arrow indicating that the lane is available, or a red "X" indicating the lane is not available. The "X" symbol is also used (displayed in red or amber) during the lane clearance interval. Lane management can form part of an ATMS with applications that include reversible lanes on urban arterials to manage peak direction traffic demand or for traffic management purposes in tunnels and bridges during incidents or planned lane closures.

When considering a reversible traffic lane as a traffic management strategy, a key consideration should be the volume of off-peak traffic and the ability to accommodate this volume within the remaining lanes available. Any congestion in the off-peak direction should be considered in conjunction with the benefit gained by peak direction traffic to ensure that the net benefit to the transportation network is considered.

Ontario Experience

An example of an urban application of lane management can be found on Jarvis Street in Toronto where the direction of travel in the centre lane alternates on a time of day basis to provide capacity for the peak direction of travel. Lane management is also utilized on the Champlain Bridge across the Ottawa River between the City of Ottawa and Gatineau, Québec where the system manages a reversible HOV lane to accommodate peak direction traffic flows.

High Occupancy Vehicle (HOV) / High Occupancy Toll (HOT) Lane Management

High Occupancy Vehicle (HOV) lane management provides priority treatment for HOVs through the provision of reserved lanes with higher operating speeds and more reliable travel times. This approach discourages the use of single occupant vehicles during periods of congestion, encourages ride-sharing and off-peak travel and emphasizes the use of available infrastructure to move people rather than vehicles. Priority treatments for HOVs have proven to be very effective.

A related strategy – and a relatively recent lane management concept – is that of High Occupancy Toll (HOT) lanes. HOT lanes combine HOV and pricing strategies by allowing vehicles that do not meet passenger occupancy requirements to gain access to HOV lanes by paying a toll. It is a form of congestion pricing (also known as value pricing) where the transportation agency sells to motorists, on a time-of-day or congestion-level basis, the excess capacity available from the operation of HOV lanes. Information on price levels and travel conditions is normally communicated to motorists via dynamic message signs, providing potential users with the information they need in order to decide whether or not to utilize the HOT lane. HOT lanes may be created through new capacity construction or conversion of existing lanes. Conversion of existing HOV lanes to HOT operation is the most common approach.

Ontario Experience

HOV lanes have been operating in Toronto on Highway 403, in both directions between 407 ETR and Highway 401 and more recently have been implemented on Highway 404 between Highway 7 and Highway 401. The HOV lanes, marked by special signs with diamond symbols painted on the pavement, allow buses and vehicles carrying at least two people to bypass congestion in the general purpose lanes.

Ramp Metering

Ramp metering uses a traffic control signal on freeway entrance ramps to control the rate at which vehicles can enter a freeway facility. In this way, the flow can be moderated to more closely match the available capacity of the freeway and to improve merging by breaking up vehicle platoons into groups of one or two vehicles. Candidate locations for ramp metering include high volume entrance ramps where there is adequate space to store vehicle queues waiting to access the freeway, as well as sufficient ramp length to allow vehicles to accelerate from a stop condition to freeway speeds. Consequently, the benefits of ramp metering include improved freeway operations (reduced delay, reduced stops, etc.) and a general improvement in safety due to a reduction in merge-related collisions.

The drawback of ramp metering includes the relatively high cost to install and operate such a system, and the potential for negative public reaction. Ramp metering is a traffic management strategy that is typically regarded by the public as a method for optimizing flows on the freeway, to the detriment of the operating conditions on the adjacent arterial routes. Ramp metering is also perceived to favour longer trips rather than short trips, thereby encouraging more dispersed land development and more travel. However, if ramp metering is implemented properly, and particularly if it can be integrated with the local traffic signal control system, the efficiency of the entire transportation network can be improved. The success and benefits associated with ramp metering is demonstrated by the large number of ramp metering stations (estimated to be 2,370 in North America in 2005[3]) that have been implemented and are successfully operating throughout North America.

Ontario Experience

The MTO currently uses ramp metering on the Queen Elizabeth Way through Mississauga.

3.6.3 Corridor Management and Network Management

Corridor Management involves the application of several traffic management strategies within a specific corridor to ensure that available capacity is well utilized and the overall corridor operates efficiently. The strategies that are deployed will depend on the operational objectives for the corridor, the prevailing operating conditions and the physical layout. Typically this involves the monitoring of several parallel routes and the implementation of traffic management strategies that maximize the efficiency of each route as well as the overall corridor.

Network Management is similar to corridor management, applying traffic management strategies to various corridors with a view to optimizing the operation of the overall network. It can be implemented on a stand-alone basis where

[3] *Ramp Management and Control Handbook.*

each corridor functions independently and the operator manually selects traffic management strategies to manage the road network. Alternatively, it can be implemented on an integrated basis where the corridors interact with the rest of the transportation network. The second option is preferred as it addresses specific unique corridor functions, yet integrates the system so that the transportation network functions more efficiently.

In addition to the measures used for congestion and incident management, strategies for corridor and network management employ the following measures.

Diversion Strategies

Diversion strategies are implemented when an incident blocks one or more lanes. The goal of a diversion strategy is to move vehicles around the incident as efficiently as possible. There are several types of diversion strategies – local, strategic and tactical. Depending on the location and severity of the incident and the systems and devices available, one or more of the diversion strategies can be implemented.

Diversion of traffic to alternate routes should not be actively promoted unless current traffic condition data is available for the alternate route and preferably, traffic control systems are available to respond to the increase in traffic flow. The ATMS gathers detailed travel data from each route and runs an algorithm to determine which route is the fastest at that point in time. This information can then be disseminated to motorists through a variety of methods, such as Dynamic Message Signs (DMS) and other traveller information devices. It is crucial that information provided to motorists is accurate and reliable. In order for route balancing strategies to be effective, traffic monitoring facilities must be available on both routes. Care must be exercised to ensure that the implementation of the strategy does not result in an oscillation of the travel time imbalance between alternate routes. The percentage of motorists willing to alter trip patterns will vary according to the nature of the road network, the level of travel time imbalance, and the nature and location of information provided to the motorist.

Local Diversions

Local diversion strategies for incidents involve small deviations from the motorist's original route to avoid the incident site. Local diversions may use any roadway type (i.e., freeway, arterial, collector, etc.), but typically avoid minor residential streets. However, given the unpredictable nature of arterial incidents, it may be necessary to include residential streets in the temporary incident diversion route. In the case of arterial routes, local diversions may be as long as several city blocks. For freeways, local diversions may be from interchange to interchange and can range from the simple closure of the affected lanes to diversion of freeway traffic to adjacent arterials to bypass the incident site. A passive approach to local diversion can be achieved by providing advance incident information for the primary route, enabling motorists to make informed routing decisions based upon individual trip patterns and knowledge of the local road network. If active diversion strategies are to be employed, it is important to involve the various affected local agencies in an advance planning process to identify candidate diversion routes.

Strategic Diversions

Strategic diversions involve a shifting of routing on a region-wide scale. These diversion strategies are used in the event of major incidents or a full closure. In such cases, it is desirable to advise and re-route traffic several kilometres upstream from the actual incident site. This higher level of advance warning allows motorists to select alternate routes from a number of options, thereby spreading the diverted traffic over as many corridors as possible. It also provides the opportunity for motorists to divert to other freeway corridors which are better equipped to handle high volume traffic flows. Strategic diversion strategies could also encourage diversion to other modes of travel, or possibly avoiding trips all together as a result of current conditions.

Tactical Diversions

Tactical diversions fall in between local and strategic diversion strategies. They are used where parallel arterial routes have been identified, and the appropriate traffic control mechanisms are in place (e.g., ATMS in combination with a responsive or adaptive signal control system). A tactical diversion response strategy would provide data to the responsive/adaptive signal system to initiate a special signal timing strategy on the parallel arterial to accommodate traffic leaving a freeway. Tactical diversion strategies could also encourage diversion to other modes of travel or possibly avoiding trips all together as a result of current conditions.

Ontario Experience

Through the operation of the COMPASS ATMS on Highway 401 in Toronto, the MTO observed that motorists often use Highways 409 and 427 in the vicinity of Pearson Airport to by-pass Highway 401 in this area. The Highway 409/427 "airport triangle" serves as an alternate route to avoid Highway 401 congestion resulting from a discontinuity in the express/collector configuration. Recognizing the network management potential, the MTO has recently implemented traffic monitoring on the alternate route and overhead DMSs on both the westbound and eastbound approaches to the diversion decision points.

Parking Guidance

Traffic circulating in search of available parking can contribute to network congestion within busy retail or entertainment areas, etc. The provision of real-time parking information through static signs, DMSs or Highway Advisory Radio (HAR) can significantly reduce on-street traffic volumes in high parking-demand areas. This strategy is of particular benefit in areas that experience high tourist activity, where the visitors are less familiar with the local parking facilities.

Scheduled Event Management

Scheduled events present an opportunity to develop adequate traffic management strategies that coordinate the efforts of traffic control systems, police, traveller information, etc. ATMS may be used to monitor and react to the event as it proceeds. For events that are scheduled and recurring, monitoring and post-event reviews allow for the refinement of the event management strategies.

Surface Street Control System Integration

The ability to monitor on-street conditions in real time provides certain advantages when employed in combination with a surface street control system. Pre-determined traffic control system plans can alter traffic signal splits, cycles and offsets to suit the goals of the network management plans. Traffic Operation Centres can monitor the progress of the network management plan and implement alterations to the plan to benefit on-street conditions.

3.6.4 Travel Demand Management

The objective of Travel Demand Management (TDM) is to improve traffic flow by managing travel demand. In general, it is achieved through one of the following initiatives.

Electronic Road Pricing

Electronic Road Pricing facilitates demand management and operations to mitigate the impact of traffic congestion. It features additional user charges and differentials based on time, place, distance of travel, and vehicle type to effect changes in travel behaviour.

A few cities around the world have implemented various forms of congestion pricing, including Singapore, Orange County (California State Route 91), City of London in the U.K., Cities of Trondheim, Oslo and Bergen in Norway, and the 407 ETR in Ontario. For the Congestion Pricing System implemented in London, U.K. since February 2003, motorists driving in central London on weekdays between 7:00 am and 6:30 pm are required to pay £5, increasing to £8 in July 2005. The congestion pricing system uses a network of video cameras to record license plate numbers, and optical character recognition (OCR) technology to read this information, identify "unpaid" vehicles, and generate citations for violators.

Ontario Experience

In Ontario the 407ETR, a multi-lane, electronic toll highway which serves the Greater Toronto Area, varies toll charges by time of day and day of week. Higher toll charges are utilized during the peak traffic periods.

Ride-Matching and Carpooling

Ride-matching/carpooling makes ridesharing easier and more convenient for travellers, and encourages the use of high occupancy vehicles during periods of congestion. Carpooling involves two or more people sharing a ride to a mutual, nearby or consecutive destination to save gasoline, driving and the environment. Incentives to promote carpooling involve priority parking privileges (costs and spaces), guarantee of an emergency ride home and the use of special lanes. Some HOV facilities in operation in North America are connected either directly or indirectly to park-and-ride lots to promote the use of both ride-sharing and HOV facilities.

Ontario Experience

In Ontario, the Share-a-Ride program has expanded from a government employee-only program to a province-wide computer ride-matching system. The Smart Commute Initiative (www.smartcommute.ca), a partnership of Greater Toronto Area municipalities and the City of Hamilton, with financial support from Transport Canada and the private sector, was launched in June 2005 to offer commuters choices for getting to work or school and to provide direct services for employers and their employees. The Government of Canada has also launched the new ride-matching system (www.Ottawaridematch.com) in May 2006 for federal employees working in Ottawa, Ontario, and Gatineau, Québec, to find potential carpooling matches based on proximity to home and work, and similar working hours.

Pre-Trip Travel Information

Pre-trip travel information provides information to travellers in order to select the best transportation mode, departure time and route prior to their trip, and helps to reduce single-occupancy vehicle demand by assisting travellers in finding ridesharing opportunities. This can be done through a telephone call-in number, a cable TV traffic station, or information from the internet. MTO maintains a website (www.mto.gov.on.ca/compass.htm) to provide real-time traffic information for the Greater Toronto Area (GTA) and the Niagara Peninsula regions. The City of Toronto maintains a similar website (www.toronto.ca/rescu/) for real-time traffic information on major Toronto roadways.

3.6.5 Summary

The following items should be considered when identifying relevant ATMS strategies:

- Involve experts in the ITS field to assist with strategy development;
- Incorporate stakeholder input when identifying relevant strategies;

- Discuss strategies with local transportation agencies, including operators of existing ATMS systems;
- Focus on strategies and products that are proven and readily available;
- Incorporate maintenance and life-cycle costs into decisions regarding ATMS strategies;
- Consider methods of phasing in strategies (one at a time) so that impacts can be discretely observed; and
- Ensure that strategies are well understood by the motoring public before they are implemented. Strategies that are outside of the local traffic operations experience may result in motorist confusion or misunderstanding.

3.7 Identification of ATMS Subsystems and Components

3.7.1 Mapping Subsystems to Strategies

ATMS applications incorporate various subsystems, which facilitate the traffic management strategies as illustrated in Table 2.

3.7.2 Subsystem Descriptions

Monitoring

The Vehicle Detection Subsystem (VDS) provides for the collection of current traffic data. A series of sensors measure vehicle presence and is interfaced to a roadside field controller which computes traffic volume, occupancy and speed data. Data is typically aggregated into 20 or 30 second summaries for transmission to a central computer.

Table 2 – Mapping of Subsystems to Strategies

Subsystem	Incident Management	Congestion Management	Corridor & Network Management
Monitoring			
Vehicle Detection	X	X	X
CCTV	X	X	O
Advisory			
Dynamic Message Signs	X	X	X
Arterial Advisory Signs	O	O	X
Queue Warning Signs	X	X	
Traveller Information	O	X	X
Traffic Control			
Traffic Signals	O	X	X
Ramp Metering	O	X	O
Lane Management		X	

Note: X – Primary Role
O – Secondary Role

The CCTV camera subsystem (pan/tilt/zoom video camera) is a monitoring tool used by operators to monitor traffic flow and confirm incidents and congestion events. CCTV cameras are a valuable tool to the operator capable of providing a variety of information related to the event. Cameras are typically mounted on roadside poles or high-level rooftop locations adjacent to the corridor.

Advisory

Various approaches are used to provide scheduled and unscheduled event information to motorists:

- *Dynamic Message Signs (DMSs)* are typically comprised of an overhead or roadside-mounted pixel display capable of rendering any number of messages, and are located within the corridor in advance of key motorist decision points, such as freeway to freeway interchanges.

- *Arterial Advisory Signs* are smaller-scale DMSs located on crossing arterial roads in advance of freeway entrance ramps.

- *Queue Warning Signs* are smaller-scale DMSs located along the corridor, spaced at regular intervals to provide advance warning of congestion and improve safety.

- *Traveller Information Systems* employ a variety of information media to provide current traffic condition information to motorists – pre-trip or en-route. Systems might include commercial broadcast media, Highway Advisory Radio (HAR), interactive voice response, pager service, internet sites, fax service, etc.

Traffic Control

The traffic signal subsystem employs traffic signals to control conflicting vehicle and pedestrian movements at arterial intersections. Traffic signals may operate on an isolated basis (independent of the operation at adjacent signalized intersections) or in a coordinated mode, typically done under the supervision of a central control and monitoring system.

The ramp metering subsystem employs traffic signals to meter the flow of traffic entering the freeway, thereby improving merge conditions on the freeway.

The lane management subsystem provides lane-specific information to motorists indicating lane availability. It is typically used for alternating or reversing lane direction to improve capacity of urban arterials in order to meet peak direction traffic demand, or in tunnels or bridges to assist in traffic control during incidents or planned lane closures.

3.8 Project Implementation

To define the project scope, the ATMS goals and objectives established in Section 3.4 are applied to the needs and problems identified in Section 3.3. The geographic scope of the ATMS deployment will begin to materialize as each goal is overlaid on a problem area. Based on this analysis, it may be apparent that significant incremental benefits can be realized if modest extensions to the ATMS geographic scope are implemented.

An initial schedule for ATMS implementation should be developed, using the geographic scope to gauge timing needs and phasing. The schedule should reflect construction coordination issues with other jurisdictions identified in Section 3.5. Also, the roles and responsibilities of other jurisdictions during ATMS implementation and operation can be identified once the geographic scope of the ATMS project is determined.

A preliminary budget should be developed that prioritizes funding based on the key problem areas and needs, and their corresponding goals and objectives.

Savings in construction costs can be realized by staging ATMS equipment installation with planned infrastructure improvements. Whenever possible, provisions for ATMS infrastructure can be included in these construction projects (e.g., spare duct for ATMS communications purposes). Coordination of construction activities also helps to reduce disruption to the motorist.

Ontario Experience

- *City of Toronto Road Emergency Services Communications Unit (RESCU)* – A detailed five-year implementation plan was developed at the outset of the City of Toronto RESCU system development (formerly Gardiner-Lake Shore Corridor Traffic Management System). The project life cycle was defined in terms of functional and geographic areas of activity, and staged over a five-year timeframe in consideration of annual capital funding availability. Key areas of activity included:

  – system definition
  – detailed design and specification
  – software development
  – civil/electrical provisions installation
  – field subsystem installation
  – testing and integration
  – operations and maintenance support.

- *Ontario ITS Strategies Framework Study and Five-Year COMPASS Implementation Plan* – The Ministry of Transportation Ontario's five-year implementation plan established an implementation plan for COMPASS expansion projects. The plan was developed based on priorities established as a result of the evaluation of candidate projects, including benefit/cost analysis and scheduled to meet fiscal constraints. The implementation plan also considered other projects committed to by the MTO or other agencies (such as the MTO's Corridor Investment Plan and increasing priority for national security), as well as unique situations to provide a logical phasing of projects. It is noted that there is not a single solution to any implementation plan. Different phasing and scheduling needs to be considered to meet changing needs and priorities.

- Ontario experience in managing major multi-year ATMS deployment programs suggests that it is important to:

  – undertake a benefit-cost assessment to rationalize investment;
  – employ value engineering techniques in the system definition and design processes;
  – develop a phased implementation, making optimal use of funding and staffing levels;
  – ensure that the ATMS system proposed addresses specific needs;
  – define a reasonable, not optimistic, timeframe for deployment; and
  – use peer review groups to analyze the components of the study to ensure a reasonable approach and scope are adopted.

3.9 Determination of Recommended Solutions

The following is a summary of the pre-construction ATMS development process as presented in the preceding sections:

- Define the project environment in terms of current and future physical environment, traffic demand, etc.;
- Define user needs and develop project goals with stakeholders;
- Identify specific system strategies to facilitate the goals;
- Identify the specific required subsystems and the current state of the enabling technologies;
- Develop system performance requirements;
- Prepare a system preliminary design; and
- Develop an implementation plan for the functional and geographic deployment of the system.

4. ATMS Design Considerations

An Advanced Traffic Management System (ATMS) refers to the application of current and innovative traffic operation technologies to monitor and control vehicles in response to a dynamic traffic condition. ATMS integrates new and existing traffic management and control systems servicing all modes of transportation. The major components of ATMS are identified as follows:

- Information Collection (real-time data)
- Surface Street Control
- Highway Control
- Regional Traffic Control
- Traffic Information Dissemination
- Computer System
- Communications System.

The available technologies for ATMS applications are evolving rapidly. Many of these technologies benefit from research and product development for broader industry applications beyond transportation, such as communications, entertainment, and security. It is important that the ATMS authority undertakes a structured approach to technology review at the preliminary design stage of any major new deployment initiative. The technology review process typically incorporates the following activities for each candidate ATMS subsystem:

- Identification of user needs;

- Identification of system performance requirements;

- Identification of evaluation criteria including functional performance, physical requirements, electrical requirements, environmental parameters, maintenance requirements, failure rates, adherence to standards, availability, and cost;

- Investigation of industry best practices through consultation with other ATMS operators and advisors;

- Investigation of current available products;

- Investigation of ongoing research and development efforts to identify emerging technologies;

- Short-listing of candidate technologies/products;

- Detailed analysis against evaluation criteria; and

- Recommendations of technologies/products to be incorporated in the detail design process.

In some cases, the technology review process will result in an in-situ comparison test of candidate products supplied on loan from product distributors and/or suppliers.

The discussion on technologies in the following sections has been based on technologies that are current and proven at the time of publication and not emerging technologies, unless indicated otherwise. It is important for the practitioner to evaluate the latest technological advancements and consider adopting the state-of-the-art and/or state-of-the-practice in technologies at the time of their ATMS deployment.

4.1 Information Collection (Real-time Data)

To implement ATMS, real-time traffic monitoring and information collection capabilities must be provided. Advanced technologies for vehicle detectors, closed-circuit televisions, call boxes, vehicle probes, weather data systems, etc., have rapidly emerged in the last few years, making comprehensive and sophisticated traffic monitoring and information collection capabilities readily available. This section discusses the application of systems related to real-time information collection functions.

4.1.1 Vehicle Detection System

Concepts

A vital element of ATMS is the vehicle detection system, which is used to provide a means for a traffic operator to monitor traffic conditions, detect incidents, and implement control procedures. The primary role of the vehicle detection system is to collect accurate traffic flow data (volume, occupancy and speed), on a real-time basis, that can be used to determine traffic flow characteristics for monitoring and statistical purposes.

A vehicle detection system is typically comprised of the following functional elements:

- *Sensors* – measure traffic parameters and are installed in the pavement in the case of magnetic detectors and inductive loops; or above pavement in the case of ultrasonic, video imaging, microwave and infrared detectors.

Figure 2 – Typical Cabinet Arrangement

(a)

(b)

(c)

- *Electronics Unit* – housed in the controller cabinet to support functions such as selection of loop sensitivity and pulse or presence mode operation. In some cases, such as microwave, the sensors and the electronics unit may co-exist. In other cases, such as loops, they may be separate pieces of equipment, with the electronics unit containing an oscillator and amplifiers that excite the embedded wire loop. As a vehicle passes over the loop or is stopped within the area enclosed by the loop, the change in inductance is sensed by the electronics unit, and interpreted as a detected vehicle by the controller.

- *Field Controller* – used to process, summarize, store and transmit detector data. Depending on the controller, the detector data is either transmitted to a central site in raw form or summarized locally prior to transmission. Some detectors include these functions with the sensor.

Functions

One of the key functions for the vehicle detection system is to provide traffic data to a Traffic Operation Centre.

The function of the vehicle detection system is to monitor traffic flow characteristics in terms of the following traffic parameters:

- Vehicle Count (lane/location)
- Vehicle Speed (lane/location)
- Occupancy (lane/location)
- Vehicle Classification (by different length group)
- Headway (lane/location)
- Flow Rate (selection, hour and day).

Typically, vehicle count and occupancy measurements are directly obtained from the detector. In some cases, speed can also be directly measured. The remaining parameters can be derived or extrapolated based upon the available raw data.

The vehicle detection system is also employed to provide real-time display of traffic statistics. Typically, vehicle counts, speed and occupancy are shown graphically to reflect real-time traffic conditions. The vehicle count information is also useful for traffic engineers for historical traffic analysis and forecasting.

4.1.2 Detector Technologies

Vehicle detectors form an integral portion of practically every modern traffic control and management system. There is a wide range of available vehicle detection technologies, each custom tailored to the ATMS application environment. It is difficult to identify a single leading detection technology, as the appropriate selection varies according to a number of parameters. Most significantly, the ATMS authority must consider:

- *What is the relative priority of the traffic data parameters required for the ATMS application?* Some applications, such as traffic signal actuation, must have very robust presence detection capabilities. Others, such as travel time monitoring, emphasize speed data collection capabilities.

- *What are the limitations of the physical environment?* In-pavement technologies, such as the inductive loop detector, may not be viable if road resurfacing is planned. Conversely, overhead-mounted detection may be cost-prohibitive if there is a lack of existing structures to facilitate mounting.

The vehicle detection market is a varied, competitive market characterized by large-scale diversified vendors as well as niche suppliers. A significant volume of comparative technology assessment documentation is available in the ITS industry, although the content of past efforts tends to become outdated quite rapidly.

Currently available detection systems can be grouped into the following categories:

- Embedded Detectors
- Non-intrusive Detectors
- Environmental Sensors
- Probe-Based Sensors.

Table 3 provides a summary of the advantages and disadvantages of the embedded and non-intrusive detectors that are currently available. Detailed information on these detectors can be found in the *Freeway Management and Operations Handbook* sponsored by the Federal Highway Administration and the U.S. Department of Transportation.

Detailed descriptions of the three detector technologies that have been installed or are being tested in Ontario, namely the inductive loop detector, video image detection and microwave radar detection are provided below.

Inductive Loop Detection (ILD)

Inductive loops provide the required volume, occupancy and speed data for ATMS applications in a cost-effective manner and are considered to be very accurate. Some field controllers can also estimate vehicle size, gap and headway. Loops operate well if installed correctly for the specific data required and the "amplifier" is set to appropriate sensitivity. Figure 3 illustrates a typical arrangement of a double or speed inductive loop.

The major advantages of an inductive loop detection system include:

- Solidly proven and reliable technology – ILD has been used since the earliest computerized traffic control systems;
- Good passage and presence detection providing accurate volume, speed and occupancy data; and
- Design of the "amplifier" electronics have significantly reduced earlier problems associated with loop detectors such as oscillation, cross-talk, variations in activation and deactivation delay, and sensitivity adjustments and range.

While loop technology is proven and effective with a relatively low initial capital cost, if not installed correctly loops may require a significant and continual maintenance program of replacement. This disadvantage can be significant since loop installation works, if not coordinated with other construction work, may result in substantial disruption to traffic due to lane closures.

The typical failure mode for loops is not the wire embedded in the roadway pavement, but the amplifier contained within the electronics unit, which can be repaired by one staff person, without a bucket truck, and at a cabinet which is off the roadway in a protected area.

Figure 3 – Typical Inductive Loop Arrangement

Table 3 – Summary of Traffic Detectors

Technology	Advantages	Disadvantages
Inductive Loop	• Flexible design to satisfy large variety of applications. • Mature, well-understood technology. • Large experience base. • Insensitive to inclement weather such as rain, fog, and snow. • Easy to calibrate. • Provides best accuracy for count data as compared with other commonly used techniques. • Common standard for obtaining accurate occupancy measurements.	• Installation requires pavement cut. • Improper installation decreases pavement life. • Installation and maintenance require lane closure. • Wire loops subject to stresses of traffic and temperature. • Multiple detectors usually required to monitor a location. • Detection accuracy may decrease when design requires detection of a large variety of vehicle classes.
Magnetometer (Two-axis fluxgate magnetometer)	• Less susceptible than loops to stresses of traffic. • Insensitive to inclement weather such as snow, rain, and fog. • Less susceptible than loops to stresses of traffic and temperature. • Easy to calibrate.	• Installation requires pavement cut. • Improper installation decreases pavement life. • Installation and maintenance require lane closure. • Models with small detection zones require multiple units for full lane detection.
Magnetometer (Induction or search coil magnetometer)	• Can be used where loops are not feasible (e.g., bridge decks). • Some models are installed under roadway without need for pavement cuts. However, boring under roadway is required. • Insensitive to inclement weather such as snow, rain, and fog. • Less susceptible than loops to stresses of traffic and temperature. • Easy to calibrate.	• Installation requires pavement cut or boring under roadway. • Cannot detect stopped vehicles unless special sensor layouts and signal processing software are used.
Microwave Radar	• Typically insensitive to inclement weather at the relatively short ranges encountered in traffic management applications. • Capable of direct measurement of speed. • Multiple lane operation available. • Installation maintains integrity of pavement surface.	• Doppler sensors cannot detect stopped vehicles. • Installation and maintenance typically requires lane closure

Table 3 – Summary of Traffic Detectors (cont'd)

Technology	Advantages	Disadvantages
Video Image Processing	• Monitors multiple lanes and multiple detection zones/lane. • Easy to add and modify detection zones. • Provides wide-area detection when information gathered at one camera location can be linked to another. • Installation maintains integrity of pavement surface.	• Installation and maintenance, including periodic lens cleaning, require lane closure when camera is mounted over roadway (lane closure may not be required when camera is mounted at side of roadway). • Performance affected by inclement weather such as fog, rain, and snow; vehicle shadows; vehicle projection into adjacent lanes; occlusion; day-to-night transition; vehicle/road contrast; and water, salt grime, icicles, and cobwebs on camera lens. • Requires 50 to 70 ft (15 to 21m) camera mounting height (in a side-mounting configuration) for optimum presence detection and speed measurement. • Some models susceptible to camera motion caused by strong winds or vibration of camera mounting structure. • Generally cost-effective when many detection zones within the camera field-of-view or specialized data are required.
Active Infrared	• Transmits multiple beams for accurate measurement of vehicle position, speed, and class. • Multiple lane operation available. • Easy to calibrate. • Installation maintains integrity of pavement surface.	• Operation may be affected by fog when visibility is less than 20 ft (6 m) or blowing snow is present. • Installation and maintenance, including periodic lens cleaning, may require lane closure.
Passive Infrared	• Multizone passive sensors measure speed. • Easy to calibrate. • Installation maintains integrity of pavement surface.	• Passive sensor may have reduced vehicle sensitivity in heavy rain, snow & dense fog. • Installation and maintenance, including periodic lens cleaning, may require lane closure. • Some models not recommended for presence detection.

