Low Cost Total Monitoring Stations
for
Rural Highway Applications

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ABSTRACT

There is a proven need for reliable, accurate road surface and environmental monitoring and motorist-alert systems on rural highways. These systems are frequently required along sections of isolated highways where conventional telephone services and power supplies are not readily available. Furthermore, when they are available, they are associated with both a high initial cost and significant ongoing annual costs.

This paper describes a practical, low cost approach to the deployment of monitoring stations on rural highways that were recently implemented by Delcan for the Ministry of Transportation of Ontario, with support from Transport Canada and ENTERPRISE. The deployed "Total Monitoring Station" (TMS) demonstrates the ability to cost-effectively interface to different combinations of field devices and sensors, to monitor road conditions and provide automatic warning to assist road operators in rural areas.

A key component of the TMS is the application of a commercial digital wireless (1xRTT) communications network. Although monitoring sensors are a relatively common feature of ITS, the use of 1xRTT and the peer-to-peer network with automatic operation via the TMS's, is a valuable new, but practical application. The major advantages of a 1xRTT network (versus typical dedicated lease lines) are a rapid deployment time and reduced leased costs.

In order to support the need for TMS's in rural areas, where power may not be readily available; the demonstration project was solar powered.

1.   INTRODUCTION

The rapid deployment by the major cellular telephone service providers of digital wireless communication networks to support new Personnel Communication Services (PCS) provides a new communication option for Intelligent Transportation Systems (ITS). The cellular wireless data network, upon which these services are based, is a wholly digital network and provides different communication interfaces from traditional ITS deployments. It was necessary, when implementing the TMS project that the designers be aware of, and take advantage of, the characteristics of the communication network and the ITS application being implemented.

Intelligent Transportation Systems monitor a large number of roadway, traffic and environmental conditions, using a wide variety of sensors. The TMS demonstration project was designed to determine if visibility alerts could be generated reliably when visibility at road level falls below a specific threshold. Three types of sensors were selected for the demonstration:

■   visibility sensors which measure light reflected by particles or vapour,
■   overhead vehicle sensors to measure traffic volume, speed and type, and
■   video cameras to provide investigators and users an opportunity to visibly review site conditions.

In order to integrate the sensors and process data in the field, controllers were required. It was decided to utilize the Ministry of Transportation, Ontario's (MTO) standard Advanced Transportation Controllers (ATC) which are deployed by the Ministry to support Advance Transportation Management Systems (ATMS), such as COMPASS,[1] along the 400 series highways throughout the major urban centres. The ATC's were selected because they:

■   utilise industry standard computers,
■   are an open, non proprietary, design,
■   meet the environmental conditions,
■   use suitable core software which is available, and
■   were readily available.

Since the project was designed to demonstrate applications of ITS in a rural environment, an "off the grid" power solution was proposed. Each TMS was powered by an array of solar panels and storage batteries.   In order to reduce the power requirements, the ATC's and sensors were configured to operate on direct current and unnecessary options were disabled.

A section of Highway 21, close to Lake Huron, was recommended by the MTO South West Region due to the frequent requirement to close the highway due to snow squalls off the lake. The local was ideal for testing the TMS since many poor visibility periods occurred. Data and video images were collected during the winter of 2005 / 2006.

The analysis conducted during the winter and spring indicated that the correlations between poor driving conditions due to poor visibility and the data from the sensor could

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[1] COMPASS is the ATMS deployed along Highway 401 throughout the greater Toronto area.

be determine. It was concluded that the communications was very reliable and the energy derived from the solar panels, even under very adverse conditions, was adequate for continuous operation during the winter periods.

The remaining sections of this paper address in greater detail:

- Communications
- System Design
- Site Selection
- Data Collection and Evaluation
- Conclusions and Recommendations.

2. COMMUNICATIONS

2.1. Background

Cellular communication service providers have rapidly moved to deploy all digital networks in order to provide advanced cellular services to their subscribers. These new digital networks provide personal communication services (PCS) for both voice and data. The digital data service is a significant advance over previous commercial wireless data offerings, providing Internet Protocol (IP) access and data rates from 40 to 144 kb/s.