Table 3 – Summary of Traffic Detectors (cont'd)

Technology	Advantages	Disadvantages
Ultrasonic	• Multiple lane operation available. • Capable of overheight vehicle detection. • Large Japanese experience base. • Installation maintains integrity of pavement surface.	• Environmental conditions such as temperature change and extreme air turbulence can affect performance. Temperature compensation is built into some models. • Large pulse repetition periods may degrade occupancy measurement on freeways with vehicles traveling at moderate to high speeds. • Installation and maintenance, including periodic lens cleaning, may require lane closure.
Acoustic	• Passive detection. • Insensitive to precipitation. • Multiple lane operation available in some models. • Installation maintains integrity of pavement surface.	• Cold temperatures may affect vehicle count accuracy. • Specific models are not recommended with slow moving vehicles in stop-and-go traffic.
Laser Radar	• Transmits multiple beams for accurate measurement of vehicle position, speed, and class. • Multiple lane operation available. • Installation maintains integrity of pavement surface.	• Operation may be affected by fog when visibility is less than 20 ft (6 m) or blowing snow is present. • Installation and maintenance, including periodic lens cleaning, may require lane closure.

Source: *Freeway Management and Operations Handbook* (September 2003) by the Federal Highway Administration and the U.S. Department of Transportation.

The disadvantages of an inductive loop detection system include:

- Disruption to the flow of traffic during installation if it cannot be coordinated with highway construction or maintenance;
- Detectors cannot be effectively installed in inadequate pavement conditions;
- Heavy trucks cause pavement flexing, resulting in loop damage in poor pavement;
- Winter conditions can delay loop replacement for long periods of time;
- Pavement rehabilitation projects often destroy loops; and
- Reliability and useful life are strongly dependent on proper installation procedures.

Ontario Experience

In Ontario, several traffic management systems that utilize Inductive Loop Detection (ILD) technology are not operating properly due either to improper installation, poor maintenance, or breakdown of the road surface.

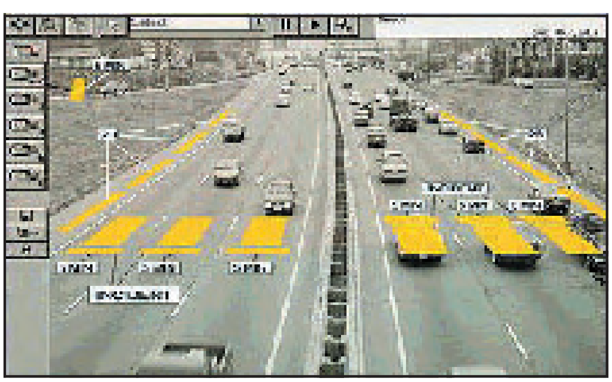
Volume and occupancy determination is susceptible to errors from improper sensitivity settings, loop geometry, and driver behaviour. Speed measurement is particularly susceptible to inaccuracies and it has been found that speed data obtained from two loops configured in tandem, a known distance apart, provide more accurate data. As a result, MTO has gradually replaced single-loop stations with double-loop stations.

Due to the express-collector freeway configuration on Highway 401, the impact of loop repair on traffic flow is minimal. In most cases, the loop servicing can be carried out when the express or collector section is closed for pavement rehabilitation projects.

Video Image Detection (VID)

The utilization of video camera images for vehicle detection and data collection is commonly used in advanced traffic control systems. A typical image from a video image detector is provided in Figure 4.

Figure 4 – Typical Image from VID



A video image detection processor is a combination of hardware and software components that extract information from the output of an imaging sensor. The system typically consists of the following components:

- *Imaging Sensor* – The imaging sensor is an electronic camera that overlooks a section of the roadway and provides the desired image information. It can use the visible or infrared spectrum, and can provide full-frame (two-dimensional) images or a series of line (one-dimensional) images.

- *Video Processor* – This combination of hardware and image processing software determines the vehicle presence or passage from the images received by the imaging sensor.

- *Data Processor* – Performs calculations derived from the presence data, such as occupancy and count, as well as compensation and communications.

These components can either be separate units or combined into one housing unit. There are two basic approaches used in the video processor:

- *Tracking* – Tag and track the progress of vehicles through the field of view thereby determining the trajectory and speed of each tracked vehicle; and

- *Loop Emulation* – Define and monitor detection zones on the highway to identify when traffic enters and leaves the zone.

Tracking Approach

For VID systems employing the tracking approach, existing video signals from the monitoring system are fed into the video imaging processor, which runs a detection algorithm based on tracking techniques and trajectory analysis to detect stopped vehicles within the field of view of the camera. This approach requires significantly more signal throughput, in that each vehicle, in all directions and traffic lanes visible in the image, is identified and tracked through the camera's field of view. It measures vehicle speed directly and is a potentially useful application in identifying incidents.

While cameras can be installed on any type of support, such as poles, gantries or masts, support stability is fundamental to obtain the best performance of the system. To avoid masking effects, cameras are preferably located in a central position with respect to all traffic lanes being monitored. It is preferable that the camera is oriented with traffic moving away from the unit in order to avoid blinding effects at night on some types of cameras (i.e., blooming) due to vehicle headlights.

The advantages of tracking-based VID systems include:

- Ability to provide multiple-lane coverage;
- Tracks the trajectory of a vehicle and can detect incidents if the vehicle leaves the road or changes speed suddenly; and
- Can replace numerous in-ground inductive loops.

The disadvantages of tracking-based VID systems include:

- Cameras need to be dedicated to VID purposes only (i.e., no pan/tilt/zoom for operators' use in scanning roadway) in order not to sacrifice data accuracy;
- Zone of tracking may be determined by the range of the camera;
- Errors caused by occlusion;
- Errors caused by severe rain, fog and snow conditions;
- Cost-effectiveness of small installations;
- Cost for structure to mount cameras – while structures installed for other purposes may be used, they will seldom be in the optimal location for the VID camera; and
- Cost to maintain cameras which includes the use of specialized equipment, such as bucket trucks to access the cameras and multiple staff required to meet health and safety requirements for working at heights.

The following issues must be evaluated when considering tracking-based video image detection.

- Shadows which are projected to the front or rear of a vehicle may create false vehicles for tracking.
- Vibration, caused by unstable mounting, may oscillate the virtual detection zone over lane markings resulting in erroneous data.
- Variations in ambient light, particularly during day/night transition periods, may affect data accuracy and incident detection.
- Severe fog or other similar atmospheric conditions can filter out vehicles which may affect data accuracy and incident detection.
- Minor fluctuations in accuracy may be experienced during periods of inclement weather, but generally result in only very minor aberrations in the data stream.

Ontario Experience

MTO's experience with tracking-based video image detection at the Highway 3/Highway 401 overpass and the Highway Occupancy Vehicle Bypass Tunnel at Highway 404/Highway 401 interchange raises a number of concerns including:

- The ability to detect incidents/queues in very slow-moving traffic;

- Difficulty in detecting white vehicles on salted roadways in winter due to lack of contrast; and

- False calls caused by stopped vehicles (e.g., at stop bars) adjacent to the tracking zone, requiring careful placement of cameras to avoid such occurrences.

Loop Emulation Approach
VID systems employing the loop emulation approach is more common in the transportation industry and can detect traffic in multiple locations within the field of view of the camera. In these systems an interactive graphics screen is used through which the operator is able to locate and size the desired number of detection zones on an image of the camera's field of view. Once the detection zone is established, every time a vehicle passes through the detection zone, a signal is generated by the video imaging processor software. This signal is similar to that produced by loop detectors which can be used to determine vehicle presence, volume, speed, occupancy, vehicle length, etc. Special purpose detection zones can also be created to identify, for example, vehicles on the shoulder or stopped vehicles.

Limited traffic monitoring can also be provided with a VID system. The monitoring function, however, will require repositioning of the camera, which will impact the performance of the video image processor in its vehicle detection mode. There is therefore a trade-off in data accuracy in combining the functions of vehicle detection and video monitoring into the same processor.

Creating detection zones on the video image requires care to ensure that the required area of the detection zone is not obstructed and can distinguish between vehicles in each lane. The effect of occlusion, where a high-profile vehicle obstructs or partly obstructs the view of another vehicle, must be carefully considered when selecting camera placement and mounting arrangement.

The advantages of loop emulation-based VID systems include:

- Ability to provide multiple-lane coverage;

- Placement of vehicle detection zones on the road, as reflected by the positioning of the cameras, is not locked to a particular detection configuration. The configuration can be controlled manually (by an operator at a computer terminal) or dynamically (by software) at any time, as a function of traffic flow;

- The shape of the detection zone can be programmed for specific applications, such as incident detection and the detection of queue lengths, that cannot easily or economically be derived by conventional devices; and

- Can replace numerous in-ground inductive loops.

The disadvantages of loop emulation-based VID systems include:

- Cameras need to be primarily dedicated to VID purposes only (i.e., no pan/tilt/zoom for operators' use in scanning roadway) in order not to sacrifice data accuracy;

- Errors caused by occlusion;

- Errors caused by severe rain, fog and snow conditions;

- Cost effectiveness for small installations;

- Cost for structure to mount cameras – while structures installed for other purposes may be used, they will seldom be in the optimal location for the VID camera; and

- Cost to maintain cameras which includes the use of specialized equipment, such as bucket trucks to access the cameras, and multiple staff required to meet health and safety requirements for working at heights.

The following issues must be evaluated when considering loop emulation-based video image detection.

- Shadows created by vehicles which are projected into adjacent lanes may produce erroneous data in the adjacent lane.
- Shadows created by a vehicle which are projected to the front or rear of the vehicle may skew occupancy determination.
- Vibration, caused by unstable mounting, may oscillate the virtual detection zone over lane markings, resulting in erroneous data.
- Variations in ambient light, particularly during day/night transition periods, may affect data accuracy and incident detection.
- Vehicle headlights or reflections from wet pavement may be erroneously identified as a vehicle and may skew occupancy determination.
- Severe fog or other similar atmospheric conditions can filter out vehicles, which may affect data accuracy and incident detection.
- Minor fluctuations in accuracy may be experienced during periods of inclement weather, but generally result in only very minor aberrations in the data stream.
- Discrimination between closely spaced vehicles may affect vehicle count and occupancy determination.

The accuracy of video image detection systems for all three primary traffic data parameters (volume, occupancy and speed) has been demonstrated in numerous site test demonstrations to be generally less than that of inductive loops installed in a double loop configuration.

Ontario Experience

City of Toronto's experience with video image detection systems includes loss of effectiveness and accuracy with changes in weather, and calibration problems due to unorthodox mounting of cameras (i.e., mounted on a 44-story building adjacent to the corridor).

Microwave Radar Detection

Microwave radar detection is a proven and reliable technology in some applications while it does not work very well in other applications (refer to Ontario Experience for details). Radar is an acronym, which stands for Radio Detection and Ranging. Microwave, is a reference to the wavelength of the transmitted energy. There are two basic approaches that have been employed to manufacturing and marketing a microwave radar detector for vehicle detection purposes:

- *Doppler Shift* – A measurement of the Doppler shift of the transmitted and received signals; and
- *Time of Flight* – A measurement of the difference in time between when the signal is transmitted and the time the signal is received.

Doppler Shift Detection

Doppler shift radar detectors transmit a continuous wave of electromagnetic energy. The detector is designed to sense the change between the transmitted frequency and the frequency which is received by the detector. The difference in frequency denotes the passage of a vehicle and is equal to the Doppler frequency produced by the vehicle speed. These detectors provide speed data and are unable to detect stationary traffic, eliminating the ability to obtain occupancy information.

Doppler shift radar detectors project a single footprint image onto the roadway surface. In order to collect speed data for individual lanes, a detector is required for each lane mounted on an overhead gantry. Radar units can be configured with a wide beam width to obtain average speed across multiple lanes or narrow beams to measure speed in a single lane.

The advantages of Doppler shift microwave systems include:

- Accurate speed measurement;
- Easy set-up;
- Installation does not require pavement cut; and
- Physical mounting, with respect to cameras, is simple.

The disadvantages of Doppler shift microwave technology include:

- Problems with occlusion and slow moving vehicles;
- Inability to detect stopped vehicles;
- Inability to visualize the detection zones made possible with other imaging sensors; and
- Installation and maintenance requires a bucket truck and two staff members.

Time of Flight Detection
Microwave time of flight detection measures the difference in time from when a signal is transmitted to the time when the signal is received. The difference, or time of flight, can be used to detect the presence or passage of a vehicle by comparing this time to the time required for the energy to be reflected off the roadway surface. For this reason, these detectors can measure the presence of stationary vehicles. Speed data can also be provided, but the accuracy is dependent on the field configuration.

Microwave time of flight detection projects a footprint onto the roadway. Some designs provide a single zone of detection per microwave unit. These devices are capable of detecting traffic in only one lane and would generally be mounted overhead on a gantry. Speed determination would be measured based on the known or assumed length of the detection zone over the time the detector senses a vehicle presence. The variations in vehicle length, occlusion from closely spaced vehicles, and the effective length of the detection zone can result in significant errors in determining vehicle speed with single zone microwave radar detectors in much the same manner as a single inductive loop.

A more sophisticated approach to time of flight microwave radar detection is to provide multiple detection areas within the projected footprint. The zones are defined by arcs, or range slices, radiating from the detection unit. These types of detectors are capable of being mounted in a side-fire configuration (see Figure 5) to obtain vehicle data parameters in multiple lanes. This type of configuration offers significant cost advantages versus single-zone detection devices and installation of overhead gantries. However, the determination of speed in this configuration is subject to the same errors as discussed above. Typically, speed data is provided in terms of average speed which can be accurate over large sample sizes, but prone to errors for individual vehicles.

The advantages of time of flight microwave systems include:

- Physical mounting is simple;
- Ability to provide multi-lane coverage;
- Can replace numerous in-ground inductive loops;
- Placement of vehicle detection zones on the road is not locked to a particular detection configuration, but can be defined by the users and through set-up configuration.

Figure 5 – Microwave Detection Unit (Side-Fire Mode)

The disadvantages of the time of flight microwave technology include:

- Less accurate speed measurement;
- Problems with occlusion and slow moving vehicles;
- Inability to visualize the detection zones made possible with other imaging sensors;
- Pole distance from roadway is restricted, with insufficient right-of-way in some urban settings;
- Set-up requires steady flow of traffic;
- Fine tuning of the detectors can sometimes be problematic; and
- Installation and maintenance requires a bucket truck and two staff members.

Microwave technology, like video technology, suffers from the effects of occlusion, though to a lesser degree. The long microwave wavelength and the range-measurement capability of some microwave detectors allows for enhanced visibility of vehicles in far lanes that are obscured by larger vehicles in near lanes. Side-fired installations suffer the disadvantage of more difficult detection zone placement since a video image is not presented. Careful manipulation of the microwave sensitivity parameters as well as close observation of the detector outputs and actual traffic flow will provide accurate data.

Ontario Experience

Currently, the time of flight microwave radar system has been employed in Ontario at urban intersections, as well as being used as a temporary vehicle detection system on freeways during construction.

The MTO's experience with microwave radar on Highway 401 indicates that, while the presence of stopped vehicles can be detected, there is difficulty in differentiating one vehicle from another during stop-and-go traffic and congestion conditions. This is mainly due to the fact that the size of the detection zone cannot be controlled, only the location. MTO's experience, however, shows that microwave radar is effective as an alternative to loop detectors during pavement rehabilitation and construction periods. Experience in urban applications supports these findings with the most successful deployments situated in mid-block locations, measuring vehicle passage rather than presence.

4.1.3 Future Trends

Intelligent Transportation Systems are generally input-data intensive and transportation authorities will continue to seek low-cost, reliable, accurate means of collecting real-time traffic flow data. While much work has been done on overhead sensors, little progress has been made in finding a true replacement for the inductive loop sensor. While there are a number of non-intrusive detectors available, none have shown the accuracy or life cycle cost effectiveness of loops. The more promising technologies appear to be microwave and video. Both offer accuracy approaching that of loops in at least some measures, and offer significant flexibility in installation. For this reason, they make excellent replacements for loops during construction where lanes are regularly being shifted and pavement being changed.

Trends in the industry also indicate an increasing interest in the use of technology to collect real-time traffic flow data using vehicle probes. This approach offers low-cost data which is particularly useful for applications requiring information over a large geographic area. Wide area monitoring and the use of vehicle probes are described further in Section 4.1.8.

4.1.4 Standards/Interoperability

Most sensing applications employ separate sensor(s) and a microprocessor-based controller. The interfaces between the sensor units and the controllers are unique to the various sensing technologies and may incorporate proprietary manufacturer protocols. From the standpoint of overall ITS architecture, the controller and sensor(s) can be considered as a functional unit, and hence the interface issue only exists between the controller and the overall system architecture.

To date, the typical approach for collecting real-time data from sensor subsystems is to have dedicated trunk communications channels between the central system and the outlying field controllers. The central system and the field controllers incorporate custom communication software which polls each field controller site at prescribed intervals to collect data packets of a prescribed format. Many operating authorities, such as the Ministry of Transportation Ontario, have specified and developed custom software to be used within their jurisdiction, supported by standard off-the-shelf controller hardware such as the type 170 controller, or more recently the Advanced Traffic Controller (ATC). Most North American regional traffic control systems incorporate the collection of current traffic volume, speed and lane occupancy data at certain intervals for processing by incident detection algorithms. A number of jurisdictions have adopted the use of the National Transportation Communications for ITS Protocol (NTCIP) to provide a common protocol for the collection of detector data from the field.

4.1.5 Incident Detection Algorithms

Concepts

Automatic incident detection (AID) functions are commonly incorporated in more advanced regional traffic management systems. Detected changes in traffic conditions reflect the potential occurrence of an incident. The main objective of automatic incident detection is to assist a traffic operator in detecting potential incidents, enabling the operator to effect incident management procedures.

Types of AID Algorithms

An incident detection algorithm is a specific logical and analytical procedure, used along with data obtained from traffic detectors, to ascertain the presence or absence of a capacity-reducing incident. The measures of effectiveness generally used in evaluating detection algorithms are detection rate, false alarm rate, and mean time to detect. When selecting an algorithm, there is normally a trade-off between these measures of effectiveness. In general, the fraction of incidents detected can be increased only at the expense of an increase in the false alarm rate. To shorten the mean time to detect, a higher false alarm rate will be expected.

Algorithms Overview

Widely used algorithms employed in various traffic management systems around the world include the following types:

- Pattern Recognition Approach
  - California
  - All Purpose Incident Detection (APID)
  - Pattern Recognition (PATREG)

- Statistical Approach
  - Standard Normal Deviate (SND) Model
  - Bayesian Algorithm
  - AIDA

- Time Series Model Approach
  - RIMA, Smoothing Model
  - Double Exponential Smoothing (DES)
  - High Occupancy Algorithm (HIOCC)
  - Filter Model
  - Dynamic Model

- Catastrophe Theory Approach (McMaster Algorithm)

- Neural Network Approach (ODINN)

- Fuzzy Logic (TTI Fuzzy Approach)

- Wide Area (IDEAS, AIDA)

Pattern Recognition Algorithms compare traffic parameters between upstream and downstream detector stations. These algorithms rely on the principle that an incident is likely to significantly increase occupancy upstream while reducing the occupancy downstream. Statistical Algorithms are based on statistical analysis to determine if the recorded traffic data differ statistically from historical conditions or a defined threshold. The Time Series Model Approach Algorithms perform comparisons between short-term forecasts and the actual conditions, and identify calibrated deviations as incidents. The McMaster Algorithm uses traffic flow theory and Catastrophe Models to forecast expected traffic conditions on the basis of current traffic measurements for incident and congestion detection. The Neural Network Approach uses back propagation, hidden layer and nerve connections, and such networks exhibit learning memory and an ability to address the "noise" of real world data. The Fuzzy Logic approach uses fuzzy logic decision rules instead of analytic control laws in traffic flow control. The Wide Area detection approach is based on machine vision incident detection schemes associated with video image detection systems.

Ontario Experience

Experience indicates that Modified California Algorithms and the McMaster Algorithm have been rated the highest on the basis of reported performance, operational experience and model complexity. These algorithms claim to be able to achieve a detection rate of 70% to 85%, with a false alarm about 1% of the time[4]. In Ontario, the APID (All Purpose Incident Detection) and McMaster Algorithm have been implemented and both operate at a detection rate of about 40%, which seems to be a more realistic detection rate.

The City of Toronto has recorded similar performance statistics for the APID and McMaster incident detection algorithms. The City of Toronto also keeps closer tracking of auto-detected queues and congestion than the COMPASS system.

It should also be noted that the ability of an operator to detect incidents and congestion manually is directly related to the level of training and experience of each individual operator.

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[4] *Traffic Incident Management Handbook,* Federal Highway Administration.

There are different approaches in the industry for design and implementation of AID systems. These approaches are summarized as follows:

- *Central Detection Processing* – The AID algorithm resides in the central computer system whereby traffic data from multiple detection stations can be used for incident detection.

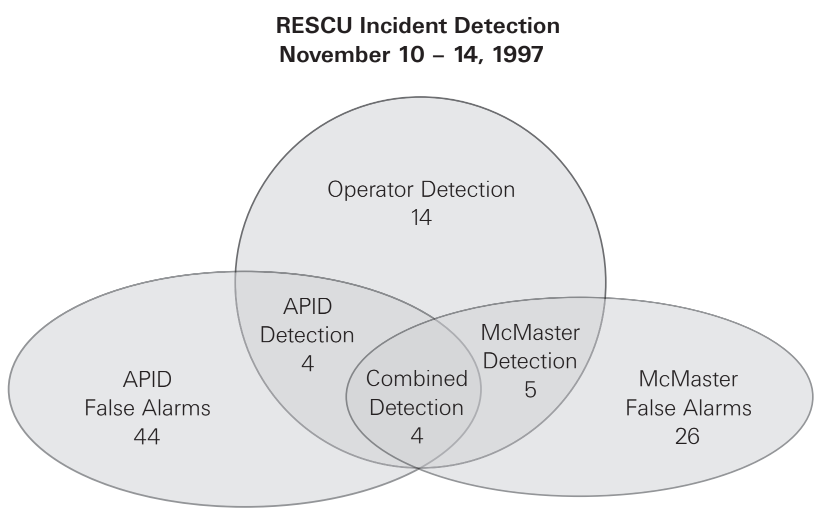
- *Local Detection Processing* – The AID algorithm resides in the local controller/field cabinet whereby only data from a single detection station can be used for incident detection.

- *Public Domain Algorithms* – These algorithms are well used and published around the world, and can be applied with all types of vehicle detectors. Typically, no user fees are required for implementation. Examples are APID, California set of algorithms, HIOCC, DES.

- *Proprietary Algorithms* – These algorithms are usually tied in with the design of the vehicle detectors and are manufacturer dependent. Typically, the cost of the software is part of the detector cost.

Statistics show that although most ATMSs in North America have some form of automated incident detection algorithm, most agencies get incident information more quickly and more frequently from other sources (e.g., operator detection – especially those systems with full CCTV coverage, reports from police, cellular telephones, etc.). Figure 6 and Table 4 show the findings for the incident detection system for RESCU in November 1997. For the purpose of this document, the illustration is not meant to evaluate different incident algorithms (the results were based on the findings during a short period of time in 1997 and algorithm performance may vary since then), but to illustrate the different possibilities of detection and their number of counts of detection at that time.

Figure 6 – Example of RESCU Incident Detection Data



Note: The intersection of simultaneous false alarms by APID and McMaster at a single station is not logged by the system.
Source: RESCU, City of Toronto.

Table 4 – Summary of Example of RESCU Incident Detection

November 10th – 14th	McMaster	APID	Operator Exclusive
Operator Confirmed Detection	9	8	14
System Declared False Alarms	26	44	N/A
Total (Detection and False Alarms)	35	52	14
Detection Rate (System detection of actual events)	39%	34%	N/A
False Alarms (System detection verified as false)	74%	85%	N/A
System Detection Rate (combined detection rates for both algorithms)	40%	40%	N/A

Source: RESCU, City of Toronto.

4.1.6 Closed Circuit Television Monitoring

Closed Circuit Television (CCTV) monitoring systems have been employed for many years to provide visual monitoring of the freeway system. In recent years, such systems have also been used to monitor selected urban intersections. CCTV monitoring systems are typically used for the following functions:

- To confirm the presence of an incident and determine its nature and severity;
- To monitor traffic flow conditions; and
- To monitor field equipment operation.

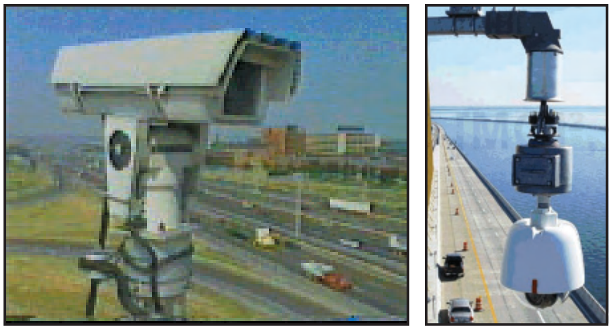
CCTV equipment applied for ATMS applications is primarily sourced from the security industry. This industry continues to drive rapid advancements in imaging technology. A wide range of comparable, compact, solid-state, low-light camera and lens products is available at ever-decreasing costs.

A key consideration for ATMS applications is the physical environment. The technology review process should consider various camera housing and pan/tilt configurations suitable for the relatively harsh roadside environment. Ambient light levels should be considered to identify the optical performance requirements for night-time operation. Furthermore, given the difficulties in accessing roadside, pole-mounted cameras, considerable attention should be directed at robust configurations characterized by low-maintenance requirements.

Ontario Experience

For the Ministry of Transportation Ontario and the City of Toronto, the CCTV camera system has migrated from black-and-white in the early 1990s to colour, as camera technology developed. In recent years, the MTO and the City of Toronto started to install the dome camera in addition to the conventional pole-top-mounted cameras (refer to Figure 7). As of 2006, the CCTV camera and lens specifications of the currently installed units have the following key performance requirements:

Figure 7 – Typical CCTV Camera Types for COMPASS ATMS



Pole-top Camera Unit

- Minimum of 1.9 lux at f/1.2;
- 13 lux full video with a useable picture at f/1.2;
- 1/3", Charged Coupled Device (CCD) colour camera;
- Minimum of 768 (horizontal) x 494 (vertical) active pixels;
- Minimum of 470 lines horizontal resolution;
- Greater than 50 dB signal to noise ratio; and
- Automatic Gain Control (AGC) backlight compensation.

Dome Camera Unit

- 1/4" colour, inter-line transfer, solid state CCD image sensor;
- Minimum of 768 (horizontal) x 494 (vertical) active pixels;
- Minimum illumination of 0.5 lux with 1/4 sec open shutter;
- Minimum of 470 lines horizontal resolution;
- Standard colour NTSC composite video signal output with an output impedance of 75 ohms; and
- Weighted signal to noise ratio shall be greater than 50 dB at 1.0 V p-p (AGC off).

Dome Lens

- 1/4" format zoom lens with automatic iris and spot filter;
- Minimum focal length range of 4-88 mm, providing 22x optical zoom and compensated with 10x digital zoom; and
- A neutral density spot filter providing a maximum aperture of f/1.6.

In general, a CCTV monitoring system is comprised of the following functional elements:

- Video camera unit with pan/tilt/zoom features;
- Camera housing and mounting structure;
- Communication system between the camera and the Traffic Operation Centre;
- Controller cabinet; and
- Video monitors and camera controls in the Traffic Operation Centre.

A CCTV monitoring system, which provides full visual coverage of the roadway, is a very effective incident confirmation system. Such a system allows the Traffic Operation Centre operator to confirm the presence of an incident, and determine its nature and severity with minimal delay. In addition, CCTV can be used to scan the roadway to monitor traffic conditions, and verify field equipment is operating correctly. The monitoring functions are more typical of urban applications of CCTV, where the operator is interested in traffic signal operations and the impact of their operation on traffic conditions within the corridor.

To assist the Traffic Operation Centre operator to react immediately to an incident detection alarm, the advanced CCTV monitoring system is designed to automatically position the camera to the corresponding incident location upon detection of a potential incident.

Video transmission can be accomplished using either full-motion video or compressed video. Full-motion video is typically transmitted at a rate of 30 frames per second by coaxial cable or fibre optic cable. This transmission type provides real-time video information of the monitored roadway to the Traffic Operation Centre operator. However, if the communications medium required for full-motion video is not feasible, compressed video transmission can be used. Upon compression, the video data can be transmitted over conventional telephone lines or cellular channels. Compressed video transmission is typically transmitted at a rate of 10 frames per second. As such, some information will be lost between each picture update.

Standards/Interoperability

Several governing bodies have been involved in developing the standards associated with the CCTV camera subsystem, including standards developed for television, video signal transmission, and CCTV camera operation.

- *The National Television System Committee (NTSC)* – The NTSC originally set the broadcast television standards in 1953 for North American Television. When broadcasting a video signal, the NTSC standard requires a 6 MHz bandwidth to carry 29.97 frames per second of colour picture and sound information. This standard is still in use today.
- *The Motion Picture Experts Group (MPEG)* – MPEG is a working group of ISO/IEC in charge of the development of international standards for compression, decompression, processing, and coded representation of moving pictures, audio and their combination. MPEG video digitization schemes include the original NTSC composite signal (143.2 Mbps), along with the CCIR 601 (270 Mbps) and SMPTE 240 M (1,485 Mbps) standards. Several compression schemes are available, i.e., JPEG, MPEG-1, MPEG-2 and Px64, which are suitable for full-motion video.
- *National Transportation Communications for ITS Protocol (NTCIP)* – Document 98.01.03, released in draft form in July of 1998, has developed control requirements for the CCTV camera subsystem, including cameras, lenses and pan/tilt units. There are no existing standards that define how these devices communicate with other related equipment, and as a result, each manufacturer has developed its own protocol to meet their particular needs. Consequently, integrating camera systems manufactured by different companies requires considerable work.

Ontario Experience

It should be noted that with video compression, there is a trade-off between refresh rate and image quality – the higher the refresh rate, the lower the image quality. The experience of the MTO is that once operators are used to seeing full-bandwidth/motion video, anything less will not be well received.

Based on the City of Toronto's experience, the pre-set function used for the auto positioning of cameras is a frequent source of failure for the camera controllers. The failure of the particular card that provides this function can have a large number of undesirable affects on camera operation (i.e., pre-sets drift, failure of cards inhibit full range of movement on camera or causes "jerky" movement, failure of card disables all camera control, etc.).

The MTO has recently undertaken a CCTV camera demonstration to determine the following:

- Lowest level of illumination required by the camera;
- Overall picture quality (e.g., colour, reflection, day time viewing);
- Blooming and smear characteristics; and
- A review of available technology.

The demonstration showed that the evaluation of the image quality of a camera is very subjective, with many observers rating camera performance differently. The inability to quantify blooming and smear characteristics also makes specification of the cameras difficult, since inferior units could be proposed which meet the defined specifications, but are unable to provide the desired performance. Based on the comments of the observers, the blooming of the cameras appears to have the greatest effect on perceived camera performance.

The demonstration also showed that cameras with essentially the same stated specifications behave much differently in real conditions. The performance was rated from good to unusable in the eyes of the observers. To ensure that the selected camera meets the requirements of the agency, it is recommended that the cameras be demonstrated to the agency under field conditions. The best method would be to set up a permanent site where the vendors can submit their cameras for approval.

Since technology changes rapidly, camera specifications must be reviewed frequently to allow an agency to take advantage of the latest improvements.

4.1.7 Call Boxes

Call boxes are located at intervals along a freeway so that a motorist can seek assistance from the operating agency. Traditional call boxes are equipped with specific buttons for need identification. Once the call box is opened, the motorist can seek help by pushing the appropriate buttons. Specific buttons can be selected to indicate the need for an ambulance, a police vehicle, a tow truck, etc. Another type of call box can be referred to as an emergency telephone box. When the motorist reaches the emergency telephone box and picks up the telephone, he or she will automatically be connected to an operator who can record the location and type of emergency response vehicle required.

Although a system of call boxes with coded message buttons is usually less expensive than an emergency telephone system which requires voice transmission, the latter system is more popular. Direct conversation between the motorist and the system operator will, in most circumstances, quickly identify specific needs and allow the appropriate responses to be dispatched.

A cellular emergency call box system is also available. These call boxes are connected to a 24-hour computerized response centre, which monitors all incoming calls and dispatches services as requested by the callers. Each cellular call box can be powered by a solar panel with re-chargeable battery. The cellular call box system is virtually a self-supporting system, which can be implemented wherever there is cellular coverage.

In general, the call box system is comprised of the following functional components:

- Call box equipment panel or telephone hand-set;
- Solar panel with back-up batteries;

- Communications by one of the following:
  - regular leased telephone lines or cellular network;
  - an agency owned communications cable system; or
  - a radio transmitter and receiver.

Ontario Experience

The Ministry of Transportation Ontario no longer uses emergency call box systems due to safety concerns associated with their tendency to encourage pedestrian activity alongside the highway, the additional maintenance costs they generate due to the harsh roadside environment, and the potential for vandalism. The proliferation of cellular telephones over the past decade has also significantly increased the motorist's communications capabilities from their vehicle, thereby reducing the need and effectiveness of call box systems.

In the recent past an emergency call box system was in place on the Garden City Skyway on the QEW in St. Catharines, which is a 2 km long, six-lane structure over the Welland Canal, with no shoulders. Similar systems were also installed on short sections of Highway 400 and Highway 417 as a pilot project. These roadways sections now have full CCTV coverage with active monitoring of these roadway sections from a nearby Traffic Operations Centre, significantly increasing the level of monitoring in these roadway sections.

4.1.8 Vehicle Probes

AVI/AVL-Equipped Vehicles

Vehicles equipped with on-board units, travelling on the roadway, can serve as moving sensors to collect traffic information. This type of probe vehicle has become one of the key components to perform monitoring functions for advanced traffic management systems. The real-time locations and identities of the probe vehicles, once transmitted to the operation centre, can be used together with other sources of information to determine the following traffic parameters:

- Travel speeds
- Travel times
- Origin and destination of the probe vehicles.

Traditionally, there are two approaches to collecting traffic parameters using probe vehicles, Automatic Vehicle Identification (AVI) and Automatic Vehicle Locating (AVL). The concepts and the associated technologies of these two approaches are discussed in the following sections.

Automatic Vehicle Identification (AVI)

Automatic vehicle identification systems identify probe vehicles as they travel through a detection area. AVI systems typically consist of a roadside communications device that broadcasts an interrogation signal from its antenna. When a probe vehicle equipped with a tag or transponder moves within the range of the antenna, the transponder or tag returns the identification code of the vehicle to the roadside device. This information will then be sent to a central computer system for further processing. Transponders can be further classified based either on power sources or on programmable information.

Based on the type of power source, the following three classes of transponders are available:

- *Active* – Power to this type of transponder is supplied from an internal battery or a connection to the power supply of the vehicle. The transponder responds to the signal originated from the roadside device by broadcasting its own signal containing the vehicle identification code. As such, this type of transponder is more reliable and has a greater communications range.

- *Passive* – No internal or external power supply is required for this type of transponder. The interrogation signal from the roadside antenna is modulated and reflected to the reader. As such, the return signal is weaker and has a shorter communications distance.

- *Semi-active* – Like the passive transponder, the semi-active transponder activates only after an interrogation signal is received from the reader. Similar to the active transponder, a semi-active transponder uses internal power to boost the return signal to the reader so as to increase the communications distance.

Based on the intelligence of transponders, three classes of transponders are identified as follows:

- *Type I* – This is a read-only transponder that contains fixed data, such as identification number. The fixed data can only be programmed or reprogrammed at the manufacturer's plant.

- *Type II* – This transponder has both read and write capabilities. Typically, some of the memory contains fixed data such as an identification number, and cannot be field programmed, while memory such as time, data and location can be entered in the scratch pad memory.

- *Type III* – This transponder has extended memory and is capable of full two-way communications. This transponder has an RS232 interface to communicate with extended Universal Mobile Telecommunication System (UMTS) and has an internal modem.

AVI systems have been used as a means of collecting travel time information as well as incident detection. In the Buffalo area, electronic toll transponders (E-ZPass) are used to collect link speed information on select highway links for traffic management purposes. The MTO is currently contemplating a similar deployment on the Ontario side of the border to monitor border conditions and estimate border wait times. The trend is that future vehicles will be equipped with 5.9 GHz transponders under the IEEE 802.11 standard.

Automatic Vehicle Location (AVL)

Automatic vehicle location systems track the location of vehicles as they traverse the road network. By continuously locating the probe vehicles, travel speed can be estimated for each link on the journey, and the overall travel time can be obtained and monitored in the operation centre. Typically, global positioning systems (GPS) technology is used to locate the position of the probe vehicles. As a potential source of link travel time, the data collected can also be used to detect incidents and determine their severity.

Automatic vehicle location systems are typically employed by the following agencies:

- Transit agencies – to track transit vehicles so as to improve system management and to provide passengers with arrival and delay time;

- Emergency services – for dispatching and scheduling purposes;

- Courier companies – for dispatching and scheduling purposes; and

- Vehicle manufacturer/operating agencies – to track stolen vehicles and vehicles with inflated air bags.

Cellular Telephone Probes

An emerging trend in probe-based monitoring is the use of cellular telephones as probes. There are two fundamental approaches to determine traffic flow data through the use of cellular telephones in vehicles. These two approaches help determine the vehicle location using equipment at the cell tower or by using the satellite-based global positioning system (GPS) with a receiver on the handset.

Network-Based Approach
The network-based approach relies upon network equipment to locate the probe. The probe could be a cellular telephone or a special-purpose device used for location purposes. This method uses the cellular network "hand-off" as cellular telephone users transfer between cells. The "hand-off" would occur as long as the cell telephone is powered on, regardless if it is in use or not. By sampling the location of a cellular telephone over a period of time, the route and velocity at which the telephone is travelling can be determined. Cell sizes vary widely based upon cellular network capacity requirements. Essentially, denser urban areas have smaller cell sizes than larger rural areas. Locating a cellular telephone would be more accurate in urban areas. While an individual record of a cellular telephone's position is typically less accurate than that of a corresponding global positioning system (GPS) record, this is compensated for by the large number of cellular telephones on any road, knowledge of the underlying road network, and the application of additional network equipment that would further narrow down a telephone's location using other techniques, such as relative signal strength, time delay or triangulation.

The ability to position a telephone within a cellular network is well understood. However, to create highly accurate traffic information, there are a number of challenges to be overcome. These include collecting data without compromising an individual user's privacy, de-cluttering the millions of data points available into a usable data stream, and map-matching the resulting patterns to the road network so as to measure velocity and travel time.

Full working sites, using live cellular telephone probe data, have been successfully developed in the Tel Aviv area of Israel, Antwerp in Belgium, and Baltimore in the United States.

Handset-Based Approach
The handset-based approach uses GPS receivers incorporated into a cellular telephone. The GPS receiver would locate the vehicle using a traditional GPS receiver or an assisted GPS (AGPS) receiver. Location data is recorded at regular intervals (e.g., every ten minutes) using on-board GPS and data recorders. The time taken to pass through pre-determined, geo-fenced areas are then calculated using advanced algorithms. The AGPS receiver relies upon the location of fixed landmarks, usually cell sites, to improve the accuracy and acquisition time of the handset's location. The location of the vehicle can then be communicated via the network, typically using the cell networks data service.

In Canada, field trials are being conducted with a number of suppliers in developing traveller information services with the use of AGPS receivers. The services would use vehicle probes, who are subscribers to the service, to collect location-based data, which would then be used to develop travel time information. The information could then be used to provide subscribers with subscription-based alerts, as well as to provide travel information via traditional websites.

4.1.9 Patrol Vehicles

Patrol vehicles travelling on highway, arterial and city roadways during their normal work assignment can be used to detect and confirm incidents, as well as to coordinate with the Traffic Operation Centre for incident management. Typical patrol vehicles include the following:

- Police patrol vehicle
- Service patrol vehicle
- Maintenance patrol vehicle.

The primary use of patrol or municipal vehicles at an incident site is to provide for long-term closures of lanes or roads, as well as to facilitate clean-up or emergency management services (EMS) investigations. Patrol personnel are also normally responsible for the proper cleanup of debris.

Service patrol vehicles are vehicles that are assigned to a roadway facility to patrol the highway and provide assistance to motorists in need. They are not typically used as a primary resource to collect traffic and incident information in regional traffic management systems since there are high capital, operating and maintenance costs associated with patrol vehicle operation. Also, the incident detection times are typically long and unpredictable, depending on the number of vehicles covering the highway.

When an incident is reported to the police or is detected by other monitoring means, patrol vehicles can be dispatched to the incident site to confirm the nature of the incident and provide the necessary assistance.

4.1.10 Private Citizen Calls

Private citizen calls are becoming one of the major sources of incident information as the number of cellular telephones on the roadway rapidly increases. The advantages of this method include:

- Quick detection of the incident;
- Low set-up and operating costs; and
- Direct conversation between the motorist and the system operator.

However, the accuracy of the data provided by the private citizen calls is an issue to be considered since many motorists are not able to accurately identify the location of the incident or the direction of travel. The effectiveness of this method of information collection depends on the willingness of the motorists to report traffic problems, and the number of the cellular telephones on the roadway. As a result, some traffic management agencies have established toll-free cellular call numbers for reporting traffic problems. This special number can be set up to connect motorists directly to the agency responsible for incident management. One drawback is that multiple calls on a single incident might occur, potentially overloading the operator and the associated cellular network. Nevertheless, it is estimated that half of all incidents reported are through cellular telephones.

Ontario Experience

Experience in Ontario indicates that for this method to succeed, it is very important to set up and run a public campaign to inform motorists on what number and who they should call to report traffic problems. The benefits of the call-in system must be explained to the general public.

4.1.11 Information from Other Agencies

The primary agencies involved in responding to traffic problems on highways and city roadways are the provincial government, the municipality, police, ambulance services and the fire department. From the information collection and incident management perspective, it is extremely important to share the traffic information among various system operators and notify the appropriate agencies. In particular, following the detection of an incident, basic notification requirements should include:

- Determination of which agencies should be notified;
- Notifying the appropriate agencies;
- Providing the incident details to each agency; and
- Advising each agency of incident location and relevant traffic information.

Typically, traffic management teams are formed to plan overall traffic management and coordinate response to roadway problems. These teams may include the following agencies:

- Provincial government
- Municipal government
- Transit operators
- Police department
- Fire department
- Ambulance services
- Environmental agencies
- Towing services.

4.1.12 Advanced Road Weather Information Systems (ARWIS)

An advanced road weather information system is a network of weather data gathering and road condition remote sensing systems. ARWIS is implemented to inform the road agency of road surface, pavement and atmospheric conditions in order to improve the efficiency and effectiveness of winter road maintenance. A typical advanced road weather information system will collect and inform the operating or maintenance agencies of the following:

- Atmospheric conditions (e.g., air temperature, wind speed and direction, humidity, precipitation occurrence, visibility, etc.);

- Road surface conditions (e.g., temperature, wet/dry, etc.); and

- Subsurface conditions (e.g., temperature at various depths).

The system will track and report the current and forecasted pavement conditions, and advise the related agencies.

By linking detailed weather and pavement conditions, a road weather information system can advise the road operating agencies where and when to send the winter maintenance equipment, as well as how to treat the surface with various de-icing or anti-icing methods. By combining information obtained from pavement sensors and meteorological sensors, pavement condition forecasts can be made to identify which portions of the roadway network are likely to be problem locations.

Investigations conducted around the world indicate that road weather information systems can reduce the cost of snow and ice control by assisting road operating agencies to be proactive in allocating resources to deal with inclement weather.

Ontario Experience

Since the late 1980s, Ontario's ARWIS has combined current and forecasted weather with observed road conditions for distribution to maintenance managers, municipal authorities and the private sector around the province. In 1992, the MTO started to use roadside sensor information to enhance its decision making in winter operations. In effect, they have planned salting, sanding, and plowing operations based on three sources of information: pavement forecasts, weather forecasts, and pavement sensor data. Given the successful implementation of ARWIS, MTO has expanded the ARWIS system to approximately 112 sites located throughout the province as of 2006[5].

4.2 Surface Street Control

This section provides an overview of the existing surface street control systems, the development of their latest capabilities, and their interface with other Advanced Traffic Management Systems. For details related to the design and operation of signalized

[5] *MTO Maintenance Technolgy Project – 2003-2004: 8th Season,* http://www.mto.gov.on.ca/english/transtek/m03-04/03-04fs.htm.

intersections, the reader is referred to OTM Book 12 (Traffic Signals) which replaces the Traffic Signals Chapter of the Manual of Uniform Traffic Control Devices.

4.2.1 Control Techniques

The coordinated operation of traffic signals to provide progressive traffic flow on an arterial road network can be achieved using a variety of control techniques including:

- Time-based coordination
- Time-of-day control
- Traffic responsive control
- Traffic adaptive control.

Time-Based Coordination

Under time-based coordination, the operation of a group of traffic signals is based on the use of predetermined timing plans (cycle length, split and offset) at each intersection. These timing plans are developed based on historical traffic information using signal timing optimization software, such as TRANSYT, PASSER, SYNCHRO, etc. Timing plans at each intersection are selected and implemented based on the time of day. Coordination between intersections is then dependent on the ability of the time clock in each controller to maintain time in an accurate manner.

In a time-based coordinated system, there is no requirement for a physical interconnection or communications link between intersections or to a central control and monitoring system. This lack of communications presents some significant disadvantages to the operating agency, such as requiring field staff to physically visit an intersection to make any adjustments to the timings, and not allowing any monitoring functions to report equipment malfunctions or the collection of real-time traffic data.

Time-of-day Control

Time-of-day control is similar to time-based coordination in that predetermined timing plans are used at each intersection and implemented based on a time-of-day schedule. The difference with this control technique is that each intersection is interconnected with a control and monitoring system to maintain synchronization between intersections, as well as provide a means of monitoring field equipment and updating signal timings from a central location, and collecting real-time traffic data.

Traffic Responsive Control

Traffic responsive control provides an alternative form of traffic signal control to the traditional time-of-day approach. In this control technique, real-time traffic data is monitored. Based on the traffic patterns detected, one of a series of predetermined timing plans is selected. As a result, signal timing plans are allowed to vary in response to changing traffic patterns. Typically, under traffic responsive control, real-time traffic data is collected every 5 to 10 minutes with signal timing plans being selected at a frequency of not less than every 15 minutes. To operate under traffic responsive control, a central control and monitoring system is required.

Any one intersection or group of intersections can be controlled under traffic responsive control.

Traffic Adaptive Control

Traffic adaptive control represents a significant departure from the more traditional concepts outlined above. It is a control concept that allows signal timing parameters to change continuously in response to real-time measurement of traffic variables. As a result, there are no predetermined signal timing plans required, and timing plan changes can occur as regularly as once every cycle. To operate under traffic adaptive control, a central control and monitoring system is required.

4.2.2 System Types

Various types of surface street control systems are currently available in the marketplace. All offer time-based coordination, time-of-day and traffic responsive control, while the traffic adaptive control is only available in select systems. Surface street control systems can be categorized into one of the following types:

Arterial Master Systems

An arterial master system is comprised of three primary components: the intersection controller, the master controller, and a central control and monitoring system. The intersection controller is located in the field at every intersection, and is responsible for the control of the intersection signal operations on a second-by-second basis. The on-street master controller is also located in the field, and is connected to each intersection controller within a control area. Each master controller is responsible for area control functions (such as timing plan selection and/or traffic responsive control), as well as the storing of alarms, detector data and other recorded events. Each master controller then reports to the central system upon critical alarms or on an operator-predetermined or manual basis.

Central Second-By-Second Control Systems

Central second-by-second control systems have been available in the marketplace since the 1970s, utilizing a central computer to control and monitor the operation at every intersection under system control on a second-by-second basis. In this type of system, each intersection under system control is connected to the central computer through the communications network with all control decisions (both intersection and area control functions) made by the central computer. In the event of a failure of the communications system or the central computer, coordinated operation is not possible unless the local intersection controllers are capable of time-based coordination.

Distributed Control Systems

With the availability of more intelligent intersection controllers, distributed control systems have become increasingly popular. With this system type, the local intersection controller is responsible for both intersection and area control functions using time-based coordination techniques (with the exception of traffic responsive control). While each intersection is interconnected with the central system, communications with central is significantly reduced with each intersection polled once every 5 minutes to report events (e.g., alarms, detector data, etc.) and receive commands from central (e.g., change of timing plans, synchronize time clocks, etc.). This approach provides a more failsafe type of operation in the event of a communications or central computer failure and significantly reduces the system's data transmission requirements, thereby allowing the use of alternative communications media such as radio.

Traffic Adaptive Control Systems

Traffic adaptive control systems and the associated real-time control strategies were originally developed in the 1970s and early 1980s when central second-by-second systems were common. Due to the technology available at the time and the processing power required, the control algorithms were resident in the central computer with detector data being received and control commands delivered to every intersection on a second-by-second basis. This similarity with central second-by-second systems allowed traffic signal management systems to be developed that offer both standard time-of-day and traffic responsive control with adaptive control capabilities to be implemented in select areas of the city.

Of the many different adaptive or real-time systems that were developed in the 1970s and 1980s, only two have become commonly available as a commercial product, SCOOT and SCATS. SCOOT (Split, Cycle, Offset Optimization Tool) was developed by TRRL (Transport and Road Research Laboratory) in the U.K. SCATS (Sydney Coordinated Adaptive Traffic System) was developed by the Roads and Traffic Authority (RTA) of New South Wales, Australia. More recently, considerable research has taken place in the area of distributed adaptive control where much of the data processing and timing optimization is carried out in the local controller. While the features of distributed adaptive control are much the same as central adaptive control, the major difference is in the communications requirements. Currently, distributed adaptive control systems are just emerging into the marketplace.

4.2.3 Design Considerations

In the planning and design of a surface street control system, a number of factors should be taken into consideration.

System Capacity

To effectively manage a jurisdiction's traffic signal network, the surface street control system should have adequate capacity to monitor and control the entire signal system. This should include consideration of both current and future traffic signal requirements, as well as the potential to include traffic signals in adjacent jurisdictions, as appropriate.

Traffic Control Requirements

Identification of the traffic control requirements of a road network is a critical task in establishing the type of traffic signal control concept (i.e., time-of-day, traffic responsive, traffic adaptive, etc.) required. This type of analysis should include a review of traffic volume data, variations over the day, predominant land use (i.e., shopping, special event venues, etc.), directional split, etc.

Existing Field Equipment

The type of field control equipment in use at a signalized intersection represents a significant investment for a jurisdiction. It can also present a significant constraint, and can limit the available choices in signal systems. As a result, existing field equipment and the opportunities and constraints that they present should be carefully considered in the planning and design of a surface street control system.

Pre-emption/Priority Requirements

The provision of pre-emption or priority control of traffic signals for rail crossings, emergency response vehicles, transit vehicles, etc., is an area that is typically controlled through the local intersection control equipment. Central control of this feature, however, can be involved when there are more sophisticated requirements, such as route-based pre-emption or signal priority based on requests from an AVI/AVL system which monitors vehicle location.

A system and method of centralizing traffic signal pre-emption/priority for roadway emergency operations provide for increased accuracy and coordination of emergency response vehicles along an emergency route. A centralized pre-emption/priority system receives status and location information (e.g., GPS) from emergency response vehicles via a fleet management system or dispatch centre. As an emergency route is determined and projected in real-time, pre-determined policies are applied to create an overall pre-emption/priority plan of traffic lights at intersections along an anticipated route. The pre-emption/priority plan results in directives being transmitted to the surface street control system controlling traffic signal controllers at intersections along the route. The centralized pre-emption/priority system may coordinate among many traffic management systems, which provides for a much larger pre-emption/priority service area including multiple jurisdictions.

Communications Requirements

Communications typically represents the largest cost component of any surface street control system over the life of the system. As a result, it should be carefully considered in the system design. This includes reviewing the communications requirements of alternative systems, as well as reviewing alternative methods of providing the necessary data transmission capacity to each intersection. For example, second-by-second control systems require a dedicated wireline communications network, while distributed type of systems can use wireless communications media such as radio.

Interface to Other Systems

The management of the traffic signal network is only one component of a regional traffic control system. As a result, to be effective on a regional basis, a surface street control system should be designed using open architecture concepts to allow electronic sharing of information using industry standard interfaces. Examples of the type of systems a surface street control system could interface with include:

- Public transit vehicle location systems for the provision of transit priority when a transit vehicle is running behind schedule;
- Incident management and/or lane control systems to select a specific signal timing plan when traffic is being diverted to an arterial corridor due to an incident on a parallel freeway;
- CCTV systems to provide video images to the surface street control system operator in the event of an incident; and
- Other city systems (i.e., maintenance management, GIS, etc.) to provide electronic sharing of data and the generation of combined reports for management and/or reporting purposes.

4.2.4 Lane Control Signs

Lane Control Signs (LCSs) have been used successfully on arterial streets and bridge and tunnel structures for purposes of managing incidents, reversible lanes and other traffic management operations that necessitate frequent and routine changes to lane designations. Control signs provide lane condition information (open or closed) to motorists on a lane-by-lane basis at frequent intervals along the roadway. Lane control signs are spaced at relatively close intervals and the information presented on them is very simple in nature and easy to understand at a glance. For instance, “X” would indicate a closed lane while a downward-pointing arrow would indicate an open lane. The main objectives of an LCS system are to:

- Provide information on lane availability for congestion management;
- Provide a more sophisticated level of management for routine and special maintenance activities (e.g., in tunnels and on bridges); and
- Provide reversible lane capabilities.

Messages Displayed on LCS

Two types of messages (regulatory and diversionary) are required to meet the above objectives. The following lists the typical symbols used.

Regulatory

X Red colour to indicate lane closed. This symbol is also used for reversing lanes and is legally enforceable.

↓ Green colour to indicate lane is open.

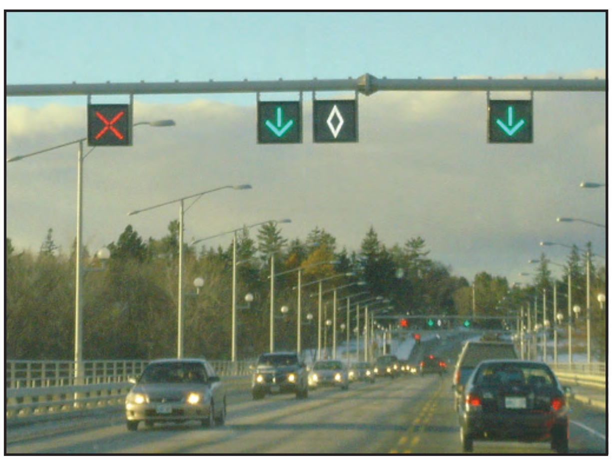
Diversionary

↙ Amber colour, to direct motorists in the lane below the arrow to move one lane to the left.

↘ Amber colour, to direct motorists in the lane below the arrow to move one lane to the right.

Although LCSs are proven to be effective in tunnel and bridge traffic management systems and on arterials for reversible lane management, it may not be cost-effective to install LCSs over an extensive length of open freeway. The use of LCSs is more frequent in Europe than in North America, where LCSs are installed as a combined lane and speed control system to increase safety.

Figure 8 – Champlain Bridge Lane Control Signs



Ontario Experience

LCSs are currently used for reversible lane operation on Champlain Bridge in Ottawa, Thorold Tunnel in Thorold and Jarvis Street in downtown Toronto.

Figure 9 – Thorold Tunnel Lane Control Signs

Figure 10 – Jarvis Street Lane Control Signs

4.3 Highway Control

4.3.1 Ramp Metering System (RMS)

Ramp metering is a method of improving traffic operations at entrance ramps to a freeway facility by regulating the rate of ramp traffic entering the freeway. This reduces freeway congestion and improves the safety of the merge operation.

Ramp control signals are placed on the ramp in advance of the acceleration lane to control the entry of vehicles. Typically, one vehicle is allowed to enter the freeway with each green signal phase. The ramp control signal can be pre-set to a fixed metering rate (e.g., 2 seconds of green followed by 5 seconds of yellow/red) or the system can be operated in conjunction with vehicle detectors sensing traffic conditions on the mainline approach and on the entrance ramp. In the latter scenario, the RMS will have a changing metering rate that adjusts to the traffic conditions.

The metering of entrance ramps provides a mechanism for balancing upstream and downstream traffic flows on the freeway by controlling the rate of vehicles entering the freeway. This can be an effective traffic management strategy for purposes of eliminating or reducing operational problems resulting from freeway congestion or managing traffic flows upstream and downstream of an incident on the freeway. Ramp control also reduces the turbulence created when platoons of vehicles attempt to merge into the mainline traffic. Reduced turbulence in the merge zones has been found to reduce side-swipe and rear-end type collisions.

The benefits of a ramp metering system include:

- *Improved System Operation* – Delay is reduced on the freeway and increased on the entrance ramps. This redistribution of delay minimizes overall delays to freeway users, particularly those that travel longer distances in the freeway corridor.

- *Improved Safety* – The overall freeway operates with more stable, uniform traffic flow, resulting in reductions in vehicle crashes from stop and go conditions and congested merging operations.

- *Reduction in Vehicle Emissions and Fossil Fuel Consumption* – A reduction of fuel consumption and vehicle emissions is realized as a result of a reduced delay and number of stops, and the maintenance of more uniform speeds in the freeway corridor.

- *Promotion of Multi-modal Operation* – The granting of preferential treatment to High Occupancy Vehicles (HOV) at entrance ramps (allowing them to bypass the ramp metering signal unimpeded) can promote travel mode shifts and reduction of single-occupancy vehicles.

Techniques

Ramp metering systems vary in sophistication and capabilities. The design of the system should be based on existing traffic conditions, the amount of operational improvement desired, and the costs associated with installation, maintenance and operations. Typically, there are three types of traffic control strategies: fixed rate, traffic responsive, and system responsive.

- *Fixed-Rate Control* – The fixed-rate control strategy is the simplest form of ramp metering. With this type of control, the traffic signal holds and releases vehicles in accordance with a fixed metering rate. The metering rates are selectable on a time-of-day/day-of-week basis. The use of different metering rates allows the system to adjust to variations in traffic flow throughout the day. The metering rates are calculated on the basis of historical data relating ramp flows, traffic demand and capacity of the freeway. In general, fixed-rate control is not recommended except as a failure mode.

- *Traffic-Responsive Control* – Unlike the fixed-rate control strategy, traffic-responsive metering is directly and immediately influenced by the mainline and ramp traffic conditions during the metering period. The metering rates are continually adjusted on the basis of data collected by detectors on the mainline of the freeway and on the ramp, as well as the capacity of the adjacent freeway section. There are two principal traffic responsive strategies used to determine metering rates. Demand-capacity control uses the real-time comparison of upstream volume and downstream capacity to select metering rates. Occupancy control measures the density of the traffic flow in terms of the occupancy at the ramp entrance and on the mainline of the freeway. For each level of occupancy measured, a metering rate can be extrapolated from predetermined values of occupancy and metering rates to adjust to different flow conditions.