In 2002, the author identified the possibility of reducing the recurrent and initial installation communications costs for urban traffic control systems by using the data network, being installed to support enhanced PCS cell phone technology, for communications with traffic signal controllers. In addition to offering the benefits of reducing communication costs by an estimated 50%, by using commercial wireless service, new intersection controllers could be deployed rapidly with consistent installation and lease charges. Leased services for traffic signal communications have typically required the installation of new local circuits through construction by the telephone company. This is expensive and has a schedule which is dependent upon the telephone company's overall outside plant construction schedule.

A proposal for funding for a study was submitted to ENTERPRISE[2] by Delcan and MTO with the support of Transport Canada at the end of 2002. The objective of the study was to determine if these new digital data service offerings, utilizing 1xRTT[3] technology, are suitable to provide effective communications for urban traffic signal control systems.

The resulting Study conducted a careful analysis of communication protocols, network specifications and physical testing. The tests, using a variety of different traffic signal controllers and a central traffic control system, measured network delay, latency and

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[2] The ENTERPRISE Program is supported by a group of State, Provincial and Federal transportation agencies. http://enterprise.prog.org/

[3] 1xRTT, Single carrier radio transmission technology which provides 3rd generation digital voice and data services on the cellular network.

error rates. It was concluded by the Study[4] that the 1xRTT technology could be effectively utilised for advanced urban traffic signal control. In fact, York Region is using 1xRTT communications to control some of it current intersections.

Drawing upon the conclusions of the study, the TMS Demonstration Project using 1xRTT communications and Total Monitoring Stations was undertaken during the winter of 2006/2007.