- *System-Response Control* – System-responsive metering combines individual ramps into a system so that the metering rates of each ramp can be established with the objective of maximizing mainline traffic flow. The metering rates of each ramp are based on the relationship between demand and capacity over the controlled section of the freeway. In an integrated traffic responsive system, a linear programming technique is used to calculate a set of integrated metering rates for each ramp. The system will calculate the optimal allowable entrance ramp volumes subject to the freeway capacity, allowable mainline volume and allowable ramp volume constraints.

System Components

A typical ramp metering system includes the following components (refer Figure 11):

- *Ramp Metering Signal* – a standard 3-section (red-yellow-green) signal head;

- *Local Ramp Controller*, and

- *Advanced Ramp Control Warning Signs* (with or without flashing beacons) – an advance warning sign to indicate the ramp is metered and/or a sign to advise the vehicle to stop at the stop line (e.g., "Stop here on red").

Depending on the purpose of the control strategies utilized, the following additional components could be included:

- *Demand Detector* – located immediately upstream of the ramp metering signal stop line;

- *Passage Detector* – located immediately downstream of the ramp metering signal stop line; and

- *Queue Detector* – located upstream of the signal near the ramp entrance to detect excessive back-ups on the ramp.

Design Considerations

Properly designed and well-managed ramp metering can be a cost-effective strategy for reducing congestion on freeway systems. However, ramp control is not a cure-all for freeway traffic congestion. Issues of design and operations must first be addressed before implementing any metering system.

- *Traffic Diversion* – Diversion strategies attempt to decrease entrance ramp demand, generally resulting in some diversion to other routes. When ramp metering is used, a proportion of the freeway-entering traffic will be required to wait at the on-ramps before being allowed to proceed onto the mainline. Instead of waiting, some motorists may choose not to use the freeway at all, to enter it from another location, at another time of day, or to use public transit. This traffic,

Figure 11 – Signals for Ramp Metering

made up of drivers who take alternate routes, times or modes of transportation for some portion of their trips to avoid metered ramps, is called "diverted traffic".

When diversion strategies are used, additional capacity, including alternate routes, time periods, or modes of transportation (i.e., public transit, carpools) should be available in the corridor. In order to prevent congestion on alternate routes, it may be necessary to apply such techniques as re-timing of traffic signals, installing a traffic responsive signal system, adding turn lanes at intersections, reversible lane operation, and/or road widening.

- *Non-Diversion Strategies* – Non-diversion strategies attempt to accommodate full traffic demand with metering rates that are adjusted not only on the basis of demand and capacity, but on ramp queue length as well.

- *Ramp Geometrics* – Ramp designs should provide for adequate storage of waiting vehicles, adequate acceleration distance, and merge area beyond the meter. Appropriate steps must be taken to ensure that non-freeway bound traffic on adjacent local streets is not adversely affected by ramp meter queues. The most common technique used to provide for, or increase storage space, is to increase the number of lanes on the ramp before the meter. This can be accomplished by re-striping or reconstructing ramps to allow for two or more lanes. In this case, the meters release vehicles from two lanes at a time. Downstream of the meter, the vehicles merge into one lane before entering the freeway.

- *Equity* – Ramp metering often benefits the long-distance motorist more than the short-distance motorist. Benefits to long-distance motorists include reduced travel times and increased average travel speeds due to decreased congestion on the mainline. Increased congestion on adjacent local streets due to ramp queues and diverted traffic may result in longer travel times for the short-distance motorist. The use of non-diversion strategies is one way of dealing with this disadvantage.

- *Public Acceptance* – The implementation of a ramp metering system must be preceded or accompanied by a proactive public relations program. The objective of such a program would be to inform the public of the following:
  - the basic reasons for implementing the system (recurrent congestion, inefficient use of the freeway system, etc);
  - a realistic expectation for the system users including reduced delays and user costs; and
  - the alternative choices available to the system users.

Although the benefits of ramp metering are measurable system-wide, they may not be easily recognized by motorists who experience a few minutes delay at an entrance ramp. A successful public relations program will explain the difficulties of mitigating freeway congestion problems, and the cost-effectiveness of traffic management techniques such as ramp metering. The most common method of disseminating information on ramp metering systems and their benefits is through brochures, TV, radio, and promotional videotapes.

Ontario Experience

The QEW Mississauga Freeway Traffic Management System began operations in 1975. At present, the controlled freeway section spans about 19 km and contains 62 vehicle detection stations on the mainline, ramps and arterials. The ramp metering system encompasses 6 interchanges with 10 metered ramps. Each on-ramp has queue, demand and passage detectors installed to monitor on-ramp traffic during the morning rush-hour period. The ramp controller has the capability to operate independently of the traffic control computer in a time-of-day mode or mainline occupancy traffic-responsive mode. Any failure in the central computer system will not cause a complete stoppage of the ramp metering operation. The ramp metering system can be controlled either manually by the operator or automatically by the central computer, which coordinates ramp control logic for operation in a system responsive mode.

The ramp metering system for QEW adopts a non-diversion approach. That is, the ramp metering system in Mississauga attempts to accommodate full traffic demand with metering rates that are adjusted not only on the basis of demand and capacity, but on ramp queue length as well. In general, the system operates automatically under system responsive control, typically from Monday to Friday, from 6:30 a.m. to 9:30 a.m. Under the automatic ramp control, the computer will determine when, and if, a ramp control will be turned on, based on a pre-defined schedule, as well as the volume and occupancy threshold values of the detector stations.

4.3.2 Access Control

Access control is the application of control devices such as traffic signals, signing and gates to control vehicle access to a freeway. The objective is to balance the demand and the capacity of the freeway so as to maintain optimum freeway operation and prevent operational breakdowns. In particular, if the metering rate is required to be very low over a sustained period, it may be necessary to physically close the ramp with automatic gates or manually placed barriers. As such, the entrance ramp to the freeway should only be considered for closure under the following conditions:

- Insufficient storage space on ramps, whereby vehicles waiting to enter the freeway interfere with surface street traffic;

- When the optimal metering rate to prevent demand from exceeding capacity on the freeway is so low (i.e., two vehicles per minute) that it would be more practical to close the ramp in order to prevent congestion on the freeway; and

- Substandard merge at ramp ends.

Ramps can be closed on a temporary basis, on a scheduled basis, or permanently. Temporary closure is very common for maintenance, construction and incident management activities. Ramp closure during peak periods and openings at off-peak times are typical for addressing recurring congestion. It can be considered as a form of ramp metering by implementing complete closure of the ramp at certain periods of the day. Permanent ramp closure can be a result of changes in the freeway systems. Concrete barriers are recommended to close the ramp in the case of permanent ramp closure.

Ramp closures are typically implemented with the following traffic control equipment:

- Barriers – automated gate or manually placed barrels or cones; and
- Signing for upstream traffic.

Ontario Experience

A gate is installed at the entrance of the Jameson Street on ramp to the Gardiner Expressway for both the eastbound and westbound directions. The purpose is to improve traffic operations on the Gardiner Expressway by prohibiting entering traffic at this location and balance traffic between the Gardiner and Lake Shore Boulevard during peak traffic periods through predetermined, time-of-day closures of a mechanical physical barrier.

Current operation of the Jameson Gate is as follows:

- Eastbound restriction 7:00 a.m. to 9:00 a.m.
- Westbound restriction 3:00 p.m. to 6:00 p.m.

4.4 Regional Traffic Control

4.4.1 Concepts

Regional traffic control is intended to coordinate and integrate the operation of a freeway with the surface streets and arterials that surround it. Regional traffic control utilizes highway control concepts and systems and surface street-control concepts and systems to better manage the entire freeway/arterial corridor in order to improve their safety and operational efficiency and reliability.

The integration of multiple systems within a regional control strategy provides for real-time sharing of information and coordination of traffic management activities between agencies, thereby enhancing system interoperability and enabling a regional approach to traffic management. Potential applications in regional traffic control that support the concept of inter-agency coordination and the sharing of information include:

- *Regional ATIS Database* – for the provision of real-time information and the sharing of traveller information in order to provide a single point of access for traveller information for use by information service providers (ISPs), users (e.g., via the internet), etc.

- *Coordination of Signal Timing* – for coordinated operation of traffic signals across jurisdictional boundaries. This can also be applied to freeway ramp-metering control such that the surface street/arterial signal system can change timing parameters to accommodate traffic diverting from the freeway, and vice versa, allowing the freeway to adjust metering rates based on traffic operational conditions on the adjacent arterials.

- *Emergency Management System Reporting* – allows the sharing of incident/emergency status and traffic management information. This could include the highway control system and surface street-control system supplying information to an emergency management centre so that appropriate routes may be identified for routing emergency response vehicles and/or evacuations.

- *Sharing of Displayed DMS Messages* – to inform adjacent and nearby system agencies of warning messages posted in response to an incident or other problem.

4.4.2 Centre-to-Centre Communications

The integration of two or more systems involves the implementation of interfaces and communications links between systems for purposes of exchanging information, control status, and/or control commands. This centre-to-centre communications typically involves peer-to-peer communications between multiple systems, which may be co-located within the same physical Traffic Operation Centre (TOC) or in entirely separate TOCs. The centre-to-centre communications facilitates seamless exchange of data between multiple systems and agencies. Examples include data exchange between arterial and freeway systems, with municipalities, as well as between Ontario and U.S. agencies when dealing with border-related information. It is necessary to identify the number of systems to be integrated and where they are located, and then to identify the communications links between these systems. Communications system requirements are discussed under Section 4.7.

To allow for integrated operation, agencies should ensure that system designs are compliant with the ITS Architecture for Canada, with adoption of open communications protocol. The ITS Architecture for Canada and associated standards facilitate sharing of information and coordinated operations through use of common data elements across agencies.

4.4.3 Technologies and Strategies

The most appropriate technologies and strategies to be implemented will depend on the degree of integration agreed upon between agencies, and how the information exchanged will be utilized. Various levels of interaction are possible, including:

- Communicate via phone, fax;

- Share system data/video on "view only basis";

- Share system data/video control during special events;

- Share system data/video control day-to-day;

- Share system control during emergencies, or during periods when the Traffic Operation Centre is not staffed; and/or

- Share some/all system functions.

4.4.4 Integration of Legacy Systems

Regional integration will often involve a mix of new systems and legacy systems. A legacy system is, by definition, currently operational and may represent the latest technology embodying the principles of open architecture, or may be a closed system with proprietary interfaces, databases and protocols, as well as limited documentation. In the latter case (i.e., proprietary), full centre-to-centre integration may not be possible, in which case a simpler system interface (e.g., separate workstation, e-mail/browser interface) may be the most appropriate approach. Even if the legacy system is not completely "closed", as compared to an "open" system architecture, it may still be necessary to add a data exchange protocol to the legacy system to facilitate information exchange.

4.5 Traffic Information Dissemination

A motorist can be provided with a variety of real-time, travel-related information, including advisory information related to traffic, transit and roadway conditions. Current traffic data from ATMS applications is a critical component of the data set required for a comprehensive advanced traveller information system (ATIS). ATIS provides information regarding road and traffic conditions that can be obtained either prior to departure (i.e., pre-trip) or while en-route.

4.5.1 Pre-Trip

A motorist can be provided with detailed traffic information prior to their departure, using a variety of media. This information can be used by the motorist to assist in making departure time and mode choices, travel-time estimates, and route decisions. Tailored information can be obtained based on real-time interactive response to a traveller's request or based on a submitted traveller profile. Various methods of receiving pre-trip information are described below.

Fax and Pager Services

Fax and pager services are used to provide information to subscribers regarding current road and traffic conditions, including scheduled and unscheduled events. Information is provided based on preferences indicated by the subscriber. Some subscribers prefer to have updates at scheduled times (i.e., every 15 minutes, or every hour), while others prefer to be provided updates based on the occurrence of an event (i.e., whenever a collision occurs).

Subscribers to fax and pager services can include the media, transit authorities, commercial fleet companies, or other traffic authorities. MTO and City of Toronto systems both employ fax and pager services.

TV, Cable TV, and General Commercial Broadcast Radio

A motorist can use TV, cable TV, as well as general commercial broadcast radio as a source of pre-trip traffic information. These information sources have large broadcast ranges and some have specific times dedicated to providing traffic information. Usually, traffic information is broadcast only during rush hours, and is limited to a brief summary of the traffic conditions in the entire broadcast area, with emphasis on any events that greatly impact traffic flow.

As pre-trip sources of traffic information, these technologies provide information that is relevant to route and mode choices, as well as estimating travel times.

Internet

The use of the internet is impacting all areas of industry, including transportation. The internet is specifically of interest to the transportation industry as a method for providing pre-trip traveller information services.

Websites can be set up to provide motorists with information on current traffic conditions, active traffic events, and scheduled traffic events. In addition, recent or real-time images from CCTV cameras can be provided through the internet and accessed by a motorist to personally evaluate current traffic conditions. The information provided through the internet can be used to assist in making mode choices, travel time estimates, and route decisions.

Recent advances in internet applications for traveller information include the use of push/pull technologies and personalized travel information on a subscriber basis. The trend to wireless internet access using cellular telephones, personal digital assistants and palm-top personal computers will further extend the role of the internet as a medium for comprehensive pre-trip and en-route ATIS.

Ontario Experience
The MTO and the City of Toronto systems both provide real-time traffic information and access to CCTV camera images through their respective websites.

Interactive Telephone

Interactive telephone utilizes motorist input to provide personalized traffic information through an automated voice information system. For example, a motorist can phone a dedicated telephone number (e.g., City of Toronto's "RoadInfo" line) and request information regarding a particular roadway section or area by selecting from a menu using the touch-tone keypad of their telephone or through a voice recognition system. Due to the interactive nature of this application, the traffic information provided can be specifically relevant to the selected area. It should be noted that interactive telephone can be used by a motorist for pre-trip information for route and mode selection, or can be accessed using a cellular phone for en-route advisory. Recently 511 has been dedicated for the provision of traveller information in Canada. This provides one common telephone number across North America that motorists can use to obtain up-to-date traveller information.

The City of Toronto recently included the "RoadInfo" interactive telephone system as part of their traveller information services that provide motorists with real-time traffic information.

4.5.2 In-Vehicle

Motorists within a vehicle can obtain real-time traffic advisory information through a variety of methods. This information may be obtained within the vehicle through audio in the form of Highway Advisory Radio (HAR) or general commercial radio broadcasts. In addition, information can be obtained and used as input into a vehicle navigation system for purposes of route selection and guidance.

Highway Advisory Radio (HAR)

Highway Advisory Radio (HAR) systems can use a dedicated AM frequency (530-1710 kHz) or licensed FM frequency (88-108 MHz) for extended-range broadcast. The higher bandwidth of FM frequencies offers an improved signal, with a shorter range when compared to AM frequencies.

The wattage used for broadcast affects the range of the signal. Therefore, a low wattage transmitter can be used to provide specific information relevant to a small area of coverage. This information may include collisions or roadwork in the area. Alternatively, a higher wattage transmitter can be used to provide a greater amount of information to a wider area. This information can be limited to events that have major effects on traffic, or can include all minor and major events, but for a number of areas.

There are a number of issues associated with the implementation of HAR. Availability of frequency is a significant challenge since there is no dedicated frequency allocated for HAR use within Canada. This is further complicated when the location of the HAR station is in close proximity to the U.S. border, requiring federal agencies from both countries to agree on the proposed frequency. Licensing is another complication when the use of licensed radio is proposed. It can be very difficult for a public agency to hold a license for the use of a dedicated AM or FM frequency. The use of low-power transmitters can negate the need for a license. However, use of low power reduces the area of coverage of a transmitter, requiring the use of short messages to ensure a driver hears a complete message at least once. Alternatively, multiple transmitters can be used to increase the area of coverage, but this will require coordinated operation between transmitters to ensure drivers hear a consistent message as they pass between transmitters. These complicating factors, combined with the limited ability to make the HAR message interesting to listen to (typically recorded by maintenance or traffic operations personnel with no radio broadcasting experience), do not make HAR an attractive option for disseminating traveller information.

General Commercial Broadcast Radio/TV

Commercial radio has a large-range broadcast and limited time dedicated to providing traffic information. Therefore, the information provided by commercial radio generally includes a brief summary of the traffic conditions in the entire broadcast area, with emphasis on any events that greatly affect traffic. Commercial radio stations throughout Ontario provide regular traffic reports, particularly in urban areas and during peak traffic periods.

Commercial radio traffic reporting presently serves to be the most commonplace and far-reaching means of disseminating traffic information to motorists en-route. While commercial traffic reports are readily available to a widespread audience, there are limitations that arise from their means of sourcing traffic information. Typically, the information is assembled from multiple sources which can include:

- Verbal communication with authorities
- Cellular telephone callers
- Traffic monitoring using aircraft.

The multiple sources can make the data difficult to verify when there is conflicting information. Details on locations of incidents can be suspect and current information on the status of an incident difficult to obtain since few sources will report when an incident has been cleared. As a result, accurate reporting can be difficult. Providing a single source of accurate and reliable traveller information to broadcasters on a real-time basis can significantly increase the effectiveness of this dissemination medium.

With increasing market penetration of in-vehicle and personal communications and entertainment systems, there will be increasing opportunity for reception of commercial TV broadcasts en-route. This will provide the motorist with en-route access to dedicated commercial TV traffic broadcasts.

It should be noted that Europe and Japan, as well as Canada to a lesser degree, have recently embraced Digital Audio Broadcast (DAB) and Satellite Radio, which provide a significant communications bandwidth and quality improvement over FM signal capabilities. DAB and Satellite Radio provide user access to both audio and digital information (e.g., financial, traffic, sports, etc.), as well as a number of user services enhancements. These services are commencing in Canada and receivers are readily available on the market. The digital broadcast format supports the delivery of a wide range of broadcast services into the vehicle. The European and Japanese ITS programs have pursued the development of standards for the delivery of traffic information. To date, there has been little progress in this regard in North America.

In-Vehicle Guidance

A vehicle can be equipped with a route selection and guidance device using Original Equipment Manufacturer (OEM), after market or portable devices. Route selection and guidance information may also be obtained from an Information Service Provider (ISP), such as General Motor's OnStar(r) program. Route selection and guidance can be either autonomous or dynamic. Autonomous route selection and guidance relies on static information stored in a Geographic Information System (GIS), and typically selects a route based on shortest distance or travel time. Dynamic route selection and guidance utilizes dynamic information, and can therefore be responsive to current traffic, weather and road conditions.

The information used for dynamic route selection and guidance can be obtained through dedicated short-range communications (DSRC) or extended range two-way communications. The use of DSRC requires a number of roadside antennas to provide periodic traffic information updates. Due to the short range of DSRC, the traffic information provided is limited. Extended range two-way communications technologies include cellular, spread spectrum and microwave, and are able to provide a greater range of communications. Therefore, extended range two-way communications technologies are better suited to this application than DSRC applications. It should be noted that the information provided for dynamic route selection and guidance can either be obtained by a traveller based on an area-wide broadcast, or can be personalized based on preferences provided by the individual.

Significant work in dynamic route selection and guidance is currently being done, particularly in Japan. However, there are few initiatives currently underway in Ontario.

4.5.3 Roadside Dynamic Message Signs

Dynamic message signs (DMSs) are used to provide advisory information from the roadside to en-route motorists. They are typically custom-manufactured to the owner's specification, and hence a comprehensive knowledge of the state of technology is critical to successful procurement. A complete discussion of DMS applications, design principles and technologies are addressed in OTM Book 10 (Dynamic Message Signs).

Figure 12 – MTO Overhead Gantry-Mounted DMS

Figure 13 – MTO Roadside-Mounted (Cantilever) DMS

4.5.4 Role of Private Value-Added Service Providers

Currently, the public sector tends to control the dissemination of traveller information through their roadside/fleet infrastructure (e.g., vehicle detectors, incident detection algorithms, CCTV, dynamic message signs, traffic operation centres, transit management centres, emergency dispatch centres, etc.). The private sector tends to be involved in more broadly-based dissemination devices through commercial media broadcasts, as well as the use of various personal communications devices to which traffic conditions and traveller information can be broadcast. Information can be conveyed free of charge via broadcasting, with revenue to be sought through advertising in the form of a wholesaler, or customized for selling to end-use customers based on a fee-for-service arrangement in the form of a retailer. Allowing access of the information by value-added service providers affords the opportunity for the public data to serve as a potential revenue stream.

In the United States, examples of public-private partnership business models for ATIS include SmartTrek led by the Washington State Department of Transportation (DOT); AZTech, led by Arizona DOT and Maricopa County DOT; TransGuide, led by Texas DOT, City of San Antonio and VIA Metropolitan Transit; Guidestar, led by Minnesota DOT; and TravInfo, in San Francisco Bay Area led by Metropolitan Transportation Commission. Typically, information is conveyed free of charge to the public, using the internet and telephone as the primary methods of dissemination. Where contracts are arranged with the media, information is also conveyed through radio and television, and in some cases, the press. Revenue, if any, is secured from advertising on the website, subscriptions for customized information services, and sponsorships for ongoing financial contributions.

4.6 Computer System

4.6.1 System Architecture Functional Requirements

Central/Distributed Processing

Software applications serving each other in a distributed environment are the most efficient method of utilizing resources in a computer network. Besides having the best economy of scale, the client-server arrangement allows the software applications to reside where they are most appropriate. Security, however, is a major concern, especially with respect to access to servers, and should be well-planned in order to avoid unauthorized and inadvertent misuse.

Operator Interface Requirements

The software should provide a simple, point and click graphical user interface (GUI), where successive available actions are intuitive and easily identified. Easy-to-understand icons should be used instead of character acronyms. Available options should be clear to every level of user and should be followed by a confirmation request in order to minimize risk of error. A multi-purpose interface with password protection should be developed so that users have access only to functions they have been authorized to use.

External Interface Requirements

Interoperability should be considered when implementing software applications. Any inter-process communications mechanism (e.g., CORBA) selected should be capable of easily integrating into any network topology, as well as any computer platform. In addition, the database management tool chosen should permit cross-platform access to support heterogeneous network topology, as well as the convenient generation of external reports.

Communications protocol standards (e.g., NTCIP) should be adopted in all possible situations when communicating to field devices. Failing that, all communications protocols to field devices must be open as a minimum requirement. Both of these requirements promote ease of maintenance, as well as cost savings in field equipment purchase and central software development.

4.6.2 Software Functional Requirements

Incident Management Function

Incident management consists of two functional areas – incident detection and incident management.

Incidents are detected either by the execution of an automatic incident detection (AID) algorithm or manually by an operator.

Incident management monitors the transition of the incident state as a result of external stimuli. These stimuli can include operator monitoring of incident clearance activities (CCTV), confirmation and return to normal traffic operations. During the life cycle of the incident, the incident management software should act as a decision support tool for the operator in recommending actions or identifying alternatives. Regardless, all system-initiated actions must be validated by operator confirmation.

Traffic Response Strategy Function

Traffic response strategies should also be system-initiated, providing the operator a decision support tool to help in the selection of the most appropriate strategy. This decision support system can either be based on a pre-determined response plan or an algorithm (i.e., rule-based). Pre-determined response plans are the easiest to develop, but can become onerous to maintain as the system expands on both a geographical and functional basis.

Any type of traffic response should be based on the incident location and the condition or severity of the incident. Information can be disseminated to the public via DMS or other media, such as fax or internet. When conducting a traffic response, the operator must be guided, as well as reminded of critical reactions in a step-by-step procedure. Tracking of operator actions should be automatic and used for future analysis. In COMPASS and RESCU, the operator's decisions are supported by the system-recommended response. In most cases, no manual response is required.

Network Traffic Management and Optimization Function

The system should have the capability to include multiple highways as part of its configuration. To optimize operation, the traffic response strategy should be easily adjustable by the operator to account for incidents or congestion in each individual highway, a change in highway geometry (e.g., single versus express/collector), availability of equipment, or other unforeseen circumstances.

When multiple roadways are dealt with by several Traffic Operation Centres (TOCs), exchange of traffic data and equipment status is necessary in order to coordinate operations near the jurisdictional boundaries. This loosely coupled data exchange mechanism allows the systems to preserve their independence, yet react to incidents beyond the capacity of an individual system.

In the case where operations may be taken over by another TOC, full configuration and acquisition of traffic data and equipment status from the first TOC must be made available to the second TOC. Data exchange is therefore more frequent and network communications bandwidth must be readily available to support increased data transmission.

Traffic Diversion Function

Diverting traffic from one portion of a highway to another (e.g., collector to express or vice versa) requires an accurate incident or congestion detection algorithm and operator confirmation procedure. Traffic diversion is usually recommended as a result of a confirmed incident, ongoing congestion, or road work. An operator must be provided with relevant traffic conditions in the subject highway segments, as well as a method of verifying the incident before a traffic diversion strategy is initiated.

Ontario Experience

In Ontario, a passive (soft) diversion approach is adopted where the traveller is provided information on traffic conditions ahead, with no direction provided on which route to take, except in the case of a full road closure.

Device Control Function

Enable and disable functions are required to temporarily remove potentially faulty devices from the system. Once recovered, a device should be able to announce its normal state by automatically responding to a periodic status poll from the central computer. In this case, reset and/or initialize commands should be dispatched to re-initialize the device for normal operation.

Controls related to testing a device should also be made available for reasons of routine maintenance, as well as for those uncertain faulty states. For example, testing light-emitting diodes (LEDs) on a DMS on a routine basis may be necessary to ensure continual normal operation.

Manual control and/or download of the device aspects and parameters may be necessary from time to time. This may include cases where the currently displayed DMS message or a DMS library message needs to be modified.

Traffic Information Database

A traffic information database invariably includes traffic data, event logs, as well as system configuration data. This traffic information can further be categorized as current or historical. Displaying current data and status is an important part of traffic management, and therefore must be executed without delay. In addition, access to this data or status by an external system should be allowed in a controlled manner to support other possible applications.

Archiving and retrieval of this information should be performed both on a regular, as well as on an on-demand basis. Historical data should be kept for future data analysis.

Data Warehousing

With the abundance of traffic information being collected by various agencies from their respective systems, the creation of a central or common access point for data should be considered. The concept is to provide a common point where any agency can access up-to-date and accurate traffic information from multiple systems. In this approach, each agency supplying information continues to operate and maintain their systems according to their needs and requirements. They also have the option of choosing what data they wish to share and in some systems are given the option of selecting the agencies with whom they wish to share with. This approach to data warehousing allows for easy access to existing data, systems and operating procedures, while allowing each agency to continue to use the systems that best meet their requirements.

The advantages of a common access point for traffic information include:

- Provide a single resource for multiple agencies to obtain traffic information;
- Achieve consolidation of traffic information data from one source (i.e., access point), which could then be used in an off-line mode for transportation planning or research purposes;
- Allows agencies supplying information to control what information they share and with whom;
- Ability to automatically update agency website(s) using "real-time" traffic information; and
- Improved data security of the support databases by utilizing only data elements that are directly relevant to traffic information and devoid of personal or private information, as well as through the use of firewalls and other security measures to prevent unauthorized access to the database.

It should be noted that the data warehousing concept is not intended to encroach onto the existing operations and responsibilities of the various agencies. It is intended for the archiving and management of real-time information in a consistent form, as well as to provide easy access to a wide variety of users. The data to be collected will relate to road, traffic and weather conditions, and be expanded to include incident data, transit services, etc. The data collected may also be used for traffic forecasting purposes.

The use of open communications protocol will facilitate interoperability, as well as allow broad access of these data between physically distributed ITS archives that are each locally managed, thus facilitating virtual data warehousing.

4.6.3 Other Functional Requirements

System Start-up/Shut-down

Manual as well as automatic failover (on a dual host configuration) should be made available to allow for routine maintenance and unexpected host equipment failure. In either case, traffic information must not be lost. This is accomplished by ensuring shut-down is performed in an orderly fashion and files and databases are adequately synchronized on a dual host/database configuration. In a single host configuration, adequate storage must be reserved in the front-end equipment to allow a retrieval process to recover data not recorded during the shut-down period.

Fault Monitoring

Fault monitoring is typically done on a continuous basis. Equipment faults are captured as alarms, while a complete host computer failure should initiate a shut-down procedure. Faults must therefore be categorized to allow determination of a failover. Since different system platforms have different fatal errors, a configurable table for fault definition and associated action should be made available.

Logging

Logging should be performed for traffic data, system events and configuration. It is recommended that traffic data and system events be logged on a regular basis, while system configuration should be done when necessary on an on-demand basis. All events are logged in a log file as part of the historical data. Additionally, critical events can be sent to an event printer or the screen for immediate operator attention. To facilitate the assignment of event outputs, destinations can be selected for each event definition.

Safety Issues (Conflict, Reliability/Failure Modes)

Uninterruptible Power Supply (UPS) or other similar equipment should be employed to ensure a smooth and orderly shut-down in case of an abrupt power outage. When a conflict can potentially cause danger to motorists, a soft interlock matrix should be implemented in the host to ensure safety. When a piece of equipment can no longer be controlled by the system, a default, yet safe, operational mode should automatically be activated to ensure safety, as well as to prevent damage to the equipment.

Remote Access

The advent of the internet and recent advances in wireless technologies have provided unique opportunities to allow access to traffic management systems directly from remote and/or mobile devices (e.g., PDA). The system should be designed to allow access for both control and monitoring functions using web-based devices. The convenience that this feature offers to maintenance, operational and management staff is significant and can be implemented securely and easily, provided this feature is identified early in the design process.