2.2. Communications Characteristics

2.2.1. Managing IP Addressing

The 1xRTT network is a digital network which supports Internet Protocol (IP) data packets. This is unlike traditional ITS communication networks which typically support serial based communications. Addressing ITS field devices typically requires a poll response protocol which has a unique address for each field device connected to a given circuit; the addresses are re-used on each other circuits. In the "dial up" situation, a telephone number is used to provide access. Internet connected devices are managed through an IP address. The addresses are assigned by the Internet Service Provider (ISP); in this case Bell Mobility. These addresses can either be fixed or variable; known as static IP addresses or dynamic IP addresses respectively. The ISP's strongly prefer dynamic IP addressing. The application service provider, in this case Delcan, must then manage IP addresses for the field devices and ensure that when new addresses are assigned, by the ISP, the field devices and central server each are aware of the new device addresses.
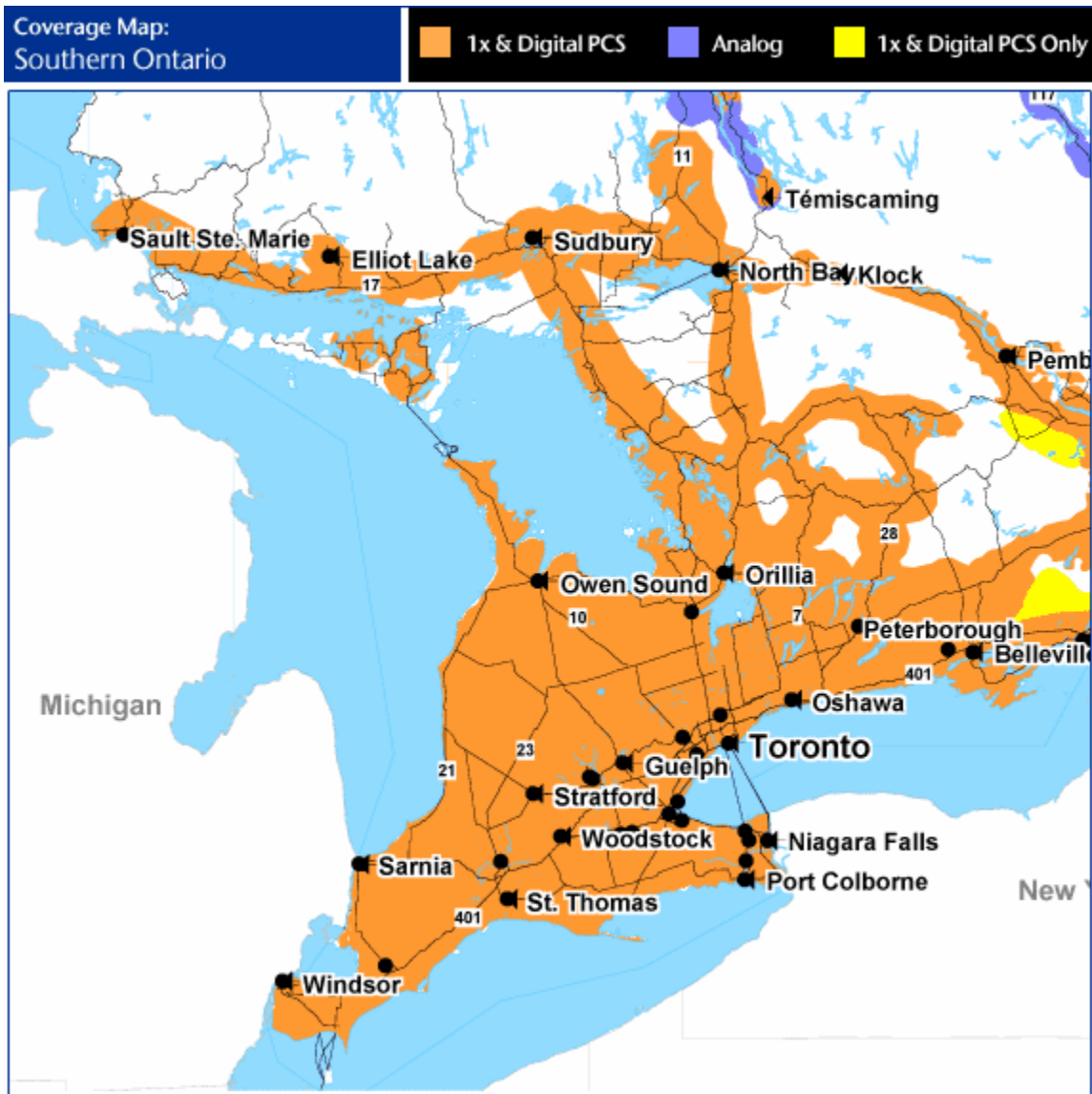
As part of the PCS study, referred to in Section 2.1 above, a schema to manage the dynamic IP addresses was developed. This methodology was refined and deployed as part of the TMS Demonstration Project.

2.2.2. Coverage Areas

A key question to be addressed when considering new wireless communications opportunities is coverage area. The 1xRTT coverage area is growing rapidly and fortunately for the transportation community the growth is typically along transportation corridors first. This was illustrated through the various stages of these projects. Initially (2003) coverage was provided in Ontario principally in the urban areas and along the major traffic corridors. By the time the TMS were installed during the winter of 2005 coverage was all of Southern Ontario, south of Highway 17, except Algonquin Park and along the major highways in the north. Figure 2.1 shows typical coverage in Ontario, however, coverage varies considerably throughout the country.

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[4] Final Report, "Test of Personnel Communication Service (PCS) Data Services for Traffic Signal Control, May 2004, for ENTERPRISE, Transport Canada, Ministry of Transportation, Ontario, by DELCAN Corporation.