4.6.4 Urban Traffic Control Functions

Due to the specific control requirements and equipment involved, surface street control systems are typically controlled and monitored using a dedicated central control and monitoring system. Electronic information exchange is then provided between systems (urban and freeway) to allow a more region-wide network approach to traffic management.

All of the aforementioned computer system requirements are considered to be important aspects of a surface street control system, and therefore equally applicable to urban systems.

It is recommended that operations from surface street control systems be separated from highway control systems, except where an exchange of traffic information is proven to be mutually beneficial. In such cases, the respective system may enhance its functions to include regional traffic control, or traffic information dissemination.

Besides the aforementioned urban traffic control functions, equipment and intersection monitoring, and data archiving and retrieval for traffic analysis functions are important aspects of the surface street control system functions.

Ontario Experience

A typical example of a regional traffic control system is the COMPASS system, currently operational in the Province of Ontario. An example of a surface street control system is the York Region CTCS (Centralized Traffic Control System). All software functional requirements described earlier are implemented in these systems. It is especially important that these functions continue to support larger areas, as well as provide enhanced services due to highway or road geometry changes. Therefore, as an application requirement, the software functions described above should allow for growth in terms of service coverage, as well as for adaptation of future functional enhancements.

4.7 Communications System

ATMS applications can draw from the full suite of wireline and wireless communications technologies and services available in the rapidly evolving communications industry. In some cases, the ATMS deployment integrates a variety of communications media in order to deliver system functionality in a cost-effective manner. Accordingly, it is important that the system definition and design process employs the services of suitably qualified communications engineering staff with an understanding of the current and emerging telecommunications technologies, products, services, standards and regulatory environment. This input is instrumental in analyzing communications options.

4.7.1 Transmission Requirements

The communications network is designed to connect the various field components of the traffic management system to the Traffic Operation Centre (TOC), as well as to disseminate traffic information to outside agencies. The various types of subsystems connected to the TOC include data, video and voice signals from the individual field equipment, such as dynamic message signs, CCTV cameras, emergency telephones, etc.

Regional Traffic Control Data Requirements

Communications networks for regional traffic control systems should be designed to support their various subsystems. Each subsystem has unique requirements, and these should be addressed during the design stage of the communications network.

The requirements for each of the existing subsystems discussed below are specific to the COMPASS system, but are typical of most ITS implementation projects. The implementation of NTCIP protocols may change the communications requirements from those listed.

Dynamic Message Signs (DMSs)

DMS communications is between the DMS master at the TOC and the individual DMS controllers in the field, and include the following message types:

- Poll for status information of current message
- Command messages
- Download new messages to the library.

During normal operation, the DMS master polls each DMS every 30 seconds for status. If the DMS requires new messages to be transferred to it, status polling is interrupted until the message transfer is complete. The DMS communications scheme is being upgraded to NTCIP using Ethernet, which requires all new controllers to support both the existing and NTCIP protocols.

A complete discussion of DMS applications and technologies is provided in OTM Book 10 (Dynamic Message Signs).

Vehicle Detection Systems (VDS)
VDS communications is between the traffic data manager system at the TOC and the individual VDS controllers, which monitor detector loops. The traffic data manager system polls each VDS controller every 20 seconds for summarized data. The VDS controller functions are integrated with the Advanced Traffic Controller (ATC) which is connected to the TOC over an Ethernet channel on the data ring.

Camera Control (CC)
CC communications is one way only between the TOC and the field unit to allow operator control of camera functions such as pan tilt and zoom. Camera control data is multi-dropped on a single channel, so only one channel per data ring is required. At the TOC, camera control can be handled by using either the standard video switch control or it can be integrated with the operator's graphical user interface (GUI). If the operator GUI interface is used, Ethernet communications is utilized using the same channel as the VDS communications. The Ethernet communications scheme requires the CC functions to be integrated with the ATC controller units. For cameras using digital Ethernet communications, the TOC control functions are integrated with the video encoders/decoders.

Ramp Metering System (RMS)
RMS communications is between the RMS master located at the TOC and the individual RMS field control units to monitor operations and control ramp metering functions. RMS functions are integrated with the ATC field control unit. The RMS communications are combined on the same channel as VDS.

Queue Warning System (QWS)
Queue warning is designed as a standalone system with no requirement for monitoring or intervention from the TOC. QWS communications is between field control units requiring each ATC to be connected by an Ethernet link. A link to the TOC can be provided for central monitoring and downloading of data which can be achieved using either a serial or Ethernet link. The speed of the connection to the TOC will depend on the cost associated with providing the communications link.

Other MTO Operation Centres
Each MTO operation centre should be allocated a connection to the central computer located at the TOC and a camera control link.

The following is recommended for communications:

- Camera control
- Low speed
- High-speed (Ethernet)
- Centre-to-centre data sharing.

Maintenance Yards
Each maintenance yard should be allocated a connection to the central computer located at the TOC and a camera control link.

The following is recommended for communications:

- Camera control
- Low speed
- High-speed (Ethernet)
- Video and data sharing.

Future Subsystems
In addition to the current subsystems, support for the following future services should be provided:

- Advanced road weather information system (ARWIS)
- Truck inspection stations, including weigh-in-motion (WIM)
- Toll tag readers
- Highway advisory radio (HAR) messaging
- Vehicle-to-roadside communications (VRC)
- Inter-agency data, such as RESCU and 407 ETR.

It should be noted that the above future subsystem data requirements have not been identified. Therefore, it is important that the communications design includes additional capacity and provides for a flexible range of data interface methods. These should include the ability to provide:

- TCP/IP and NTCIP protocols
- DSRC roadside-to-vehicle communications
- Standard TIA-232 interface
- Standard TIA-422 interface.

Surface Street Control Data Requirements
Communications networks for surface street control systems should be designed to support the control and monitoring of traffic signal controllers located at each intersection. There are various types of control systems available on the market, which have different communications requirements including:

- Arterial master systems
- Second-by-second control systems
- Distributed control systems
- Traffic adaptive systems.

Each system requires a communications link between the operation centre and each intersection in the system. The communications links are two-way, low-speed, point-to-multi-point circuits. The type and frequency of communications depends on the system selected. Traditionally, traffic systems have used either agency-owned twisted wire pair cable or leased circuits (two or four wire) from the telephone company. The option of using digital communications service (DCS) is also available from the telephone company.

Arterial Master Systems
These systems have two levels of communications. A master controller is connected by dedicated circuits to multiple controllers on a channel communicating on a second-by-second basis. Each master is connected to the operation centre over standard telephone dial-up lines.

Second-by-Second Control Systems
These systems require second-by-second control and monitoring of each intersection. The circuits are dedicated multi-point circuits with multiple controllers per channel.

Distributed Control Systems
These systems are designed such that the local controller controls the intersection, reporting status information to the operation centre every 5 to 60 seconds. The communications circuits are dedicated multi-point circuits with multiple controllers per channel using a TIA-232 interface.

Traffic Adaptive Systems
Typically, these systems require second-by-second control and monitoring of each intersection. The circuits are dedicated multi-point circuits with multiple controllers per channel. There are however several distributed traffic-adaptive systems in various stages of development, where the local controller processes the real-time traffic data and determines its control strategy. The communications requirements of this type of distributed control system are not defined at this time.

The implementation of NTCIP protocol may change the communications requirements from those listed above.

Video Requirements

The video network is used to transmit CCTV images from the field to the TOC. MTO requirements are full motion video signals, which can be provided by using analog or digital video systems. Recently, digital video transmission has been used for various projects, indicative of recent trends in CCTV technology. The design of the video transmission system should be such that all video signals are available simultaneously at the TOC. This means that the video transmission system must have the capacity to transport all video signals to the TOC. Some agencies allow remote video switching, which reduces the capacity requirements of the video transmission system but does not provide simultaneous access to all camera images.

Where cost effective, the video system design should be redundant to minimize the loss of video coverage in the event of a communications failure. At the TOC, a video switch is used to distribute the video signals, with redundancy typically provided at the multiplexer and by using a ring configuration in the network topology which provides a two alternate paths for video transmission to the TOC.

In locations where dedicated communications plant cannot be cost-effectively extended, the ability to transmit full-motion video signals may not be practical. In these instances, the use of low framing rate/low resolution compressed video should be investigated. The use of compressed video however will provide lower resolution and some image resolution problems may be experienced during camera panning.

Adjacent Traffic Operation Centres
A video link may be provided to transmit video images to other traffic operation centres within MTO or operated by external agencies. This can be provided via the communications network if available, or alternatively using a leased telephone service connection. The quality of the video image (compressed or full motion) and number of cameras to be transmitted will depend on the coordination requirements between centres and the cost of maintaining the link. Video connections between agencies can often be considered as a key interface. External agencies are typically provided the ability to choose an image, but not control (e.g., pan, tilt, zoom) of the camera.

Maintenance Yards
A video link may be provided to transmit video images to maintenance yards via the communications network if available, or a leased telephone service connection. The quality of the video image (compressed or full motion) and number of camera to be transmitted will depend on the coordination requirements and the cost of maintaining the link. Typically, the maintenance yard is provided with the ability to select the video image, but not control of the camera.

Media Agencies
To provide access to up-to-date traffic information, some media agencies have a video feed from MTO's cameras. These video feeds are not carried by the MTO's communications network, but are fed using a licensed carrier. As a result, this requirement only has an impact on the number of outputs required for the video switch.

Voice Requirements

The voice network is used to carry conversations between maintenance staff in the field and staff at the TOC or maintenance yards. The typical voice network for maintenance personnel is radio or cellular telephone. Dedicated voice circuits are not warranted, since maintenance personnel are not always adjacent to a cabinet when correcting equipment faults.

The voice network currently utilizes licensed frequency radios, including hand held and mobile portables, and a base station. This network is fully independent of the data and video networks, and users are not constrained as to location for use, except in areas of poor radio coverage.

4.7.2 Transmission Media

The choice of transmission media depends on the communications requirements of the traffic management system. Highway control systems, which include both data and full-motion video transmission, require networks with a large bandwidth. Surface street control systems typically involve primarily data transmission, which requires very little bandwidth. As a result, surface street control systems use leased telephone lines, dedicated twisted wire pair cable or low-speed data radio, while highway control systems use fibre optic or coaxial communications networks.

Fibre Optic Network

The fibre optic network can be either Asynchronous Transfer Mode (ATM) based with a separate analog video transmission network or Gigabit Ethernet based using digital video. The data system is comprised of high-speed drop-and-insert data multiplexer/switches (data nodes) strategically located along the roadway to provide low-speed data distribution to the field controllers. The data system is designed using a ring structure to provide a redundant communications path in the event of cable or equipment fault.

The analog video transmission network is comprised of point-to-point single channel links and multi-channel links. The digital video transmission system uses video encoders/decoders to transmit the camera images over the Gigabit Ethernet network using standard compression techniques, such as MPEG2 and MPEG4.

Fibre optic technology provides high-quality, long-haul transmission of both data and video. The fibre system supports all the data communications required for the traffic management system and has the capacity to allow for future expansion.

Data Network

The high-speed network utilizes drop and insert data nodes. These nodes are installed in cabinets along both sides of the highway and interconnected to form a ring. If it is not cost effective to install cable on both sides of the highway, a collapsed ring topology should be used. Each data node would have two sets of optical transmitters and receivers, one set for the clockwise direction around the ring, and one set for the counter clockwise direction. In the event of cable or equipment failure, the system is designed to reconfigure itself to maximize the number of nodes connected to the TOC.

The data node network includes intelligent status monitoring capabilities, which allow automatic detection and isolation of faults anywhere in the network. Fibre cable and node faults are reported to a dedicated network management computer at the TOC, which logs the time and nature of the fault. This is used by maintenance staff to isolate problems for rectification. There should be remote access to this system to allow maintenance staff to obtain status information from the maintenance yards. The network management capabilities should include monitoring of individual channel cards and remote loop-back testing.

The data nodes employ redundant systems for protection of data integrity in the event of equipment or link fault. Typically, redundancy is provided for the optical and power supply cards.

The low-speed network is used to distribute the serial and Ethernet channels from the data nodes to the field controllers located locally or remotely. Where the controllers are remote from the data nodes, multi-drop serial or Ethernet fibre optic modems are used.

Video Network
The video network uses two methods of transmission – analog or digital.

For the analog video transmission network, the system uses a combination of point-to-point and multiplexed video units. For video cameras close to the TOC, point-to-point fibre optic links are used. For cameras further away from the TOC, multiplexers are used to concentrate multiple video signals onto one fibre. This minimizes the number of fibres required in the cable. The multiplexers are connected in a point-to-point configuration, from the field node site to the TOC. Each camera in the field transmits its signal to the nearest video multiplexer using a single channel fibre optic link.

To improve system availability, the cameras are connected to the video multiplexers in an interleaved fashion. This allows every second camera to be connected to a video multiplexer, reducing the impact of a failure as highway coverage can still be maintained (albeit at a reduced level).

To provide equipment redundancy for the video system, each multiplexer can be configured with a redundant transmitter utilizing a separate fibre path to connect to the TOC. Upon loss of a signal, the receiver automatically switches from the primary link to the redundant link.

For the digital video transmission network, the cameras are connected to video encoders, which compress the video into a digital bit stream. The compression system is typically MPEG2 or MPEG4 depending on the available system bandwidth. The video signals are decoded at the TOC and input into the video switch for display on the CCTV monitors. The encoders also support the camera control channel. The encoders/decoders are connected over the Ethernet data network.

Fibre Optic Cable
The fibre optic trunk cable is installed within a conduit for COMPASS. The cable contains both single-mode (SM) and multi-mode (MM) fibres, in buffer tubes containing up to 12 fibres. SM and MM fibres are contained in different buffer tubes.

Multi-mode fibres are typically allocated to:

- Each subsystem for low-speed data communications
- Single channel video links
- Node-to-node aggregate data communications.

The number of fibres allocated to single channel video links varies based on the number of cameras along the right-of-way. It should be noted that the same fibre number can be used for two different cameras, since the links are constrained from the local camera to the video node.

Single-mode fibres are typically allocated to:

- High-speed aggregate data rings
- Video multiplexer links
- Links to other agencies, TOCs and maintenance yards.

Single-mode fibres should be allocated for future expansion of the system by providing fibres for potential future data ring and video multiplexers. The number of single-mode fibres generally decreases farther away from the TOC, as the number of video multiplexers requiring fibres within the cable decreases.

Twisted Wire Pair (TWP) Cable Network

The TWP cable network is primarily used for low bandwidth applications and is made up of individual pairs of wires to provide individual circuits. The cables are typically 19 AWG providing a range of 10 km to 15 km, depending on data rate and number of drops on the channel. The cable provides reliable low-speed communications. Video transmission can only be supported over very short distances (less than 2 km) with low resolution. The system is configured in a tree branch structure, and does not typically provide redundancy in the event of cable or equipment fault. It should be noted that a failure of one device does not typically affect the other devices as in the fibre optic network.

The expansion capabilities of a TWP system are restricted by the number of wire pairs in the cable.

The system is comprised of modems providing serial interface to the field controllers. Each data channel uses two or four wires depending on the system supplier requirements.

A comparison of different land-line technologies is summarized in Table 5.

Wireless Network

Wireless networks can consist of a variety of technologies including:

- Data radio
- Microwave
- Spread spectrum radio
- Cellular commercial data services
- Wireless LAN.

The advantage of wireless technologies is that the high cost of conduit and cable installation is removed. The disadvantages are that the networks require line of sight between the transmitter and receiver, space for the antenna is required, some systems need licensing, and the links are susceptible to environmental conditions.

Radio propagation analysis should be conducted for a radio system installation due to the susceptibility to site and environmental conditions.

Table 5 – Summary of Land-Line Technologies

Features	Twisted-Wire Pairs	Fibre Optics
Transmission Media	Copper wires	Glass fibres, single or multi-mode fibres
Transmission Range	10 to 15 km (depending on speed)	Limited by number of drop/insert units allowed (typically 16 to 32 with a maximum spacing of 20 to 30 km) in a ring, video links up to 60 km
Communications Topology	Point-to-point, tree and branch topology	Point-to-point, passive multi-drop and drop/insert configurations
System Capacity	Dictated by number of pairs in the cable. Each pair supports a channel	Up to OC-48 for data, 24 video channels for video per fibre
Data Rates per Channel	1.2 to 56 Kbps	DS-0 (56 Kbps), T-1 (1.54 Mbps), Ethernet (10 Mbps), OC-1 (51.84 Mbps)
Types of Information Supported	Data, voice, slow scan video	Data, voice, digital or analog video

Data Radio
These systems provide low-speed point-to-multi-point communications links. The equipment is suitable for data communications only. The radio system requires licensing from Industry Canada. The master antenna is an omni-directional antenna with yagi antennas at the field controller sites. These antennas can easily be mounted on camera poles or sign trusses.

The equipment provides a large coverage area with minimal interference from other systems, since the frequency is licensed. The number of devices which can be connected on a channel is limited due to the modem turn around times, which tend to be much longer than for standard land-line modems.

System expansion is limited by the number of frequencies available. Also, licensing for a radio network can take six to eight months. The project manager should take the time required for licensing into consideration during the design and implementation stage.

Microwave Network
These systems provide both data and video point-to-point communications links. The system requires licensing from Industry Canada. The frequency band utilized would depend on the application. For data, microwave would only be useful in trunking applications providing high-speed links (multiple T-1s) between operation centres or remote data hubs. For video, 23 GHz channels are available which provide single channel video transmission. Note that the equipment allows for reverse band data (i.e., for camera control), but this reverse-frequency use is typically not granted by Industry Canada.

The size of the antennas for microwave links depends on the frequency and range required for the application. For the lower frequencies, the antennas tend to be large, which may not be suitable for mounting on camera poles or sign trusses due to wind loading.

System expansion is limited by the number of frequencies available. Frequency allocation is regulated since there is a limited availability of radio spectrum, which must be shared between commercial, private and government users. Granting of licenses depends on factors such as interference with other users, frequency availability, public good, and availability of using alternative communications media. The approval of Industry Canada should be obtained prior to proceeding with the tender of the project.

Spread Spectrum Radio
These systems provide multi-point data and video point-to-point communications links. The systems do not require licensing from Industry Canada, but the equipment must be type approved. The maximum output power is limited, which affects the range of the equipment. Since the frequency band is not protected, there is a potential for interference from other users. The designer should be aware that larger margins should be used in the design since later installations by others may affect the performance of the system.

The frequency band utilized would depend on the application. For data, the 902-928 MHz and 2.4 GHz bands are the most common. The master antenna is an omni-directional antenna with yagi antennas at the field controller sites. The number of master antennas (i.e., channels) which can be supported within the same area is limited due to interference with each other.

Cellular Commercial Data Services
These services provide data connection leased from commercial companies. As the technology evolves, the access speed is increasing, allowing the service to meet the needs of ITS subsystems. The advantage of the commercial networks is that they provide large coverage areas, can be rapidly deployed, and the rate structure is distance

independent. The disadvantage is that the monthly lease costs are based on data usage so applications which require large data volumes (e.g., video) may not be cost-effective.

Ontario Experience
The Region of York recently implemented use of leased commercial data services through a local cellular telephone service provider for their traffic signal management system. Initial results are very good, with few transmission errors and a significant cost-savings over use of leased telephone lines.

Wireless Local Area Network (LAN)
A wireless LAN (WLAN) is one in which a mobile user can connect to a LAN through a wireless (radio) connection. The IEEE 802.11 group of standards specify the technologies for wireless LANs, which use the Ethernet protocol for path-sharing and include an encryption method for secure connection to the LAN.

The system is ideal for places where a wired connection to the LAN is virtually impossible. Recent development in the technology allows the user a high-speed connection to a LAN, eliminating the high cost incurred by installing Unshielded Twisted Pair (UTP) cables for wired connection.

Leased Networks

Leased circuits provide either low– or high-speed data services in both point-to-point and multi-point arrangements. The advantage of these services is that the telephone company is responsible for the installation and maintenance of the system providing a high level of reliability within a very large coverage area. The major disadvantage of leased services is the high annual leasing costs.

For multi-point data, the leased services can support up to 56 Kbps. Faster services such as T-1 (1.54 Mbps) and Asymmetric Digital Subscriber Line (ADSL) can support high-speed data, but typically in a point-to-point configuration.

If video transmission is required, the video signal must be digitized for transmission on the data network. The provision of equivalent full-motion video would require a minimum of 10 Mbps data stream.

4.7.3 Supplementary Communications

Telephones

Cellular telephones are often used by the public to report incidents and traffic information to the police and radio stations. This information can be used to supplement the information obtained from the traffic control system.

In limited applications, cellular telephones can provide two-way communications to remote controllers. This medium should only be used where full time monitoring is not required, since the “on air” time costs would impact the cost-effectiveness of this type of operation.

5. Special ATMS Applications

5.1 Bridge/Tunnel Management

Due to the physical constraints and the unique characteristics of bridges and tunnels, when an incident occurs traffic problems are often exacerbated due to the inherent bottleneck characteristics of the facility and lack of diversion opportunities available. In addition, there are several considerations unique to bridges and tunnels that may require specialized control and/or management systems. For this reason, bridge and tunnel management systems are becoming increasingly more common involving a wide variety of traffic control equipment. The double-deck Tsing Ma Bridge and the Route 3 Tunnel in Hong Kong are two recent examples of sophisticated bridge and tunnel management systems.

With the increasing focus on security measures, particularly on bridges and in tunnels, there is an ideal opportunity to leverage the significant investment being made in monitoring and surveillance equipment and apply this infrastructure to bridge and tunnel traffic management systems.

5.1.1 High Wind Warning Systems

High Wind Warning Systems monitor wind speed and direction and provide high wind warning information to motorists when wind conditions pose a potential hazard. High wind warnings are generally part of bridge traffic management systems.

Typically wind warnings are categorized into different levels, in accordance with pre-set thresholds of various parameters including wind speed, direction and persistence. Depending on conditions, response plans are implemented ranging from the dissemination of warning messages to approaching traffic to the full closure of the bridge under severe conditions. Since the impact of high winds will vary depending on the size of a vehicle, warning messages often target specific vehicle types, providing warnings to large vehicles first and advising drivers to reduce vehicle speed to minimize the potential hazard. Depending on the conditions, the response plan may include restricting bridge access to small vehicles only and ultimately to a full closure. Depending on the subsystems involved in bridge traffic management system, the warning messages may be disseminated via the media, Highway Advisory Radio (HAR) and/or Dynamic Message Signs (DMS). DMS design principles and technologies are discussed in more detail in OTM Book 10 (Dynamic Message Signs).

Ontario Experience

For high wind warnings at the Burlington Bay Skyway and Garden City Skyway in Ontario, the following threshold values are adopted:

- When the wind speed is between 40 km/h and 64 km/h, a high wind warning message is issued to DMSs on the bridge approaches;
- When the wind speed is between 65 km/h and 100 km/h, a severe wind warning is issued to DMSs on the bridge approaches; and
- When the wind speed is over 100 km/h, the Skyway is closed to all traffic and messages are issued to DMSs in the area advising motorists of the closure and to use alternate routes.

The warnings are displayed on DMSs located upstream of the Skyway prior to the last exit point.

5.1.2 Overheight/Overweight Detection

Overheight vehicles can cause significant damage to a tunnel or highway overpass, including equipment that may be mounted to the tunnel roof or underside of the overpass (e.g., lighting fixtures, cable trays, lane control signs, etc.). The potential damage and related costs in conjunction with the potential hazard to other vehicles from debris and the resultant traffic disruption that would be caused from an overheight vehicle, has lead many jurisdictions to install overheight detection systems.

Typically overheight detection systems include the installation of devices well in advance of the height restriction. The objective is to detect the overheight vehicle and alert the driver so they can divert to an alternate route. These devices can range from a simple mechanical device, such as chains suspended from an overhead gantry to more sophisticated electronic overheight detection systems. These devices are used in conjunction with roadside signing (both static and dynamic) to inform the driver of the overheight vehicle that they exceed the allowable clearance and to divert to the appropriate route.

Ontario Experience

The Thorold Tunnel in the Niagara Region is one of the few tunnels in Ontario. There is no detection mechanism at the tunnel, but the maximum height for vehicles to travel in the tunnel is set at 4.65 m. This meets Ontario's current minimum height requirements and, for this reason, does not require any additional signing (similar to other overpasses in Ontario).

With respect to the overweight detection, all commercial vehicles must be weighed at commercial vehicle inspection sites located at strategic points throughout Ontario's highway network. High-speed weigh-in-motion (WIM) equipment may be used at select sites upstream of the station to check and confirm commercial vehicle weights and dimensions are within legal limits. WIM is a very effective sorting tool that helps inspection officers to identify problem vehicles while allowing compliant vehicles to pass the inspection site unimpeded.

5.1.3 Noxious Fume Detection

The enclosed environment of a tunnel presents environmental challenges to ensure the tunnel is safe and free from noxious fumes and gases. As a result, noxious fume detection is a common feature in tunnel management systems. The objective of the detection system is to limit the build-up of noxious fumes from vehicle exhaust, especially during periods of congestion or slow-moving traffic. In general, the information from the detection system is used to control tunnel ventilation.

Among noxious fumes, carbon monoxide (CO) detection is the most common type of detection implemented in a tunnel. Depending on the length of the tunnel and the complexity of the tunnel management systems, other noxious fume detection may include oxides of nitrogen (NO_X).

Ontario Experience

In the case of the Thorold Tunnel, CO is the only gas tested inside the tunnel on a full-time basis. There are four CO analyzers located in the tunnel to detect levels of carbon monoxide. The air is analyzed and, depending on the CO levels, mechanical fans are adjusted to ensure there is an adequate supply of fresh air. In addition, the tunnel crew may monitor other gases as needed with a hand-held gas detector.

Significant cost savings can be realized in the operation and maintenance of tunnel ventilation equipment when their operation is managed by noxious fume monitoring systems. Therefore, it is important that a noxious fume detection system be reliable and accurate to ensure the safety of the tunnel and to achieve cost-effective tunnel operations.

5.1.4 Lane Control

The automated gate control system in the Massey Tunnel, which crosses the Fraser River between the communities of Richmond and Ladner in British Columbia, is an excellent example of lane control in a tunnel. In the Massey Tunnel system, horizontal swing gates were selected to provide a barrier to closed lanes. Located in groups of three, the gates' increasing arm lengths provide a taper effect for the safety of the high-speed traffic. The gates are utilized to control access to a reversible lane system, which enables this four-lane tunnel to operate three lanes in the peak direction of travel during peak traffic periods.

The automated gate system in the elevated freeway in Taipei, Taiwan, is another example of using automated gate control for lane control purposes. Two groups of automated gates are located at each end of the elevated freeway to control the entrance to the freeway. It is particularly useful during severe wind situations when closure of the elevated freeway can be executed remotely from the operation centre.

5.1.5 Traffic Control for Lift Bridges

Lift bridges are equipped with a lift span to allow the passage of marine traffic. With the approach of a marine vessel, traffic control devices are activated to stop oncoming traffic from accessing the bridge prior to the bridge being lifted to the fully raised position.

Ontario Experience
Adjacent to the Burlington Skyway, MTO operates a lift bridge within the Eastport Drive corridor that utilizes a traffic control system. In addition, the Burlington COMPASS system has an interconnection with the lift bridge system that warns motorists when the lift bridge on this alternate route to the Skyway is closed to vehicular traffic. This provides advanced warning of the lift bridge status, and allows motorists the opportunity of diverting to the Skyway rather than waiting for the marine traffic to pass and for the lift bridge to open again to vehicular traffic.

5.2 Smart Work Zones

ATMS applications in work zones may be described as "smart work zones", with the objective of improving motorist and worker safety. In a large part, this is done by providing motorist advisory information by one or more means. Although these ATMS solutions may be applied in both construction and maintenance work zones, they are more commonly used for construction work zones. Several ATMS technologies that can be used in work zones are described below.

5.2.1 Portable Variable Message Signs (PVMSs)

Portable Variable Message Signs are often used to provide information directly related to construction work zones. Best practices for their use in work zone traffic control is described in OTM Book 7 (Temporary Conditions). PVMSs typically include information on closures (including time and/or duration of closure), lane reductions, speed reductions, or alternate routes. PVMSs may be located on the back of vehicles or mounted on a trailer allowing them to be moved from site to site. Due to their portability and the physical space limitation of the work zone, these signs are typically much smaller than overhead DMSs, although they have similar functionality. As with other DMSs, PVMSs should be designed and placed taking into account the need for sign conspicuity, legibility, comprehension, credibility, and driver response time. PVMSs must not be used to replace any devices prescribed in the Ontario Traffic Manual. They can only be used to supplement such devices, primarily because PVMSs are not fail-safe devices.

When permanent DMSs and PVMSs are used on the same or a nearby roadway as part of a centrally-controlled ATMS, care must be taken to ensure that the PVMSs and permanent DMSs are operated in a coordinated manner, and that messages do not conflict – between signs or with the actual traffic conditions. The dynamic nature of the signs leads the public to believe that the information displayed is updated regularly, and considerable loss of credibility and reduction in safety may be experienced if two signs display conflicting information. The contractor and the road authority responsible for the ATMS should coordinate PVMS and DMS messages.