Figure 2-1   Bell Mobility Coverage 2005

Coverage Map: Southern Ontario

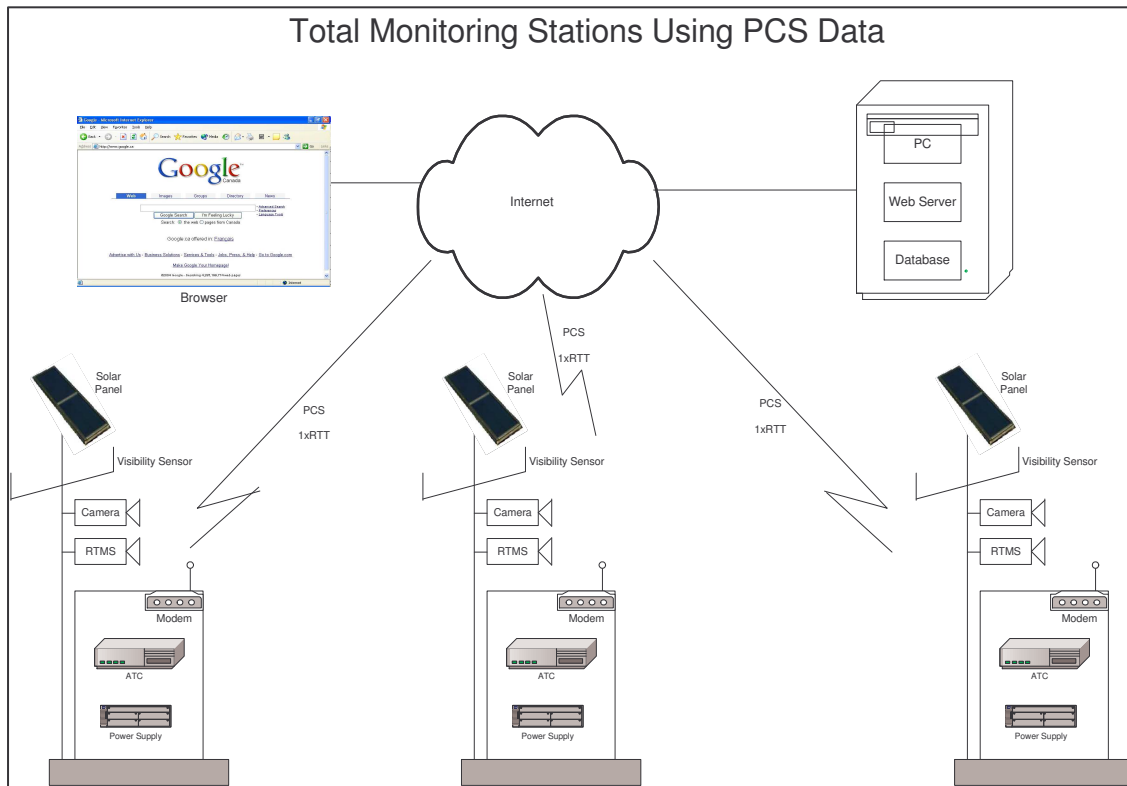Legend: 1x & Digital PCS | Analog | 1x & Digital PCS Only

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3.   System Design

The demonstration project consists of three TMS located in the field and communicating with each other, the central server and external users through the 1xRTT network and the Internet. The system design is shown in Figure 3.1 below.

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5 http://www.bell.ca/support/PrsCSrvWls_Landing.page,

Figure 3-1   System Design Diagram

Total Monitoring Stations Using PCS Data

3.1.   Total Monitoring Station Configuration

Each station in the field consists of:

- an Advanced Transportation Controller (ATC),
- a visibility sensor,
- an overhead multi-lane vehicle detector,
- an IP camera,
- an 1xRTT radio modem, and
- solar panels, batteries and associated charging system.

3.1.1.   ATC's

The ATC's have been modified to operate with lower power consumption and each has an expanded flash memory for local storage. They also are configured with serial channels and digital inputs / outputs to collect data from the sensors and control power to the connected devices.

The ATC software operates autonomously, collecting data from the sensors, storing the data locally and running local algorithms to look for poor visibility or traffic events. Periodically, currently every 15 minutes, data is sent to the sever for archival purposes.

3.1.2.   Visibility Sensors

The visibility sensor consists of a calibrated light source and sensor which are not directly aligned. The particles in the air, between the source and sensor, reflect a small amount of light into the sensor. The visibility is inversely proportional to the amount of reflected light detected at the sensor.

Figure 3-1 Visibility Sensor

The sensor electronics monitor the light readings and produce an average "equivalent visibility" reading in meters every minute.

The digital data from the sensor is sent to the controller where it is further processed and 5 and 15 minute averages are produced. In the event that the light level (visibility) is less than a specified threshold, say 500 meters, an visibility event is generated and a video stream captured and sent to the database server.

3.1.3.   Vehicle Detector

A side fired vehicle detector is mounted at each field location. The detector can monitor both travelled lanes and shoulders. It was configured to produce individual vehicle presence (count), occupancy and speeds. This data was received by the ATC and summarized into 5 and 15 minute data.

Figure 3-2   Side Fired Vehicle Detector

The ATC also contains a single station automatic incident detection designed to detect potential accidents. The detection algorithm produces an incident event which triggers the capture of a video stream from the camera.

3.1.4.   Camera with IP Interface

Figure 3-3 IP Camera

A fixed position camera with a manually adjustable zoom lens was used. The camera was mounted in a dome environmental enclosure. The camera included an integrated video encoder which produces a digital video data stream suitable for communicating across an IP network. Since the communications bandwidth and budget could not afford continuous streaming video the camera was controlled by the ATC. The ATC turns on the power to the camera, captures a video stream and sends a file to the data server containing the short video clip. By controlling the camera, the ATC not only limits the

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communications resources required but also manages the power consumption.

3.1.5. IxRTT Modem

An 1xRTT modem was installed in each TMS and a small antenna mounted above the cabinet. The modem provided the interface between Bell Mobility's network and the ATC in the cabinet. Bell Mobility then provided a link to Delcan through the Internet.

3.1.6. Solar Power System

The project team believed that in order to support remote ITS applications the TMS Demonstration Project needed to evaluate the potential use and implications of alternative power sources. Although solar power has been used for many applications, such as road weather information stations, we wanted to determine if general purpose sensors, controllers and communication devices could be configured to support the concept of a total monitoring station. That is, a station which could serve a variety of ITS applications.

Figure 3-4 Solar Panels

In order to determine the power required, and hence the size and number of solar panels required, detailed power calculations were prepared. These calculations included the average load of each device and its respective duty cycle as well as data from solar radiation charts for the geographical region of interest.

The solar system consists of four solar panels, four deep discharge batteries and a solar control unit. The solar control unit controls the battery charging rate to maximize the use of available sunlight. Through the duration of the demonstration, in spite of major snow storms and snow covered panels, the system operated without a failure of the solar power system.

3.2. Database Server

The database was located on one of Delcan's servers connected to the Internet. The server operates under Linux[6] and PostgreSQL[7], an open source database, is used to store the data.

The database server is the central repository of all data and video images. It is accessible to users through the Internet using a standard web browser. This is the principal interface to the TMS although the individual stations can also be accessed through the Internet using a browser.

The database also contains "event" observation data which have been entered during the winter by the Ontario Provincial Police (OPP) and MTO winter operations personnel.

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[6] "Linux" is a registered trademark of Linus Torvalds,
[7] Copyright © 1996 – 2006 PostgreSQL Global Development Group

These data which are based upon subjective observations in the field are co-related to the sensor data based upon a time and date record.