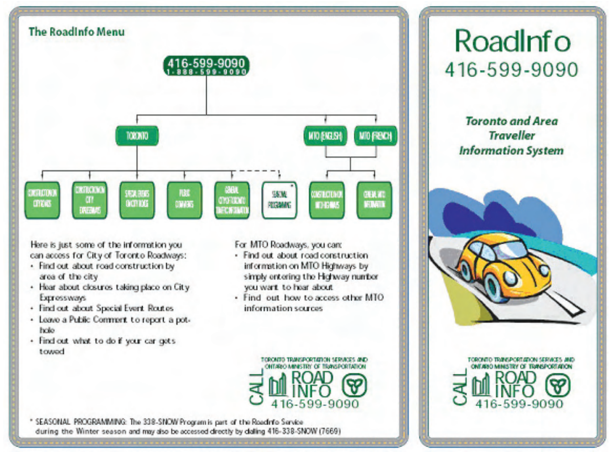
5.2.2 Highway Advisory Radio (HAR)

Highway Advisory Radio may be used to provide advisory information to motorists as they are travelling in their vehicles. Information may relate to many types of situations, including work zones. Where HAR is used to provide work zone information, it is typically necessary to cover only a limited geographical area. A brief description of alternative methods of implementing HAR in work zones is provided in OTM Book 7 (Temporary Conditions). As with any real-time travel advisory system, the information must be up-to-date and accurate, otherwise credibility will be lost.

5.2.3 Traveller Information Telephone Lines and Websites

Some road authorities have found the dissemination of traveller information through telephone lines and websites to be an effective means of communicating information to motorists on construction activities. The travelling public may be advised of this service in various ways, including brochures, newspapers and radio advertisements. It should be noted that the promotion of road information telephone numbers on highway signs, either static or dynamic, is not recommended, in order to avoid driver distraction. This policy is in effect for amber alert messages as well.

Figure 14 – Pamphlet of Road Reports for both MTO and City of Toronto (as of 2006)



Ontario Experience

The City of Toronto provides a RoadInfo public service telephone line where callers are able to get information about construction and other road restrictions on both city and provincial roadways in Toronto, as well as on provincial highways in Halton, Peel, York and Durham Regions. The information on road restrictions, including those due to construction, is also available on the city's website (www.toronto.ca/rescu/). The Ministry of Transportation Ontario provides similar services, giving motorists up-to-date information on road restrictions via telephone hotlines and via their website (www.roadinfo.mto.gov.on.ca/english/traveller/construction/index.html). A sample of the pamphlet for road reports for both MTO and the City of Toronto is shown in Figure 14.

5.2.4 Radar – Speed Display Signs (Speed Trailers)

As described in OTM Book 7 (Temporary Conditions), some devices are available on the market, which, in a combined unit, permit the measurement of vehicle speed by means of radar, along with a sign display of the actual speed travelled. Optionally, the sign may also display the legal posted speed at the time of measurement.

Such signs, while not used for speed enforcement (e.g., photo radar), have been demonstrated to reduce 85th percentile speeds an additional 4 km/h to 10 km/h over any reduction that can be achieved through the use of static speed limit signs. This level of success is thought to be largely due to drivers, when seeing their speeds displayed, are genuinely surprised and reduce their speeds. Other drivers may be uncertain whether a sign showing their speed means that enforcement is nearby, and may reduce speed to avoid a potential fine.

The effect of a single speed display sign in a work zone is likely to diminish as motorists travel downstream from the sign. This may be overcome to some degree with the use of more speed display signs. Regular drivers along the section of road in question may also become accustomed to the signs, with diminished effect, if they see no enforcement is in place. For this reason, it is desirable to supplement such signs with enforcement from time to time, to achieve the necessary degree of uncertainty for drivers, as to whether they may be charged.

Ontario Experience

MTO experience with such signs is not extensive. When used in conjunction with a legal work zone, speed limit reduction from 90 km/h to 80 km/h, use of the speed display signs was reported to result in a 6.2% reduction in 85th percentile vehicle speeds.

The Ontario government has introduced new legislation in February 2005 by way of Bill 169 to amend the *Highway Traffic Act*. This legislation which focuses on improving road safety includes doubling speeding fines in construction zones to better protect construction workers, and allows for variable speed limits on designated provincial highways to manage traffic depending on weather or traffic conditions.

5.2.5 Queue Warning

Automatic detection of queuing due to incidents or congestion within work zones, and the accompanying dissemination of information via DMS technology can serve to inform motorists of conditions ahead and improve safety of operations. This ATMS service is particularly useful on high-speed roadways and areas of reduced visibility, such as horizontal and vertical curves, where slow-moving traffic may not be anticipated and stopping sight distances are limited. More detailed information on queue warning systems is discussed in Section 5.3.

5.2.6 Roadway Information/Monitoring Systems

Some U.S. states have used mobile traffic monitoring and management systems in work zones, which deploy one or more vehicle detectors utilizing inductive loops, CCTV, video imaging detection systems (VIDs), and radar detection technologies. These are often used in conjunction with PVMSs to advise motorists of slowing traffic speeds downstream, providing a stand-alone system that automatically generates the PVMS messages.

5.2.7 Merge Control

A high percentage of work zone collisions are rear-end and sideswipe crashes, often occurring as a result of failure to notice a lane closure or to shift lanes at a lane closure, as well as the merging of a high number of heavy vehicles (e.g., trucks, bus, etc.) prior to the work zone. Merge control offers a means of facilitating such manoeuvres and improving safety. Several ITS merge-control products have been developed which promote smooth traffic flow leading into a work zone by creating a dynamic, no-passing zone upstream of the construction site, which results in reduced conflicts, fewer collisions, and reduced "road rage". The length of the dynamic no-passing zone varies with the length of the traffic backup. Trailer-mounted, portable signs typically consist of flashing lights and "DO NOT PASS WHEN FLASHING" signs. The purpose of the system is to have motorists merge early enough to prevent the backups that often occur with last-minute merging. Experience with the system has proven effective, significantly reducing travel times and collision rates in work zones. System components typically include non-intrusive traffic sensors, interface controllers, communications devices, regulatory signboard with flashers and trailer, and solar power equipment and batteries.

5.2.8 Work Zone Intrusion Alarms

Work zone intrusion alarms, though currently still in the development and test phase, appear to offer promise for improved worker safety. Intrusion alarms detect vehicles entering the buffer area between work crews in the work area and vehicles driving past the work zone, providing a warning to workers. Warning time may be short (4 to 7 seconds), but can be vital. Such alarms employ various technologies, such as infrared, ultrasonic, microwave or pneumatic tubes to detect the intruding vehicle. When the system detects an intrusion, it sounds a loud siren to warn the workers in the area. Transmission mechanisms include radio and hard-wired systems.

5.3 Queue Warning at Border Approaches

During periods of border congestion, queues of international traffic can extend long distances from the border causing significant safety concerns due to the high speed of highway traffic, the potential for rear-end collisions and the associated operational problems at entrance and exit ramps. The queue warning system is designed to detect slow-moving traffic and automatically display messages to passing motorists upstream of the queue, warning them of slow or stopped traffic ahead. The system monitors traffic conditions over the length of the freeway and automatically updates the location of the end of queue. Messages are displayed on roadside signs and the associated messages are automatically updated or removed as queue conditions change. The signs are located in queue-prone areas of the highway corridors and at strategic locations where visibility is restricted due to the horizontal or vertical curvature of the road. The system operates in a stand-alone fashion for quick response and improved fail-safe operations. However, CCTV cameras provide the ability for an operator at a nearby TOC to monitor operations, as required. Figure 15 provides an illustration of the typical elements of a queue warning system.

Ontario Experience

MTO has deployed queue warning systems (QWS) on the approaches to the international border at the following locations as shown in Figure 16:

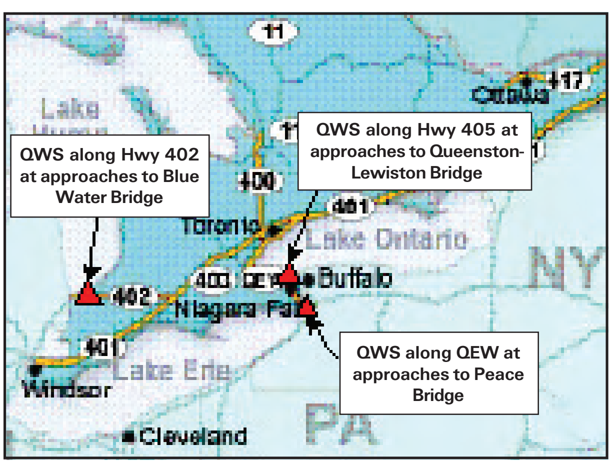
- Highway 405 approaching the Queenston-Lewiston Bridge;
- Queen Elizabeth Way (QEW) approaching the Peace Bridge; and
- Highway 402 approaching the Blue Water Bridge.

A queue warning system has also been installed in the high-occupancy vehicle bypass tunnel near Highway 404/Highway 401 interchange to warn southbound vehicles of any incidents, queues or slow-moving vehicles in the tunnel area.

In addition to the queue warning systems, the MTO has also deployed pole-mounted and portable roadside dynamic message signs at a number of strategic locations throughout the province. These signs are utilized by the various regional offices to provide traveller information relevant to construction, lane closures, incidents, etc. The signs are controlled by the local Traffic Operation Centre. Several of these roadside signs have been located at key locations on Highway 401 (Windsor, London and Kingston areas) and the QEW (St. Catharines) in the

Figure 15 – Typical Elements of a Queue Warning System

Figure 16 – Locations of QWS in Ontario



event of severe delay at border crossings. Overhead COMPASS DMS at strategic locations in the Toronto and Burlington areas have also been designated for use to display border-related information in the event of severe congestion.

Recently, the MTO has deployed an overhead COMPASS DMS on Highway 401 for westbound traffic immediately upstream of the Highway 401/Highway 402 split. The intent of this sign is to provide advanced warning to motorists in the event of poor road conditions or severe border congestion in the Windsor or Sarnia areas.

5.4 Rural Application

The rural environment is usually categorized by several distinguishing features:

- Trip distances are relatively long;
- Volumes are relatively low;
- Congestion is relatively rare, and the times and locations vary, however, the impact may be more severe;
- Alternate routes are few;
- High occurrence of single vehicle collisions;
- Many travellers are unfamiliar with the surroundings;
- Highways may traverse rugged terrain in remote areas;
- Climatic conditions can be extreme and have significant impacts; and
- Animals wandering onto or bounding across roadways present unique hazards.

ATMS applications that are frequently deployed to address the unique requirements of the rural environment are described below.

- *CCTV Cameras* – to view rural roadways for traffic monitoring and incident verification, weather and roadway conditions monitoring, DMS message verification and event management. CCTV images can be sent back through wireless communications to an information clearinghouse, via cellular digital packet data (CDPD) and cellular telephone signals.
- *Integrated Signal System* – to control signal timing at individual signal controllers. Data collected through monitoring components can be analyzed and signal timings automatically changed.
- *Route Diversion Static Signs* – to define permanent alternates to primary routes with recurrent problems, i.e., during peak tourist season. The static signs can be supplemented with DMS, HAR, road weather information systems, or other advanced technologies to enhance their effectiveness in affecting driver behaviour. Emergency detour route (EDR) trailblazer signs with PVMSs can be placed at major diversion points to help motorists navigate safely and in an orderly manner through the permanent emergency detour routes.
- *Vehicle Probes* – to collect information on link speeds and travel times, as well as to detect incidents.
- *Mayday System* – to provide notification to a response centre in case of a vehicle breakdown or collision. The emergency notification system is typically triggered by deployment of vehicle airbags and utilizes wireless communications from the vehicle to a call centre, with use of GPS location technology to automatically identify the location of the vehicle. Enhanced Mayday systems can detect and transmit crash information (e.g., primary direction of force, severity of crash, final resting position of the vehicle, etc.) to a call centre that subsequently contacts an appropriate response agency (fire, ambulance, police), and provides them with the necessary data derived from the in-vehicle Mayday system.

Rural areas cover vast geographic areas, involving extensive distances of highways. Under these conditions, monitoring traffic flow and detecting congestion, incidents, weather events, etc. can present a significant challenge. The application of wide area monitoring techniques using automatic vehicle identification (AVI) / automatic vehicle location (AVL) technologies allows the use of vehicles travelling in the rural corridors to serve as vehicle probes and act as detection devices. Wide area monitoring techniques used in combination with traditional point detection devices have proven to be the most cost-effective manner to provide a reasonable level of coverage for rural traffic management applications.

Vehicles are becoming increasingly sophisticated with on-board computers, AVI/AVL devices, cellular communications, etc. all built into the vehicle platform to help manage vehicle operations, increase safety and provide customer amenities. Use of these in-vehicle devices for wide area monitoring purposes presents a significant opportunity for future applications in rural traffic management. An example is in incident management where use of the on-board computer, AVL and cellular communications technology can be used to inform emergency services in the event that an air bag in a vehicle has been deployed.

Ontario Experience

MTO Northwestern Region deploys PVMSs throughout Northern Ontario to warn motorists of unusual traffic conditions, and to inform drivers of closure, alternate routes, safety messages, amber alerts, etc.

Services such as OnStar® have been offered by General Motors (GM) since 1997. They have more than 3 million subscribers with OnStar®-equipped vehicles on the road. They are committed to make OnStar® standard equipment in the full range of GM retail cars, trucks and sports utility vehicles in Canada and the U.S. by 2007. OnStar® features include alerting emergency services when air bags deploy, assisting authorities in locating stolen vehicles, and remotely unlocking doors when keys are left inside.

5.5 Enforcement

The effectiveness of ATMS applications in making the existing road systems smoother, safer and more efficient depends largely on driver compliance. Enforcement is a critical aspect to maintaining a reasonable level of compliance. To achieve a reasonable balance between enforcement and compliance, it is important that enforcement needs and requirements are carefully considered in the detailed design of an ATMS system. This can include the provision of enforcement areas within a roadway facility or the use of ATMS-related technologies for purposes of enforcement.

A common application of technology for enforcement purposes is the use of cameras, vehicle detectors and traffic signal controller data to enforce red-light compliance at signalized intersections. Still cameras, activated by detectors during a traffic signal's red interval, record the licence plate of an offending vehicle (a vehicle which enters an intersection during a red traffic signal). Information documenting the vehicle disobeying the traffic signal is captured by the red-light camera system and used by provincial courts in the prosecution of offences.

Ontario Experience

Since November 2000, the Cities of Toronto, Ottawa, Hamilton and the Regional Municipalities of Peel, Waterloo and Halton have operated red-light cameras at 68 signalized intersections. Eighteen red light cameras are rotated among these 68 locations. The operation of red-light cameras at these locations has shown a reduction in the types of collisions associated with red light running. This has resulted in a reduction in the number of injuries and fatalities due to traffic collisions at these intersections.

6. Institutional and Management Considerations

6.1 Operations

Assessment of accommodation requirements for staff and systems is necessary in order to facilitate a traffic operation centre (TOC) for ATMS. ATMS staff organization structures that are most effective for planning purposes are based on functionality. The following six functional areas are typically required for ATMS operation at the TOC:

- Program Management
- Traffic Management and Coordination
- System Maintenance
- Traffic Engineering
- System Development
- System Technical Support.

Staffing requirements based on the six functional areas listed above typically include:

- A Manager with overall responsibility for the operation, support, maintenance and evolution of the ATMS. Depending on the organizational structure and capabilities of the operations staff, this may be a part-time position;

- A Traffic Supervisor/Coordinator who has overall supervision of the ATMS and the TOC;

- A Traffic Engineer who oversees the traffic operation functions of the ATMS. There are close links between the traffic engineering and traffic coordination functions, so it is feasible to have a Traffic Engineer/Supervisor position, which combines responsibilities for both functions;

- The System Technical Support Officer(s) who specializes in aspects of system software, hardware and communications, but should also be knowledgeable in traffic applications functions so that the officer can assist in all areas of control-room operations, as required; and

- Operators for incident response, traffic coordination and operation. Agencies should consider sharing operator duties with other related functions, such as dispatch, public relations, etc., in order to provide variety and enrich the work experience.

In assessing the systems and staffing requirements of an ATMS TOC, operational hours need to be considered. The decision will depend on traffic conditions, incident frequency, fiscal constraints and cost-effectiveness. In this assessment, consideration should be given to other agency operations centres (e.g., emergency service dispatch, road maintenance, disaster response, etc.) and the potential to consolidate operations outside of normal business hours. The centre-to-centre communications links required to implement such an approach would also help to provide the necessary coordination with these operational centres during incident response, as well as provide these centres with an operational back-up in the event of a major system failure or disaster impacting the centre's location.

6.2 Traffic Operation Centres

6.2.1 Functional Requirements

One of the key areas to be considered for any ATMS development is the definition of appropriate organizational structure, staff resources, physical facilities, and the associated funding necessary to support the ongoing operation of the system. Typically, there will be several different organizations and contractors involved in the operation of any

ATMS – directly or indirectly – making use of the various subsystem components in an integrated manner. In a fully developed ATMS, these activities could be very diverse, including:

- Emergency incident response (police, fire, ambulance);
- Breakdown service (auto clubs, towing companies);
- Local traffic control device operation (traffic signal system, ramp metering, etc.);
- Strategic traffic management;
- Roadway maintenance management (planned lane closure coordination and public information);
- Broadcast traffic reports (radio, television);
- Targeted traffic information (auto-fax, interactive telephone); and
- ATMS system maintenance and support (hardware, software, communications, database).

For an ATMS to be successful, the roles and responsibilities of each agency, and the organizational units within each agency, must be clearly defined. In some cases, this will be relatively simple, as a clear operational mandate may have already been provided for these agencies, either by statute/regulation (e.g., police) or by contract (e.g., a network manager).

The full range of activities required to successfully plan, manage and deliver a program of traffic management and motorist information services can be organized into several distinct areas of responsibility as noted below. Each of these areas represents a logical group of activities which require a common set of staff skills and working arrangements, which can be defined and independently managed (by public sector or private contractor) within a single organizational unit. The functional requirements of each of these areas or groups of activities are described in the following sections.

Policy Direction

This function encompasses the policy-level activities that provide the basic framework within which the traffic management function takes place. Government policy should establish the overall mandate, direction and priorities to be considered at all levels of the decision-making process. In support of high-level policy, decisions must be made regarding the overall level of program funding available for traffic management and, where considered appropriate, allocation of funding to broad geographic or functional areas. Different agencies should provide input on direction, but the overall accountability for the project should be with one agency.

Programming and Planning

Programming and planning involves determining specific expenditures and investment priorities within the ATMS program. It includes an assessment of the operational requirements for traffic management across the region, in light of current public policy, fiscal situation, institutional relationships, developments in technology, traffic engineering standards and practice, and the performance of the existing system. The programming and planning function must sustain a program of planned operations, maintenance and capital investment, within an approved funding envelope, and put forward annual funding allocation proposals so that the requirements of ATMS may be successfully considered alongside other competing spending priorities.

On-Site Incident Response

The on-site incident response activity involves the dispatch of specially qualified personnel (e.g., police, fire, ambulance) or specialized equipment (e.g., breakdown service, dangerous goods clean-up crew), to respond to incidents on the road network and the subsequent management of the incident at the scene.

Although the initial identification of an incident may come from a variety of sources, the responsibility for on-site incident response will remain with the police, or in the event of fire or threat of fire, with the fire services. The ATMS operation staff will be available to provide assistance to the police. Further details on integration of these emergency service agencies are included within Section 6.3.

Consideration to incorporate motorist assistance programs or emergency response units into the ATMS must also be made.

Traffic Operation Centre Operator Services

The traffic operation centre (TOC) operator is responsible for day-to-day interaction with the ATMS. This function represents the first line of responsibility for detecting and responding to events on the road network. The service involves activities such as visual monitoring of CCTV, responding to system alarms, initiation of pre-planned system responses, setting special DMS/LCS response plans, and coordinating responses with the police and local authorities. Input of scheduled maintenance and construction closures, and the coordination of closures on the roadways, would also form part of the operator's function. Activities could also include answering emergency telephones, if required.

Traffic Engineering Services

Traffic engineering services encompasses the traffic engineering, planning, analysis and system configuration activities that are essential in the continuing use of the system for traffic management. It involves activities such as definition of operating procedures, planned responses to incidents (e.g., plan development, configuration of algorithmic response parameters), post-incident analysis, database configuration (e.g., input of equipment locations), algorithm configuration, and determining an appropriate course of action in response to equipment failures. The traffic engineering services function also provides training to the TOC operators regarding the use of the system, and is also generally involved in promoting ATMS and raising public awareness of the system (e.g., production of educational leaflets, TOC tours, etc.).

Traveller Information Interface

The traveller information interface function is responsible for managing traffic data and ensuring it is available to external agencies. The information may be issued directly from the TOC or be retransmitted or resold by third-party information service providers. This function bridges the gap between ATMS as a provider of roadside traffic management services, and the need to provide a base level of real-time traffic information to the public and third-party providers. This enables the development of a market for traveller information. Specific responsibilities of this task could include marketing and promotion of the available data, and specification of appropriate data formats to take advantage of emerging technologies and standards.

Network Management Services

ATMS network management services encompasses all coordination activities with contractors and other agencies regarding operation of the roadway network. This function provides a liaison between local authorities, police, network manager and construction contractors. It provides traffic data, incident information, etc. that describes the current performance of the roadway network. This information may be used for reporting network performance, and as input into road improvement funding decisions. In addition, this function generates reports on system performance and historical traffic data trends.

Traveller Information Service Provision

The traveller information service providers are responsible for actively disseminating information on the roadway network to a wider audience, using a variety of traveller-information services and technologies.

System Maintenance

System maintenance relates to the preventive and remedial maintenance and repair of all in-station and field equipment, communications and system software.

Monitoring and Evaluation

Ongoing evaluation and reporting of the performance of the system from a technical and strategy effectiveness perspective should be completed.

6.2.2 Spatial Requirements

The spatial requirements for the TOC must be defined in terms of specific rooms and their individual functionality. Once the rooms have been identified, the layout of each room can be configured on the basis of:

- Staff allocation
- Equipment allocation
- Ergonomic interaction among staff and equipment.

The following sections outline the spatial requirements for rooms in a TOC, depending on the functionality typically required to accommodate an ATMS of any scope and scale.

Control Room

A control room is required to house the staff and equipment dedicated to performing the major traffic monitoring and control functions of the ATMS. Spatial requirement considerations for the control room are summarized below.

Consoles and Equipment
Consoles are required for the maximum number of operators expected to occupy the control room at one time. In addition, a supervisor console should be provided, if required. Consoles must accommodate the workstation equipment used by the operator, allowing the operator to access the equipment easily and efficiently, while not blocking views of other equipment and activities in the room. Space for free paper work should also be provided. A cable management system should be incorporated into the consoles.

Adequate space, wall clearance and access space is required for any major visual display equipment to be located in the room (e.g., CCTV monitor banks, large screen displays, model dynamic message signs, etc.) and other stand-alone equipment (e.g., printers).

The layout of the equipment should support the use of this equipment and the overall functionality of the room. Sight lines to visual display equipment should be based on acceptable horizontal and vertical viewing angles from the work position of each staff member working in the control room. Equipment should be placed near those accessing it most frequently.

Staff workstations must be within a convenient visual and communications range, to allow for consultation, providing advice and coordinating responses. If a supervisor function exists in the control room, the supervisor should be able to view all accountable staff and equipment, as well as the stand-alone visual display equipment.

Lighting
Rooms should be provided with effective lighting designs. Design requirements should include variable overhead lighting to allow operators to adjust ambient light, depending upon the circumstances. The lighting should also be arranged so that there is no direct glare on the terminals and monitors. Good task lighting is required for the operators. Walls should be coloured and textured to minimize glare on terminals and monitors. Natural light through windows is desirable for a more comfortable working environment, but should be carefully controlled so as not to interfere with equipment visibility.

Storage
Storage space should be provided for manuals, equipment accessories (e.g., printer paper), and for staff belongings, particularly for staff who do not have office space elsewhere in the building.

Raised Floor
A raised floor is recommended to provide cable routing between operator consoles, computers and the communications room.

Environment
Proper temperature control is necessary for the comfort of the operators and the safe operating requirements of the equipment.

Circulation/Access
The layout of equipment should allow for logical circulation paths within the room. Proper security is required to prevent unauthorized access.

Computer/Communications Room

A computer/communications room (equipment room) is required to house the computer and communications equipment for the ATMS, such as central processing units (CPU), system consoles, communications circuit termination cabinets, modem racks, etc. Spatial requirement considerations for the computer/communications room are described below.

Equipment
Adequate space, wall clearance and access space is required for the computer/communications equipment. If required, temporary workspace for computer and communications staff, as well as space for building system equipment (e.g. air conditioners), should be provided.

Raised Floor
The room should be provided with a raised floor, for cable routing to/from the control room.

Environment
A separate air-conditioning and humidifying system with back-up may be required. Also, it is important that the power be conditioned and drains be provided for moisture. An uninterruptible power supply (UPS) should be considered a high priority.

Flood and fire detection and protection equipment should also be provided in the room. To minimize equipment damage, the sprinkler system should be linked to a power shut-off so that the power is deactivated prior to activating the extinguishing system.

Circulation/Access
The layout of equipment should allow for logical circulation paths within the room. Proper security is required to prevent unauthorized access.

Situation/Visitor Room

In the event of major emergencies and disasters, a situation room is useful as a "command post" from which external personnel can monitor and control traffic. The provision of such a space can reduce the probability of visitors inadvertently interfering with operator actions.

It is also important to accommodate visitors and inform them about TOC operations and the rationale behind the overall ATMS. The opportunity exists to use the situation room as a viewing room for visitors, when the room is not required for use as a command post. Visitors could observe control room operations and visual display equipment from the viewing room through a glass wall without disturbing the ongoing activities of the control room staff. In order to provide meaningful views of the equipment to visitors, the control room layout should be arranged so that viewing takes place from behind the operators.

For the command post application, close physical and communications links are required with the control room, so that the persons involved can effectively communicate and interact with each other. Telephones should be provided to supplement this interaction and for interactions with external agencies. Consideration should be given to setting up secondary monitoring/control facilities (i.e., operator console equipment) in this room, which would require cabling to/from the control and computer/communications rooms.

Equipment, such as a front-screen projector, projection screen, slide projector and video cassette recorder, should be provided for audio-visual presentations to visitors. In addition, blinds over the observation windows and variable intensity lighting are recommended.

Ontario Experience

The viewing rooms in the City of Toronto Integrated Transportation Control Centre (ITCC) and Greater Toronto COMPASS Traffic Operation Centre are placed so that the operators' workstations face away from the viewing room. The CCTV monitors and other visual displays are clearly visible from the viewing room. The size of the viewing room should be sufficient to manage emergency or crisis situations where media may be involved, for example, snow storm crisis. Both MTO and the City of Toronto have needed to expand their situation/visitor room space to accommodate command centre roles and media staff.

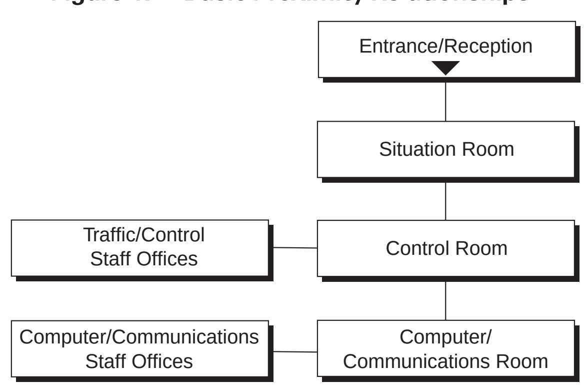
Offices and Ancillary Space

Office space should be provided for all staff operating the ATMS from within the TOC. Ancillary office support space for washrooms, kitchenettes, storage, closets, photocopying and other necessities for 24/7 operation should also be provided.

6.2.3 Proximity Relationships

After the spatial requirements have been defined, proximity relationships define which spaces should be close to, or far from, each other. Basic proximity relationships, which could apply to the spaces described above, are shown in Figure 17.

Figure 17 – Basic Proximity Relationships



The major proximity relationships depicted in Figure 17 are as follows:

- The control room and the computer/ communications room of the TOC should be in close proximity, and preferably adjacent, to each other. Either horizontal or vertical proximity is acceptable for this relationship.

- The situation room should be adjacent to, and located on, the same horizontal plane as the control room.

- Offices of control staff and traffic engineering staff should be near the control room, and offices of computer and communications staff should be near the computer/communications room.

6.2.4 Traffic Operation Centre Design

Control Room Specialized Equipment

The following specialized pieces of console equipment are standard within the control room:

- CCTV camera monitors
- Telephones
- Camera control equipment
- Call switching equipment
- Video/graphics display monitor
- Voice recorder
- Faxes
- Video cassette recorders (VCRs).

Workstations should be provided for the number of operators required for the control room. Servers and network equipment should be provided to contain and manage the capacity of information required for the TOC. Server and network equipment should be located in a secure room with proper ventilation to maintain desired temperatures.

The design of a TOC should incorporate the spatial requirements as discussed above under the control room, computer/communications room, and situation/visitor room (Section 6.2.2). The design should include access control equipment to allow operators to open security doors from the workstation.

CCTV Monitor/Large Screen Display Unit

Physical requirements for display units are based on the associated needs of the display system in terms of image size and resolution. A large screen display unit should provide the capability of displaying three main types of information and combinations:

- Graphical information, such as maps and diagrams;

- Textural data, such as freeway/arterial control information; and

- Video images in the form of CCTV camera feeds.

In order to size the display unit, the distance between the operator console and the display unit has to be determined. Designs for ITCC and COMPASS TOC were based on a 2.5 m to 3 m separation between the operator consoles and the display wall.

Image resolution for large screen display units relies heavily on three factors:

- Resolving ability of the average human eye, which has been shown to be 1 minute of arc in the field of vision;

- Distance from which the image is to be viewed; and

- Size of the image being viewed.

The required value of resolution for a large screen display unit is 794 pixels in 125 cm of image surface height. Commercially available display units of 1,024 pixels horizontal by 768 pixels vertical should be used as minimum standard.

6.2.5 Ontario Experience

- The user should develop and clearly communicate mandates for the functional responsibility groups.
- Retrofitting an existing building may be cost-cutting, but it can be disadvantageous to work around existing infrastructure.
- The size and vertical positioning of a video display should be optimized and should take ergonomics into account.
- The size and position of a workstation can obstruct the viewing area of the video display.
- Logic should be applied for the placement of shared devices/areas, such as a printer and workspace, to make the user-equipment relationship within the room efficient and convenient.
- If there are several operational components to a TOC, all the employees should be introduced to the TOC at the same time to enhance teamwork and curb individual work.
- The user should ensure adequate command/emergency areas exist for handling major incidents.

6.3 Interaction with External Agencies

6.3.1 Centre-to-Centre

For the operation of an integrated ATMS, the provision of a centre-to-centre communications network is essential to facilitate exchange of information between agencies (e.g., police computer-aided dispatch [CAD] systems), and provide joint monitoring and control of field devices, as appropriate. This enables any agency to monitor conditions on other agencies' facilities, and to implement coordinated responses to incidents and other changes in operating conditions when needed.

As an option, the co-location of agency operations centres can reduce the need for centre-to-centre communications and help to facilitate effective inter-personal communications, improve inter-agency interaction and interoperability. The experience of agencies with co-location in the past, however, has identified a number of issues relating to incompatibility between agencies on technical/operational/procedural aspects, exchange of sensitive information, security, labour issues, etc.

6.3.2 Incident Management Plan

ATMS-supported incident management plans are used to reduce the impact of non-recurrent congestion and incidents. The benefits of implementing an incident management plan are derived from the resulting reduction in incident duration. These benefits include:

- Improved safety by facilitating quicker emergency response and reducing secondary incidents;
- Savings in lost time and vehicle operating costs; and
- A reduction in the amount of harmful emissions.

The success of incident management plans depends on clear communications and a supportive, interactive relationship between the ATMS operator and the emergency service agencies. Much of the benefit to be derived from incident management plans is the savings in detection and response time for emergency service agencies. This benefit is realized when the incident is detected quickly and emergency services are able to respond to an incident already knowing the exact location, the type of incident, their responsibilities, and therefore, the number and type of response crews needed. In this respect, ATMS can play a significant supporting role.

The integration of incident management capabilities with commercial vehicle tracking assures faster treatment of incidents involving dangerous goods.

The Need for Pre-Determined Plans

Pre-determined incident management plans should be developed to facilitate responses to a variety of anticipated conditions. Incident management plans should identify the roles and responsibilities of each emergency service agency involved, command structures to organize these agencies, response methodologies, and paths of communication.

Wherever possible, pre-determined incident management plans should also identify diversion routing around anticipated incident locations. While this may be more common in a freeway incident management scenario, arterial applications may use police control and modifications to traffic signal timing to influence routing.

Plans should be developed with, and communicated to, all agencies involved to clearly delineate roles and responsibilities. Pre-determined incident management plans should be periodically reviewed by these agencies to ensure that objectives are being met in the most efficient manner.

A realistic and comprehensive pre-determined incident management plan will reduce response time, reduce incident duration, improve safety, avoid command conflicts, and reduce the potential for the deployment of inappropriate resources.

Who Needs To Be Involved?

Development of incident management strategies should involve discussions with a number of agencies, including police services, fire services, ambulance, agencies responsible for the removal of dangerous goods, emergency patrol vehicle operators, towing and other road clearance services, and communications outlets such as the media. Table 6 describes the roles of the various emergency agencies.

Ideally, the groups outlined in Table 6 should form part of a formal incident management team used to formulate policies, as well as plan, maintain, implement and perform post-incident reviews of incident management plans. These groups should work within the context of an inter-agency agreement that delineates and assigns on-site and coordinating command responsibilities and communication structures.

Determining Appropriate Response Levels

Information on incident type, location and severity is critical to determining the appropriate response. The plan needs to establish what types of information are critical, what are the reliable sources of the information, and how they should be collected and stored. Inadequate and/or inaccurate information may result in the wrong emergency service agency being deployed, or the initiation of an inappropriate response level.

By reviewing incident response levels for past events, incidents can be categorized into severity levels. Severity levels will vary according to the number of injuries, the number of lanes blocked, the anticipated

Table 6 – Roles of Emergency Response and Related Agencies

Agency	Role
Police Services (OPP/Local)	• Often first emergency agency on scene • Usually act as central command authority and manage/command the incident through to its clearance • Minimize personal injury through applying basic medical care • Assess need for additional emergency services • Control access to and from the scene • Direct the clearance of the incident • Close a portion or all the roadway (if necessary)
Fire Services	• May act as central command authority • Minimize personal injury through applying basic medical care • Provide fire suppression for incident and secondary fires • Extricate persons trapped in vehicles • Contain and control flammable, combustible, and dangerous goods • Assess need for additional emergency services
Ambulance	• Minimize personal injury through advanced on-site medical care • Perform medical needs assessments • Assist with extrication • Transport of patients to appropriate medical facilities • Assess need for additional emergency services
Towing	• Remove vehicles and debris from scene • Assess need for additional emergency services • Assess need for heavy removal equipment • May be dispatched directly or through contract service provider
Road Maintenance	• Remove debris from scene • Make emergency repairs to guide rail, electrical, etc.
Motorist Assistance Programs	• Provide roving or on-call services • Provide traffic control at incident scene • Detect, verify, and clear minor incidents • May be dispatched directly or through contracted service provider • Assess need for additional emergency services • Push or otherwise clear disabled vehicles from roadway • Provide re-fuelling, minor maintenance, first aid kits, etc.
Ministry of the Environment	• Act as central command authority for dangerous goods spills
Media Outlets	• Provide traveller information
Transportation Agencies	• Provide overall coordination of the incident • Manage incident traffic impacts, such as closures, congestion
ATMS	• Provide detection monitoring, dispatch, coordination and information dissemination services to the central command authority and other emergency service agencies

Table 7 – Example Incident Severity Level Matrix

Incident Level	Criteria (an incident which includes one or more of the following)
1	• No injuries • Blocking part or all of one lane of travel • Disabled vehicles on the shoulder with occupants • Minor collisions moved off the roadway
2	• Minor injuries • Requires emergency personnel to respond • Blocking more than one lane of travel • Expected to last more than 10 minutes
3	• Serious injuries • Involves several vehicles • Vehicles or debris blocking multiple lanes, keeping one lane open • Minor dangeros goods spill • Expected to last more than 30 minutes
4	• Multiple fatalities • Serious dangerous goods spill or cleanup • Closure of the highway • Structural or other damage to the roadway requiring immediate response • Expected to last more than one hour

Source: Salt Lake City Incident Level Example.

duration of the incident, the amount of debris or dangerous goods spilled on the roadway, etc. This information may be organized into an incident severity level matrix that ranks degree of severity for an incident. An example of a simple incident severity level matrix is shown in Table 7, which illustrates the type of data that is critical in determining appropriate response levels.

Central Command Authority to Coordinate Response Activities

To accurately assess the severity of an incident, the critical data components must be communicated back to a central point of command. The creation of this "central command authority" provides the necessary structure to comprehensively assess these incident data components, coordinate the necessary emergency service and related agencies, and effectively manage the incident.

Most incident response efforts are coordinated on-scene by a central command authority. For example, a car fire incident would be commanded on-scene by fire services with the assistance of police and towing services. This type of centralized on-site command can minimize the degree of duplication of services on-site, and the number of personal conflicts regarding roles and management of an incident. In so doing, the overall duration of an event can be shortened. By maintaining contact with an off-site TOC, centralized command can best monitor on-site activities, devise traffic control and diversion strategies, provide dispatch services, and coordinate the tasks of the involved emergency service

Table 8 – Example Emergency Agency Response Matrix

Response Agency	Severity Levels			
	Low Traffic Impact		High Traffic Impact	
	No Dangerous Goods (Lowest)	Low-level Dangerous Goods	No Dangerous Goods	High-level Dangerous Goods (Highest)
MTO (including towing)	X	X	X	X
Police Services (OPP/Local)	X	X	X	X
Fire Services		X	X	X
Ambulance			X	X
Municipalities		X	X	X
Media Outlets			X	X
Ministry of the Environment				X

agencies. Maintaining contact with TOCs and other supporting services can be facilitated through the use of a shared-use mobile command-post vehicle with on-board systems to simplify communication.

Determining the Correct Response Level

Once the incident has been assessed by the central command authority, a number of questions must be answered. Who needs the information? What information do they need? How are the information best delivered? The degree of severity of an incident, and whether dangerous goods are involved, will determine the response level to an incident. Table 8 illustrates a simplified emergency agency response matrix. By visually representing the response requirements in this way, the central command authority can quickly determine the appropriate process and responsibilities.

6.3.3 The Role of ATMS in Incident Management Plans

The duration of an incident is comprised of several "stages". These stages include the incident-to-detection time, the detection-to-response time, the response-to-clearance time, and the recovery time (i.e., the time to restore normal operating conditions). ATMS-supported incident management plans are designed to reduce the duration of each of these incident stages.

It is very important to have comprehensive coordination and advance planning with emergency services. The response capabilities of emergency service agencies can be enhanced by the following ATMS features:

Incident-to-Detection Stage

The collection and storage of historical ATMS data provides valuable information about the "normal" conditions, and reasonable levels of variation in traffic conditions. A clear understanding of this data facilitates automated incident detection routines by defining what conditions fall outside of "normal" conditions.

Active monitoring of detection data, including operating incident detection algorithms and reports by cellular telephone users, ensures rapid detection of incidents.

Detection-to-Response Stage

TOCs are suited to compile and assess incident information derived from a number of inputs, such as CCTV, multiple driver reports, automatic detectors, patrol information, etc. The TOC can ensure timely and accurate analysis of incident information, as well as assist in assessing the necessary level of emergency service deployment and in preventing confusion with respect to information on secondary incidents.

Upon detection and analysis, the critical incident information is communicated to the appropriate emergency services by the TOC operators. Often, mobile data terminals located on-board emergency service vehicles are used to receive data transmitted from the TOC or from emergency service agency dispatchers to improve the speed and accuracy of communication. Having received only accurate and pertinent information, the emergency service providers can make an accurate assessment of appropriate response levels (e.g., number of vehicles, types of equipment, etc.).

ATMS services can reduce emergency services travel time to the incident scene in a number of ways. Accurate traffic condition information can be relayed to the emergency response vehicle, thereby allowing improved route selection. Route and local modifications to traffic signal control that give priority to emergency response vehicles can be triggered by on-board transponders, once detected by intersection-specific, wayside, or GPS systems.

During this stage, TOC operators can begin to implement diversion strategies to mitigate the effects of an incident. Through the use of local diversion plans, DMSs and other modes of traveller information dissemination, and modifications to traffic control devices, TOCs can influence motorist route selection to avoid the incident area over the course of its duration. This provides relief to congestion and the traffic control measures necessary at the incident site to manage traffic.

In the event of an incident involving a vehicle carrying dangerous goods, automated notification services can provide an immediate description of the dangerous goods to the appropriate emergency responders. There are various electronic systems that could assist in the identification of vehicles carrying dangerous goods, including automatic vehicle identification (AVI) and automatic vehicle location (AVL) technologies. These services can facilitate an appropriate level of response in this circumstance. Vehicle management systems can also provide accurate information regarding the number and location of available emergency vehicles. This would allow the appropriate emergency service agency dispatcher to send the first available vehicle to the incident site.

Response-to-Clearance Stage

By working with the centralized on-site command authority, TOC operators can assist in coordinating resources, monitoring the scene, and updating traveller information. For secondary incidents, TOC operators can provide detection, dispatch and co-ordination support services to the central command authority. Managing the traffic queue also entails watching for secondary collisions. Monitoring for blocking disabled vehicles and sending assistance to them can also support site management and reduce overall incident duration. If the anticipated duration of an incident is revised, TOC operators can work with the centralized command to revise the diversion route or incident response plan.

If closures or alternate routes are required, TOCs can play a role in identifying the optimal route, informing affected responders (and the media) and altering traffic control devices (e.g., traffic signals, ramp meters, etc.) in order to manage traffic at the incident site and on the alternate routes as effectively as possible.

Clearance entails more than getting disabled vehicles and debris off the roadway. It also means using TOC capabilities to clear the queue as quickly as possible once the roadway is clear. It can also mean assisting with actual cleanup and clearance. TOC operators can evaluate an incident and send the appropriate equipment for clearance as early as possible.

Collision Reporting Centres (CRCs) are designated locations off of the transportation network where minor collisions can be dealt with. In the event of non-injury collisions, where the vehicle is still mobile and safe to drive, involved parties may proceed to a CRC to exchange details and file a collision report. The use of a CRC reduces the length of time an incident is present on the roadway. This reduces the risk of secondary collisions as well as the impact of collisions and the associated non-recurrent congestion experienced (especially in areas where there are no shoulders) by reducing rubbernecking and ensuring that the lanes return to their full capacity as quickly as possible.

The duration of major incidents involving fatalities typically extends to several hours in order to facilitate police investigations. ATMS operating agencies should work closely with the police and other emergency services to develop strategies and procedures for minimizing the investigation and clearance times under these circumstances.

Recovery Stage (Restoration of Normal Operating Conditions)

The centralized command authority can work with TOCs to safely manage the return to normal operating conditions. Once central command has indicated it is safe to do so, the TOC operators can revise traffic control strategies, update traveller information, etc. Motorist information should continue to be disseminated after an incident is cleared and until traffic flow returns to normal conditions.

The collection of data on response times and procedures, traffic conditions, and actions taken during the event can help in revising and improving pre-determined incident response plans. This may also result in recommendations for operational improvements along diversion routes.

6.3.4 ATMS Roles in Disaster Command and Control

While ATMS-supported incident management concepts and systems can be applied to emergency management, they can also be considered for application in addressing large-scale disasters and events concerning national security. These events typically occur at random with little or no advance warning, and can induce extreme traffic demand under an evacuation condition caused by severe weather or other major catastrophe.

Response to large-scale terrorist acts requires all of the resources and strategies of traffic incident management across a large geographic area, where inter-agency coordination, communication and cooperation are critical. The TOC can serve as a disaster command and control centre, with TOC personnel and systems supporting the coordination and communication efforts, or providing support to the responsible emergency operations centre. The availability of adequate centre-to-centre communications is critical in this role to provide for the real-time exchange of data and video information between the TOC and related agencies or between the TOC and the emergency operations centre.

6.3.5 Coordination of Planned Special Events

Planned special events are an activity or series of activities that take place in known locations with scheduled times of occurrence and associated operating characteristics that are expected to have significant traffic impacts. These events may increase or disrupt the normal flow of traffic on freeway/arterial corridors serving the event venue location.

With the primary goals of ATMS being improvement in traffic flow management and reduction in congestion/delay, the various ATMS strategies discussed under Section 3.6, namely, incident management, congestion management, corridor/network management and travel demand management, can assist the responsible agencies in managing the special events. Depending on the type of event, the location of the event and the duration of the event, the situation room within the TOC can serve as the central "command post" or back-up support for the coordination of the special event in conjunction with police services, organizers of the event, etc. Due to the extent of the likely impact of some of the planned large scale events, the development of corresponding event management plans, similar to the incident management plan, is recommended for better coordination and efficiency.

Ontario Experience

MTO has been advocating the development of a major incident response team program as part of its COMPASS operations. Teams would be comprised of all emergency services, municipalities, and other relevant Ministries. MTO traffic operations representatives would be available on-site as part of a multi-disciplinary incident management team, and would maintain coordination with the TOC. These proposals were initially viewed by police and fire services as an intrusion into their respective domains of responsibility. However, there is an increasing sense among various parties that the participation of a qualified representative to address local and area-wide traffic issues would help the police and fire services to focus on responding to and clearing the incident.

Regional traffic control systems, such as MTO's COMPASS system operating on Highway 401 and the Queen Elizabeth Way, and the City of Toronto's RESCU system operating on the Gardiner Expressway, Lake Shore Boulevard, and the Don Valley Parkway, provide assistance to emergency vehicle management as part of their incident management responsibilities.

The COMPASS Traffic Operations Centre in Downsview served as the command post during the visit of Pope John Paul II to Toronto for World Youth Days in July 2002 and the Rolling Stones Toronto SARS Concert in July 2005.

6.4 Maintenance

The ATMS, as a complex real-time computer-based system, requires a full maintenance program throughout the life of the system in order to protect the significant investment made and to ensure that it remains fully operational.

Consideration should be made for a maintenance and system support contract as part of the implementation of the ATMS. This maintenance contract should clearly state a defects liability or "warranty" period, in the range of 12 to 24 months. During this period, the contractor is responsible for repairing or replacing any equipment or software failures that may emerge subsequent to relinquishing the system to the owner. In addition, provisions for routine corrective and preventive maintenance and planned upgrades, as well as emergency repairs that are not the responsibility of the main contractor, should be incorporated. Such events may include minor expansions to the field infrastructure, damage to the system caused by third parties (e.g., pole knockdowns, cable cuts, vandalism), system configuration, database management activities, etc.

The maintenance requirements should be developed to cover all elements of the system, including:

- Field devices and electronic equipment
- Communications system
- Central software and database
- Computer hardware and peripherals
- TOC facilities.

The contract should establish appropriate response times for various types of failures, both during and outside of normal working hours. A schedule of rates and prices for various products and services will be required, with penalties for non-performance. Due to their high exposure, DMSs and LCSs should have a shorter response time than other subsystems to maintain safe operation and a high confidence level among motorists.

One of the functional issues to be resolved during the specification writing process will be the requirement for maintenance access to the DMSs. Several options may be considered, including front or rear access via a catwalk along the gantry structure, or walk-in type sign enclosures. The preferred solution will be dependent upon specific agency safety requirements, availability of safe maintenance vehicle pull-off sites, and the desire to minimize the frequency and duration of lane closures for maintenance purposes. These solutions must be weighed against their installation costs. It is recommended that the contract includes maintenance provisions for an initial period of three or more years, with an optional extension by mutual agreement. At the expiry of that contract, it may be necessary to re-tender the maintenance services, possibly combining ATMS requirements with other similar agency systems.

Typical annual maintenance costs for similar systems are in the range of 5% of the installed capital base. In addition to annual maintenance costs, the life of the system components must be incorporated and the costs of upgrades and replacements included. In any economic analysis, the civil components should be assumed to last for a period of 25 years, the communications infrastructure for 15 years, and the electronic and software components for 10 years.

Warranties for the ATMS system should be integrated into the original ATMS implementation contract to avoid high costs for equipment replacement and system support due to system failures

6.5 Legal Issues

Various legal issues pertaining to ATMSs need to be addressed in order to protect the travelling public, system operators and private industry. New technologies and ways of doing business often raise questions about how groups will be protected and held responsible under existing law. The same issues can be seen in almost any segment of society where a significant change has taken place. Examples that are comparable to ITS include telecommunications and information technology. This discussion focuses on four categories of legal issues:

- Liability
- Privacy
- Intellectual Property
- Procurement Practices.

6.5.1 Liability

A significant risk to both government agencies and commercial vendors is legal liability. Any new technology or process raises questions pertaining to how the user can expect to be protected, and who is at fault if the system does not perform as expected. These systems present new sources of exposure to liability, and government agencies need to protect themselves. There is potential to legislate away liability, such as that in place for the protection of public servants in the course of doing their work. However, there is a tendency not to pursue this approach at the risk of public individuals losing their rights. Indemnity can be defined in specific agreements, however, there still remains the issue of general liability. There is also the potential for exposure to liability through partnerships, and organizations need to protect themselves from such liabilities in the event of a system failure.

6.5.2 Privacy

Another barrier to widespread adoption of certain technologies is privacy. Travellers may be concerned that traffic monitoring efforts may eventually lead to “Big Brother” tracking an individual’s daily movements. The primary approach to address this issue has been to develop methods for assuring privacy through anonymity. Furthermore, public agencies have been reinforcing the understanding that travelling on public roads is not a private activity. ITS America is proposing to use a protocol called Privacy Enhancement Protocol (PEP) for guaranteeing privacy by assuring anonymity of individuals while still allowing distinction between individual vehicles.

Requirements of legislation at the provincial and/or local level that protect the privacy of individuals and access to information need to be reviewed before initiating traffic monitoring-related programs to ensure policies and procedures are put in place to protect the privacy of private citizens, and that information collected is properly handled. Specific areas of concern include:

- Tracking of transponder-equipped vehicles for travel time monitoring;
- Identification and processing of violation enforcement by outside vendors; and
- Use and distribution of CCTV video recordings.

With respect to CCTV monitoring, ATMS operators routinely record video and distribute live video feeds to the media. Policies and procedures need to be established to control the non-traffic management related uses of the video. Specific measures can include blocking detailed incident images from media distribution, and avoiding zooming the camera to the extent that license plate or individuals are recognizable. As an exception to the latter example, some ATMS agencies exercise the authority to zoom in and record activity in the roadway corridor when criminal activity is suspected.

6.5.3 Intellectual Property

Many ATMS projects involve a commercial vendor developing a customized software and/or telecommunications package for a government agency. In some cases, the initiative may be a public-private partnership, while in others it may be a conventional customer-vendor arrangement. The development of technologies and processes and the collection of data raise intellectual property and ownership issues which can be challenging to address. Vendors are accustomed to retaining the rights to whatever they develop, while a government agency may (often by law) expect to retain the rights to anything developed using tax-payer funding. While some governments have faced these issues before, typically transportation agencies have little experience in this area. Furthermore, the rapidly evolving communications and information technology industries make the issue far more complicated.

Even in cases where a practical and mutually acceptable agreement on intellectual property can be reached, existing legislation may block such a deal. Existing provincial government policies stipulate that if the province pays for development, they own the intellectual property. There is little flexibility to accommodate joint ownership. Existing laws and procurement policies were not developed with the needs and circumstances of ATMS and other information technology applications in mind. The process of modifying laws to both protect the public, and facilitate and encourage ATMS projects with intellectual property issues, can be extremely time-consuming.

6.5.4 Procurement

Public sector departments active in ATMS are typically limited in their flexibility with respect to procurement policies and mechanisms. Agencies are typically restricted to public tender and request for quotation (RFQ)/request for proposal (RFP) processes for procurement. For transport authorities, these processes are typically oriented towards hard engineering for infrastructure development and may not provide the flexibility for innovative multi-agency ATMS applications. Agencies dealing with ATMS need some degree of flexibility and autonomy to pursue these innovative solutions, while still maintaining and demonstrating open and fair procurement practices.

6.5.5 Ontario Experience

At the City of Toronto, operators use the CCTV cameras to obtain close up views of an incident or collision. The video images captured are archived. Images that show the person or license plate of the vehicle involved are not released to the media or external agencies. This also helps with any litigation placed against the camera-operating agency for revealing personal information.

The experience with legal issues to date for Ontario ATMS programs yields the following observations:

- Legislation is required to provide the flexibility for the public sector to readily enter into innovative partnerships with the private sector for ATMS development and deployment.

- It is important to have well defined contractual terms and conditions and operating procedures pertaining to the use and distribution of information collected by an ATMS.

- A comprehensive public information process needs to be established to address inquiries from the public pertaining to privacy and enforcement.

7. Evaluation of ATMS

7.1 Overview of Evaluation

The design, implementation and operations of any ATMS will require the commitment of various resources. Such resources include staff time, technical expertise, funding, etc., all of which represent an investment by the agency in ATMS. In order to determine the value of the investment to the agency and the general public, the relative priority the investment in ATMS holds with respect to other demands on public funding, and the components or types of ATMS that can be justified, an evaluation of the proposed system and its alternatives should be undertaken. This evaluation will provide information that can be used to formulate the most cost-effective ATMS, as well as help to gain support from senior management, decision makers and the general public.

Various typical evaluation techniques available for ATMS alternatives are discussed below.

7.1.1 Benefit-Cost Analysis

This technique compares the economic effectiveness of ATMS alternatives on the basis of total transportation costs, including capital cost, operating cost, maintenance cost, vehicle delays, travel time cost, etc. The associated cost criteria include:

- Benefit-cost ratio
- Rate of return
- Net present value
- Equivalent uniform annual cost.

It is generally recognized that ATMS applications are effective in facilitating better utilization of existing transportation infrastructure and can generate such benefits as relieving congestion, increasing traffic throughput, and improving traffic safety and air quality. However, the methodologies and data to quantify the effectiveness and benefits of such applications are not well documented, and the majority of benefits may not be realized under an individual project, but arise from the integration of projects. For example, the provision of monitoring devices or communications infrastructure may benefit a number of ATMS applications planned for implementation over a number of years, but may be difficult to justify under the initial project. Benefit-cost analysis may have to be addressed from an integrated or overall system perspective.

7.1.2 Performance Rating Tables

This technique simply rates the performance or usefulness of alternative systems with a low, medium or high score. Typically, the scores only reflect the perceived or anticipated performance of the components or alternative systems.

7.1.3 Linear Scoring Function Tables

Similar to the performance rating table, this technique rates and compares alternatives. Each alternative is assessed with an initial score, from 1 (lowest) to 10 (highest) against each evaluation factor. This score is then multiplied by the relative weight given to that factor. The best alternative is the one that accumulates the most points.

7.1.4 Incremental Analysis Technique

The above-mentioned techniques are based on the assumption that although the life cycle cost of an ATMS can be measured in monetary terms, the effectiveness of these costs towards the system's goals and objectives is best described in qualitative terms. A refinement to the evaluation technique is to divide the implementation of the system into stages and develop incremental benefit-cost ratios or ratings for each of the stages. The incremental analysis technique is very useful in evaluating complex and large-scale transportation investments.

7.1.5 Discussion

The selection of an evaluation technique should be based on data availability, the availability of resources, and the level of detail required for decision making. The evaluation must also rely on judgement and local experience to generate the most appropriate assumptions for the analysis. Sensitivity analysis can also be employed in the final analysis to reduce the effects of inherent uncertainties, including the rapid change of technology, the estimated benefits from simulation models, etc.

7.2 Measures of Effectiveness

Advanced traffic management systems are always designed and implemented to meet the specific goals and objectives of the area. In order to evaluate the degree of success of the ATMS in meeting these goals and objectives, a set of Measures of Effectiveness (MOEs) must be developed. These MOEs are very useful in the determination of when system expansion and possible system enhancements are required.

The MOEs must be defined in a manner so that the operation of the system can be quantitatively described and/or estimated. They should also be specified in an appropriate level of detail so that data collection and analysis are possible. The Ministry of Transportation Ontario has developed a set of typical MOEs for ATMS evaluation which are summarized in Table 9.

The Ministry of Transportation Ontario's *Ontario ITS Strategies Framework Study and Five Year COMPASS Implementation Plan* incorporates an evaluation of the potential projects for the geographic expansion of COMPASS. A comparative evaluation of the candidate segments has been conducted using the following criteria:

- *Cost* – based on the estimated present value of capital costs only, as operation and maintenance costs are usually estimated based on a percentage of the capital costs;

- *Congestion and Environmental Priority* – based on the delay savings benefits, which are also representative of fuel savings and reduced collisions, as well as environmental benefits from reduced greenhouse gases;

- *Safety Priority* – quantified in terms of reduction in secondary collisions;

- *Benefit-Cost Ratio* – based on benefit and cost estimations;

- *Length* – based on the length of the proposed sections, since the longer the length, the greater the COMPASS coverage and resultant area-wide network management improvements;

- *Proximity to Existing COMPASS Projects* – based on spatial proximity of the proposed COMPASS projects with existing COMPASS systems. This reflects the potential cost savings associated with making use of existing operation centres and better network management, data sharing, and coordination among various components; and

- *Special Situations* – used to factor in a number of different characteristics that are important considerations for expansion, such as existing provision, planned construction activities, political reasons and strategic network links.

Table 9 – Typical Measures of Effectiveness (MOEs) for ATMS

Objectives	Measures of Effectiveness (MOEs)
Increase corridor traffic throughout	• Monthly average daily traffic (veh/day) • Highest hourly volume per lane (veh/hr/lane)
Increase average travel speed	• Monthly average peak period speed (km/h) for 08:00 to 09:00 and for 17:00 to 18:00
Reduce vehicle delays	• Total monthly vehicle-hours of delay (veh-hours) • Time when travel speed is less than 70 km/h (minutes)
Decrease average travel time	• Average travel time at 08:00 and at 17:00 for a specific roadway section (minutes)
Increase utilization and effectiveness of DMS	• Number of non-default messages displayed per sign per day
Reduce number of collisions	• Total number of confirmed incidents
Improve incident detection system	• Percentage of incidents detected by system • Percentage of incidents detected manually • Percentage of false alarms
Reduce incident duration	• Total duration of incident (minutes) • Average duration of incident (minutes) • Incident detection time (minutes) • Response time to incident (minutes) • Incident clearance time (minutes)
Increase field equipment utilization	• Percentage of VDS controller-hour availability • Percentage of DMS controller-hour availability
Reduce secondary incidents	• Number of secondary incidents
Reduce vehicular delay due to incident reduction and delay reduction	• Average delay (veh-hr)
Improve quality of traffic flow	• Travel time index • Averaged speed (km/h) • Acceleration/deceleration ratio
Improve driver response (diversion) to DMS messages	• User perception to the sign • Message accuracy of the sign

7.3 Evaluation and Ongoing Bench-Marking

For each ATMS, the Measures of Effectiveness (MOEs) are not only important in determining the success of the system deployment, but also for the ongoing evaluation and bench-marking. As such, resources and funding must be planned to undertake data collection and an evaluation program over time.

In addition to the monitoring of the MOEs, there are also other factors to be considered and evaluated for the system expansion and/or migration. These factors are discussed in the following sections.

7.3.1 Quality of Service Evaluation

The quality of service should be measured, not just by the number of effectual services delivered to the public, but also in relation to the cost of delivering these services. There are no fixed rules and practices for determining the final correct combination of actions to be executed, however, some general guidelines should be considered.

Changes to an Existing System Versus Acquiring a New System

Changes to an existing system to achieve new functions can become more and more difficult as a system ages, due to a lack of original design information or a legacy platform. Planning for the next change and any subsequent changes is therefore important when deciding whether or not to proceed with a current change. An assessment must be made to determine the cost over the useful life of the system versus acquiring a new system.

Operational Versus Maintenance Cost

When considering keeping the existing system versus acquiring a new system, one must include the operational as well as the maintenance cost of both scenarios. Usually, the old system in operation has a high maintenance cost because of the associated legacy equipment. Additionally, an improvement in operation can usually be associated with a new system. Therefore, it is important that these costs are evaluated against the initial high capital cost for the new system.

Quality of Services to the Public

Another criterion for determining the final correct combination of actions is the actual level of service provided to the public. There are usually measures for calculating benefits to the public. For example, average hours for motorists stuck in traffic congestion can be associated with a total cost to motorists for loss of time.

Parameters like the aforementioned criteria can be employed wherever possible to derive an evaluation strategy.

7.3.2 Communications System

The life of a communications system is limited. The agency should regularly evaluate the performance of the communications system to ensure it meets requirements. The evaluation should include the following parameters:

- Performance
- Maintenance costs
- Ability to meet new requirements.

The decision to replace the communications system should be made prior to the system failing, since the communications system is essential for the operation of the system, and the design and upgrade requires significant time.

Performance

As the equipment ages, components will begin to degrade or fail. Ongoing maintenance activities can repair the failed components, providing a level of performance equal to the original system operation. As the equipment reaches its design life, however, the ability to maintain the same performance level will be reduced. To ensure that the system maintains the desired performance, the following major components should be evaluated on an ongoing basis. Experience shows that it will be useful to keep track of performance by recording and analyzing the component, subsystem and system reliability and availability data, including mean time between failures (MTBF) and mean time to repair (MTTR).

Cable Testing
If the agency owns the cable plant, yearly testing should be conducted to determine if degradation in the cable plant is occurring. The results of the previous year's tests should be compared to the

most recent to determine if any degradation has occurred. A benchmark should be set to determine the level of performance at which the cable plant should be replaced.

Cable would typically be replaced on a system-wide basis although, if only a specific section has been damaged, it could be designated for replacement.

The nature of the tests to be conducted will depend on the communications medium but should include:

- Sweep tests conducted on the coaxial cable;
- Optical time domain reflectometer (OTDR) and attenuation tests conducted on fibre optic cable; and
- Frequency response and attenuation tests conducted on twisted wire pair cable.

Data System Testing
Data transmission failures are typically logged by the central software, and no special testing is required to monitor channel performance. For ongoing maintenance, personnel respond to failures in the network and repair the equipment based on detailed diagnostic procedures. The need to replace the communications system should be based on any inability to resolve recurring failures and low availability rates.

Video System Testing
The operation of the video transmission system is based upon observation of the video performance by the operators. Distortion or noise in the signal is reported to maintenance personnel for correction. The need to replace the system should be based on any inability to resolve recurring failures or low availability rates.

Maintenance Costs

The second factor in determining communications network replacement is the maintenance costs associated with the system. Maintenance costs consist of:

- *Staff Time Associated With Correcting Faults* – As the network degrades, the staff time needed to troubleshoot and repair equipment increases.
- *Spare Parts Replacement* – The requirement for spare parts increases as the failure rate increases. As the system ages, the ability to source spare parts becomes more difficult, with associated higher costs. In the traffic control industry, communications systems are typically based on proprietary equipment resulting in only one vendor being able to supply and maintain the equipment. An example of this is the RF modems supplied for the coaxial cable systems.
- *Leased Costs* – The cost of certain leased services, such as analogue circuits, has increased since the telephone company is no longer interested in supplying this type of service. Other service offerings may be more cost-effective.

The decision to replace the system requires an analysis of the cost to maintain versus the capital cost of replacement.

Ability to Meet New Requirements

The third factor in determining equipment replacement is the ability of the existing system to support expansion requirements and new features desired for system operation. As ITS systems mature, new features and equipment are added to the functionality of the system, which must be supported by the communications system. The upgrade evaluation of the communications system must address the following:

- *Expansion Capability* – The communications system should be evaluated to determine the spare capacity of the system and the ability to meet future requirements.

- *Ability to Support New Subsystems* – These new subsystems will increase the number of channels and loading on the communications system. For regional traffic control systems, this could include ramp metering, queue warning and toll tag readers. For surface street control systems, this could include CCTV and DMSs.

- *Ability to Support New Protocols* (i.e., NTCIP).

- *Ability to Support Different Communications Interfaces* (e.g., Ethernet) – The older systems do not typically have the ability to provide the new interfaces and data rates necessary to support the new equipment controllers and their associated interfaces.

In summary, the communications system performance should be analyzed in an ongoing manner to ensure that the objectives of the ATMS system are maintained. This analysis should include current performance, maintenance costs and the ability to meet new requirements.

8. Integration with Other Systems

Intelligent Transportation Systems (ITS) is defined as the application of advanced and emerging technologies (computers, sensors, control, communications and electronic devices) in transportation to save lives, time, money, energy and the environment.[6] With this definition, ITS encompasses a broad range of applications, covering all modes of road-based transportation, including private automobiles, commercial vehicles, public transportation, bicycles, pedestrians, etc. The term "ITS" also includes consideration of the vehicle, the infrastructure, the driver and the user of the transportation system.

With such a broad range of applications of leading-edge technology, an extensive array of opportunities for integration presents itself, namely, integration between systems and across modes and jurisdictions that allows sharing of information and joint use of infrastructure for multiple purposes. This integration of technologies and systems not only allows for a more cost-effective approach to the implementation and operation of ITS, but significantly increases the benefits that can be achieved through the use of technology to better manage transportation networks.

The integration of systems requires a framework or architecture that identifies all of the potential opportunities and how this can be achieved. The ITS Architecture for Canada was developed for this purpose and to serve as a framework to assist jurisdictions in the planning, design and implementation of their ITS systems.

[6] *ITS Canada website.* http://www.itscanada.ca/english/aboutits.htm

The *ITS Architecture for Canada* is a product of the 1999 Federal Government *ITS Plan for Canada entitled "En Route to Intelligent Mobility"* (Transport Canada, 1999). In this document, the architecture is described as the communication and information backbone that unites key ITS initiatives enabling them to communicate with each other, and a framework that identifies the requirements for supporting integration of functions and inter-operability across specific applications, modes and jurisdictions. As a jurisdiction develops its ITS program, the intent is to use this framework as a tool in the planning, design and implementation of their ITS systems. This tool will help the local transportation authority to think of the "big picture", the functions each application performs, and how these applications can work together with existing systems to meet both current and future needs.

In this section, various user services of the ITS Architecture for Canada are discussed and potential opportunities for integration with ATMS applications identified. For more information on the ITS Architecture for Canada and the related user services, the reader is referred to Transport Canada's website (www.its-sti.gc.ca/Architecture/).

8.1 ATMS Integration with Traveller Information Services (ATIS)

Traveller information consists of services designed to use advanced systems and technologies to manage information and help travellers decide when to travel, the mode and route to take, as well as provide assistance in arranging ridesharing and providing information for a variety of traveller-related services and facilities. It integrates information from various modes and sources for decision-making purposes and consists of:

- *Real-time Traveller Information Services* – Provide travellers with information prior to their departure and en-route through a variety of personal and in-vehicle devices to assist them in making mode choices, travel time estimates, and route decisions.

- *Route Guidance and Navigation Services* – Provide travellers with instructions on turns and other manoeuvres to reach selected destinations. In a simple form, a user would input a destination and be provided with a fixed recommended route. In a more dynamic mode, the user would receive instructions on route selection as he/she proceeds to the destination. This could include information that takes into account traffic conditions.

- *Ride-Matching and Reservation Services* – Expand the market for carpools and vanpools by providing real-time ride-matching information along with reservations and vehicle assignments.

- *Traveller Services and Reservations* – Provide the traveller with access to "yellow pages" type information regarding a variety of travel-related services and facilities. The information will be accessible to the traveller in the home or office to support pre-trip planning and while en-route through in-vehicle devices or public facilities, such as public transit terminals or highway rest stops.

The integration of ATMS and traveller information is fundamental to the success of both of these ITS applications. ATMS utilizes vehicle sensors to monitor traffic conditions, and CCTV cameras for monitoring purposes and verification of incidents. Sharing of traffic and incident information provides a source of real-time data for traveller information purposes, thereby improving the ability of ATIS to disseminate accurate and reliable information on a timely basis. The broad distribution of this information through traveller information devices also provides benefits to the ATMS applications by providing advanced warning of unusual traffic conditions, encouraging traffic to divert to other routes, balancing traffic between corridors, and ultimately providing the ability to better manage the overall transportation network.

8.2 ATMS Integration with Advanced Road Weather Information Services (ARWIS)

Traffic management services within the ITS Architecture for Canada consists of a broad range of user services designed to use advanced systems and technologies to improve the efficiency and operation of the existing surface transportation infrastructure, as well as create safer conditions for travellers. This user service is the focus of this manual and the majority of traffic management applications are well documented within this book.

Advanced road weather information systems (ARWIS) monitor current road and weather conditions using a combination of weather service information and data collected from environmental sensors deployed on and about the roadway. The collected road weather information is monitored and analyzed to detect and forecast environmental hazards, such as icy road conditions, dense fog, and approaching severe weather fronts. This information allows road maintenance staff to respond to weather conditions in a planned and pro-active manner. This includes enabling road maintenance staff to make better informed decisions in the deployment of resources and the selection of de-icing materials.

The integration of ARWIS and ATMS allows data sharing between these systems that can be used for a number of purposes including:

- Providing ATMS operators with information on surface conditions, which in turn may be used to adjust traffic control strategies (e.g., signal timing plans), increase monitoring of select corridors for incident detection, etc.; and
- Providing road maintenance staff with access to real-time traffic information and congestion levels, as input to snow plow operation and route optimization as part of their fleet management systems.

8.3 ATMS Integration with Advanced Public Transport Services (APTS)

Public transport services include urban, suburban and rural transit in fixed route, route deviation and demand-responsive modes operated by bus, heavy rail, light rail, commuter rail, van, carpool, or shared ride taxi. All forms of short distance transportation not involving a single occupant automobile benefit from these services which include:

- *Public Transport Management* – Applies advanced vehicle electronic systems to various public transportation modes, and uses the data generated by these systems to better manage the operation and maintenance of the vehicles, planning and scheduling of routes and scheduling personnel in order to improve the level of services provided to the customer. It includes vehicle tracking, real-time schedule information, fleet management, multi-modal connection protection, etc.
- *En-route Transit Information* – Provides travellers with real-time transit and high-occupancy vehicle information allowing travel alternatives to be chosen once the traveller is en-route. This user service integrates information from different transit modes, and presents it to travellers for decision making.
- *Demand Responsive Transit* – Involves the use of technology to flexibly route transit vehicles from their pre-established route to pick up or discharge passengers in order to provide more convenient service to customers.
- *Public Travel Security* – Supports innovative applications of technology to improve the security of public transportation. Security concerns include protecting transit patrons and employees from street crime, maintaining an environment of actual and perceived security, and developing innovative technical measures to respond to incidents.

The opportunities for integration between ATMS and APTS applications are significant, and are primarily related to the sharing of traffic and incident information. Examples include:

- Provision of ATMS traffic congestion and incident information to the transit fleet management systems. This information can be used to estimate bus arrival times for real-time passenger information systems, optimize routes for demand responsive transit, and assist transit dispatchers in re-routing buses in the event of a major incident.

- Use of vehicle tracking information from the APTS to provide transit signal priority through the ATMS. This can be conducted for individual intersections, as well as for routes incorporating multiple signalized intersections. It can also incorporate variable levels of signal priority depending on whether the transit vehicle is full/empty, ahead/behind schedule, etc., when it is interfaced with real-time schedule information and automated passenger count systems.

- Use of buses as vehicle probes to monitor traffic conditions or as a method of detecting incidents to supplement ATMS and its ability to monitor conditions on the arterial street network. Information can be obtained through driver supplied information (e.g., verbal reports, text messages, etc.) or using vehicle location technology (e.g., GPS).

- Sharing of video images from security cameras at transit stations and major transfer points to supplement ATMS CCTV systems, and increase the ability to verify incidents within the transportation network.

8.4 ATMS Integration with Electronic Payment Services

The electronic payment user service allows travellers to pay for transportation services by electronic means. This includes such applications as electronic toll collection, electronic fare collection, electronic parking payment, and electronic payment services integration. It may also serve broad non-transportation functions, and may be integrated with credit and debit cards in banking and other financial transactions.

Opportunities for integration between electronic payment services and ATMS primarily relate to the joint use of in-vehicle devices that allow electronic payment equipped vehicles to be used as vehicle probes to monitor traffic conditions. The transponder identification number is used to track individual vehicles between reader locations as a measure of link speeds and travel times. This however requires the cooperation of the owner of the transponder.

8.5 ATMS Integration with Commercial Vehicle Operations (CVO)

Commercial vehicle operations is concerned primarily with freight movement and focuses on services which improve private sector fleet management, freight mobility, as well as streamline government/regulatory functions. This includes:

- *Commercial Vehicle Electronic Clearance* – Consists of both domestic and international border electronic clearances. Domestic electronic clearance allows commercial vehicles to continue past inspection stations without stopping. International border clearance allows vehicles to bypass international border checkpoints without stopping, or at least with expedited checks. As a vehicle approaches an inspection station or checkpoint, vehicle-to-roadside communications take place that identify the vehicle and make available to authorities the necessary data about credentials, vehicle weight, safety status, cargo, and occupants. Enforcement personnel can then select potentially unsafe or non-compliant vehicles for inspection and allow safe and legal vehicles to bypass the inspection station/checkpoint.

- *Automated Roadside Safety Inspection* – Provides automated inspection capabilities that check safety requirements more quickly and accurately during a safety inspection that is performed when a vehicle has been pulled off the highway at a fixed or mobile inspection site. An example would be a rolling dynamometer which checks brake performance.

- *On-board Safety Monitoring* – Provides the ability to sense the safety status of a vehicle, cargo, and the driver at mainline speeds. Driving time and driver alertness would typically be the type of conditions sensed for a driver. Warnings or indications of the safety status are provided to the driver. This data would also be provided to the carrier, and to enforcement authorities.

- *Commercial Vehicle Administrative Process* – Includes systems that allow the carriers to track and monitor vehicle location and operations, and automatically generate reports required to purchase commercial vehicle credentials. This includes automated mileage and fuel reporting, electronic purchase of credentials, and international border electronic clearance.

- *Intermodal Freight Management* – Provides the ability to monitor the location and status of freight in-transit and at freight terminals.

- *Commercial Fleet Management* – Provides real-time communications for vehicle location, dispatching and tracking between commercial vehicle drivers, dispatchers and intermodal transportation providers, thereby providing dispatchers with real-time information on freight location and estimated time of arrivals, and providing drivers with the ability to receive routing information en-route in response to congestion, incidents or changes in pick-up locations. Commercial fleet management includes the management of taxi fleets.

The opportunities for integration between CVO and ATMS are similar to the opportunities discussed under electronic payment with the joint use of in-vehicle devices and vehicle location information to enable the use of the commercial vehicles as vehicle probes to estimate link travel speeds and/or travel times as a method of measuring traffic conditions, locating areas of congestion/ incidents, etc.

8.6 ATMS Integration with Emergency Management Services

Emergency management includes services that relate directly to the detection, notification and response by emergency service agencies to traffic incidents. This includes:

- *Emergency Notification and Personal Security* – Provides the capability to automatically or for a user to manually initiate a distress signal for incidents like mechanical breakdown or non-injury collisions. The signal would automatically include information regarding the location, nature and severity of the collision to an emergency service agency dispatcher and/or to hospital and emergency room personnel.

- *Hazardous Materials (HAZMAT) Incident Response* – Provides cargo-related information to emergency response agencies at the scene of an incident.

- *Disaster Response and Management* – Coordinates disaster response strategies from a virtual control centre, and disseminates information to agencies and individuals on traffic conditions, diversion routes, etc.

- *Emergency Vehicle Management Service* – Reduces the time from the receipt of notification of an incident by an emergency service agency dispatcher, and the arrival of emergency response vehicles on the scene. It includes emergency vehicle fleet management, route guidance to the incident scene or a suitable hospital, and pre-emption of traffic signals on an emergency response vehicle's route to receive more green display.

The opportunities for integration between ATMS and emergency management applications are similar to those discussed under APTS, and are primarily related to the sharing of traffic and incident information. Examples include:

- Provision of ATMS traffic congestion and incident information (including CCTV images) to the emergency response agency's dispatcher and computer-aided dispatch system. Details of the incident could help the dispatcher to better assess the incident, and establish the equipment and personnel to dispatch to the scene. The sharing of real-time traffic information with the emergency fleet management system would allow the system to select routes for the emergency response vehicles based on shortest travel time using current traffic conditions.

- Use of vehicle tracking information from the emergency fleet management system to provide transit signal priority through the ATMS. This can be conducted for individual intersections as well as for routes incorporating multiple signalized intersections.

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Appendix A – Definitions

Acronyms

AADT	Annual Average Daily Traffic
ADSL	Asymmetric Digital Subscriber Line
AGC	Automatic Gain Control
AGPS	Assisted Global Positioning System
AID	Automatic Incident Detection
AMC	Area Maintenance Contractor
APID	All Purpose Incident Detection
APTS	Advanced Public Transport Systems
ARWIS	Advanced Road Weather Information Systems
ATC	Advanced Traffic Controller
ATIS	Advanced Traveller information Systems
ATM	Asynchronous Transfer Mode
ATMS	Advanced Traffic Management Systems
AVI	Automatic Vehicle Identification
AVL	Automatic Vehicle Location
AWG	American Wiring Gauge
CATV	Cabled Television
CAD	Computer Aided Dispatch
CC	Camera Control
CCD	Charged Coupled Device
CCIR	Canadian Council of Insurance Regulators
CCTV	Closed Circuit Television
CDPD	Cellular Digital Packet Data
CO	Carbon Monoxide
CORBA	Common Object Request Broker Architecture
CRC	Collision Reporting Centres
CPU	Central Processing Units
CTCS	Centralized Traffic Control Systems
CVO	Commercial Vehicle Operations
CW	Continuous Wave
DAB	Digital Audio Broadcast
DCS	Digital Communications Service
DES	Double Exponential Smoothing
DHV	Design Hour Volume
DMS	Dynamic Message Signs
DSRC	Dedicated Short Range Communications
ETC	Electronic Toll Collection
FHWA	U.S. Federal Highway Administration
FTMS	Freeway Traffic Management Systems
GIS	Geographic Information Systems
GPS	Global Positioning System
GTA	Greater Toronto Area
GUI	Graphical User Interface
HAR	Highway Advisory Radio
HCM	Highway Capacity Manual
HOT	High Occupancy Toll
HOV	High Occupancy Vehicle
IEC	International Electrotechnical Commission
ILD	Inductive Loop Detection
IP	Internet Protocol
ISO	International Organization for Standardization
ISP	Information Service Providers
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
JPEG	Joint Photographic Experts Group
KHGSPM	King's Highway Guide Signing Policy Manual
LAN	Local Area Network
LCS	Lane Control Signs
LED	Light Emitting Sign
MM	Multi-Mode
MOEs	Measures of Effectiveness
MPEG	Motion Picture Experts Group
MTBF	Mean Time Between Failures
MTO	Ministry of Transportation Ontario

MTTR	Mean Time To Repair
MUTCD	Manual of Uniform Traffic Control Devices
NOx	Oxides of Nitrogen
NTCIP	National Transportation Communications for ITS Protocol
NTSC	National Television System Committee
OPP	Ontario Provincial Police
OTDR	Optical Time Domain Reflectometer
OTM	Ontario Traffic Manual
PATREG	Pattern Recognition
PEP	Privacy Enforcement Protocol
PVMS	Portable Variable Message Signs
QEW	Queen Elizabeth Way
QWS	Queue Warning Systems
RESCU	Road Emergency Services Communications Unit
RF	Radio Frequency
RFP	Request for Proposal
RFQ	Request for Quotation
RMS	Ramp Metering Systems
ROW	Right-of-way
RTA	Roads and Traffic Authority of New South Wales
SCATS	Sydney Coordinated Adaptive Traffic System
SCOOT	Split Cycle Offset Optimization Technique
SM	Single-Mode
SMPTE	Society of Motion Picture and Television Engineers
SND	Standard Normal Deviate
TCP	Transmission Control Protocol
TDM	Travel Demand Management
TOC	Traffic Operation Centres
TRRL	Transport and Road Research Laboratory
UPS	Uninterruptible Power Supply
UMTS	Universal Mobile Telecommunications System
UTP	Unshielded Twisted Pair
V/C	Volume-Capacity Ratio
VCR	Video Cassette Recorder
VDS	Vehicle Detection Systems
VID	Video Image Detection
VIP	Video Image Processing
VRC	Vehicle-to-Roadside Communications
WIM	Weigh-in-Motion

Definitions

A

Advanced Public Transport Systems (APTS)
The application of advanced electronic and communications technologies to improve the safety and efficiency of public transit systems. See also Intelligent Transportation Systems (ITS).

Advanced Road Weather Information Systems (ARWIS)
These systems monitor the current road and weather conditions using a combination of weather service information and data collected from environmental sensors deployed on and about the roadway. The collected road weather information is monitored and analysed to detect environmental hazards, and used to more effectively deploy road maintenance resources and issue general traveller advisories.

Advanced Traffic Management Systems (ATMS)
Systems using high-technology devices, on both freeways and urban streets, to more efficiently manage traffic. These include roadside sensors, ramp metering, cameras, dynamic message signs, HOV lanes and synchronized traffic signals that respond to traffic flows.

Advanced Traveller Information Systems (ATIS)
This system provides travellers with information to help in trip planning and changing course en route to bypass congestion, e.g., broadcast traffic reports, in-car computerized maps and highway DMSs. Also can include automated transit trip planning and automated rideshare matching.

Automatic Incident Detection (AID)
Automatic Incident Detection systems analyze traffic data using algorithms to quickly and automatically detect incidents in order to improve the incident response time. Algorithms can be based on a variety of strategies and techniques.

C

Catastrophe Theory Approach (McMaster Algorithm)
The Catastrophe Theory Approach is a technique used in Automatic Algorithm Detection. The algorithm uses traffic flow theory and Catastrophe Models to forecast expected traffic conditions on the basis of current traffic measurements for incident and congestion detection.

Commercial Vehicle Operations (CVO)
The application of advanced electronic and communications technologies to improve the safety and efficiency of commercial vehicle/fleet operations. See also Intelligent Transportation Systems (ITS).

Comprehension
The ability of drivers to understand the meaning of a sign message, including any symbols or abbreviations.

Congestion Management
Congestion Management is an ATMS strategy designed to mitigate the impacts of recurring and non-recurring congestion. Components include congestion monitoring, pre-trip and en-route advisory, lane management, and ramp metering.

Conspicuity
The ability of a traffic control device to attract or command attention, given the visual setting in which it is placed.

Corridor Management
The process of managing and controlling traffic between/among parallel roads within a corridor.

D

Dynamic Message Sign (DMS)
An array of sign technologies that have the capability of displaying different messages to suit changing conditions on the roadway. Included within the family of Dynamic Message Signs are full-matrix displays, single line or character-matrix displays, multiple pre-set message displays and simple on-off or “blank-out” displays. The terms “Changeable” and “Variable” are used in the OTM to describe specific sub-sets of Dynamic Message Signs.

E

Emergency Agency Response Matrix
The Emergency Agency Response Matrix is a tool used to aid in Incident Management. The matrix consists of the various agencies involved on one axis, and the level of severity on the other axis. By visually associating the response requirements in this way, the central command authority can quickly determine the appropriate process and responsibilities.

F

Fault Monitoring
Equipment is continuously monitored for failure. When a fault is detected, an alarm is raised, the fault is categorized, and the appropriate action is taken.

Fuzzy Logic Approach
A mathematical technique for dealing with imprecise data and problems that have many solutions rather than one.

H

Headline Incidents
Incidents that tend to attract a significant amount of media attention, such as severe collisions, dangerous goods spills, and traffic incidents involving fatalities or heavy vehicles.

I

Incident
An incident may be any of the following: traffic collision, stalled vehicle, load spillage, or other action that affects one or more lanes of traffic. A collision typically involves a moving vehicle striking or being struck by another vehicle, person, or object.

Incident Management
The goal of Incident Management is to provide early detection and response to unscheduled events. The components are incident detection/confirmation, emergency response/motorist assistance, and pre-trip and en-route advisory.

Incident Severity Level Matrix
The Incident Severity Level Matrix is a tool used to aid in Incident Management. The matrix contains several levels of severity with the associated characteristics. This allows for incidents to quickly be ranked by severity so that the appropriate response can be implemented.

Intelligent Transportation Systems (ITS)
A wide range of advanced electronics and communications technologies applied to roads and vehicles, designed to improve safety and decrease congestion. When the term is applied to transit, it is called APTS; in commercial trucking, it is referred to as CVO.

L

Lane Management
Lane management involves the restriction of specific lanes of a roadway to designated vehicle types, direction of travel or other purposes. It involves the use of Lane Control Signs (LCSs) and a central control and monitoring system. The primary objective is to maximize the capacity of existing roadway infrastructure for specific vehicles or to alter a direction of travel.

Legibility
Sign legibility is governed by the distance at which the sign becomes legible and the duration for which it remains legible. Legibility depends on character, word and line spacing, character height, font, contrast ratio and clarity of symbols.

Light-Emitting Diode (LED)
Light-emitting diode or LED VMSs are currently the preferred type of light-emitting sign technology. The pixels for LED signs are comprised of multiple light emitting diodes, which are solid state electronic devices that glow when a voltage is applied. Adjusting the voltage that is transmitted to each pixel controls the intensity of the light emitted from each LED pixel.

N

National Transportation Communications for ITS Protocols (NTCIP)
A family of communication protocols developed, or being developed, for the transportation community.

Network Management
Network Management is an ATMS strategy designed to balance the level of service within the network as a function of current conditions.

Neural Network Approach

(1) A non-linear approach used for designing traffic applications.

(2) A non-linear mapping between a set of input and output. For example, the approach can associate patterns in traffic data with various traffic conditions. It offers an advantage over conventional incident detection algorithms in that no mathematical model of traffic operation or incident detection process is required, thus eliminating the imperfection in model formulation.

NO_x
Oxides of nitrogen.

P

Pattern Recognition Approach
Pattern recognition is a technique used in Automatic Incident Detection. Algorithms compare traffic parameters between upstream and downstream detector stations.

Pixel
An individual dot of light that is the basic unit from which the images on a variable message sign are made.

Portable Variable Message Sign (PVMS)
Portable signs typically have the same functionality and basic design as fixed location Variable Message Signs and can be comprised of discrete characters or full matrix arrangements.

Q

Queue Warning System (QWS)
Queue Warning Systems are designed to provide advanced warning of stopped or slow-moving traffic. The systems, also referred to as Queue-End Warning Systems, usually consist of Vehicle Detection Systems, Dynamic Message Signs, communications and controller hardware, and use an algorithm to determine the queue-end location.

R

Ramp Metering
A system used on a freeway or expressway entrance ramp in which the rate of entry of vehicles onto the freeway is metered by a traffic signal; the signal allows one vehicle to enter on each green indication or green flash. The operation of the metering signals is normally carried out only during rush hours and in a preferred direction (normally toward the Central Business District (CBD) in the morning and outbound from it in the evening).

S

Secondary Incidents
When an incident occurs, there is an increased risk that additional, secondary incidents will occur due to the effects caused by the primary incident.

Statistical Approach
Statistical algorithms are used in some Automatic Incident Detection strategies. Statistical analysis determines if the recorded traffic data differ statistically from the historical condition or defined threshold.

T

Time Series Model Approach
The Time Series Model is a technique used in Automatic Incident Detection. Algorithms perform comparisons between short-term forecasts and the actual conditions, and identify calibrated deviations as incidents.

Travel Demand Management
Improving traffic flow by managing travel demand using strategies such as congestion pricing and ramp metering.

V

Variable Message Sign (VMS)
A specific subset of Dynamic Message Signs. VMSs provide the highest level of functionality of all of the DMSs. VMSs contain a variable display, made up of a grid or matrix of discrete dots, known as Pixels. Combinations of pixels render the appearance of a continuous formed character or graphic symbol. The VMS can display a full array of alphanumeric characters and symbols to form message combinations and can also have full graphics capability.

Vehicle Detection System (VDS)
Detects the presence of a vehicle and its attributes at a particular location and collects data used in many ATMS applications.

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