3.3. Browser Interface

Access to the database and TMS is provided via the Internet using a browser. A series of simple pages were developed for the demonstration project to allow access to the data for evaluation and to enable users to access real time data and video clips. Sample screens are illustrated below.
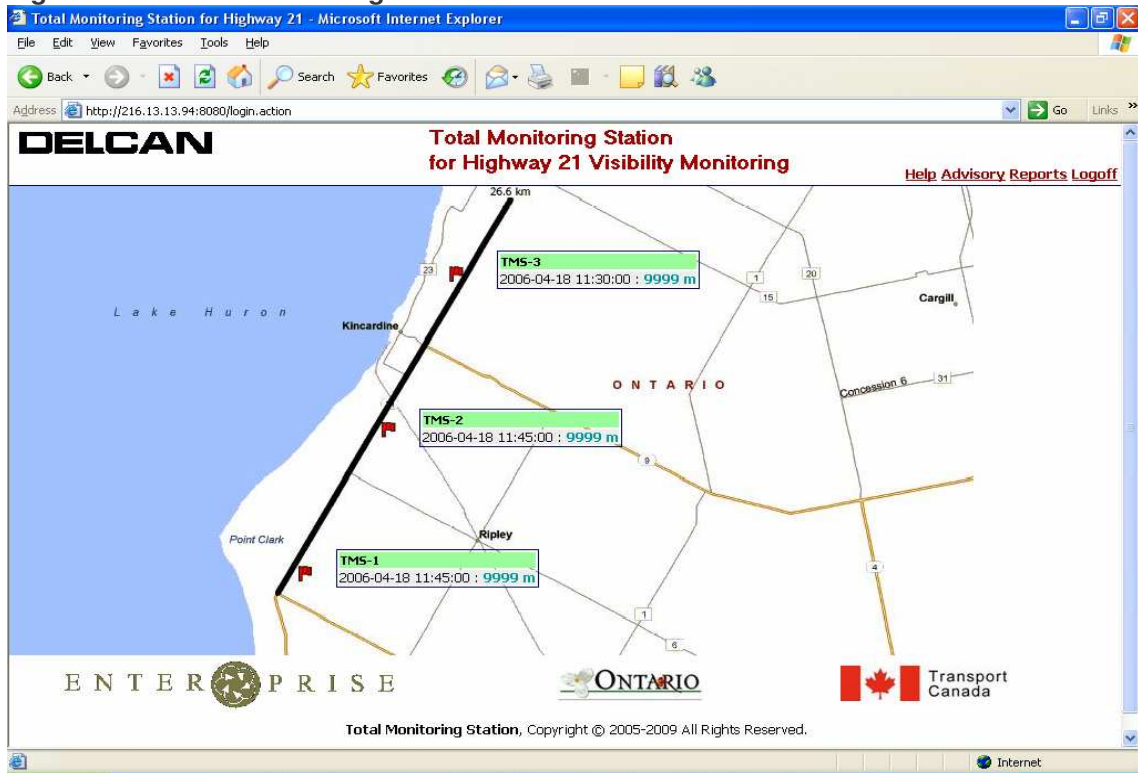
Figure 3-5 Main Interface Page

Figure 3-6 Typical Report Page

A variety of data reports are available. These data can be printed or exported for use in other databases and spreadsheets.

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4.   SITE SELECTION

The project team was looking for a site which would have frequent fog in order to have as many visibility events occur as possible for the purpose of calibration. The MTO South West Region suggested we look at Highway 21, not because it experienced heavy fog but, because during the winter the highway is frequently closed due to white out conditions.

Three locations along Highway 21 near Kincardine, south of the Bruce Peninsula, were selected. Refer to Figure 3.5 for the approximate locations and Figure 4.1 for typical installation. As well as the general location, sight specific surveys were conducted to select appropriate locations. As is illustrated in Figure 4.2 below, weather conditions were as promised.

Figure 4-1   Typical Installation

Figure 4-2   Blowing Snow

Figure 4-3   Fog Conditions

There were many adverse weather conditions and a wealth of data was collected during the demonstration period for analysis.

5.   DATA COLLECTION AND EVALUATION

The TMS Database Server contains a complete repository of data which are transmitted every fifteen minutes. The data are however stored at a finer resolution and hence the reports noted below are available:

- 5 Minutes' Average Traffic Data
- Hourly Average Traffic Data
- Daily Average Traffic Data
- 5 Minutes' Average Visibility Data
- 15 Minutes' Average Visibility Data
- Hourly Average Visibility Data
- "Events" including Visibility Threshold, Traffic Events, Manual Events generated by users and System Events such as occur when IP addresses are changed.
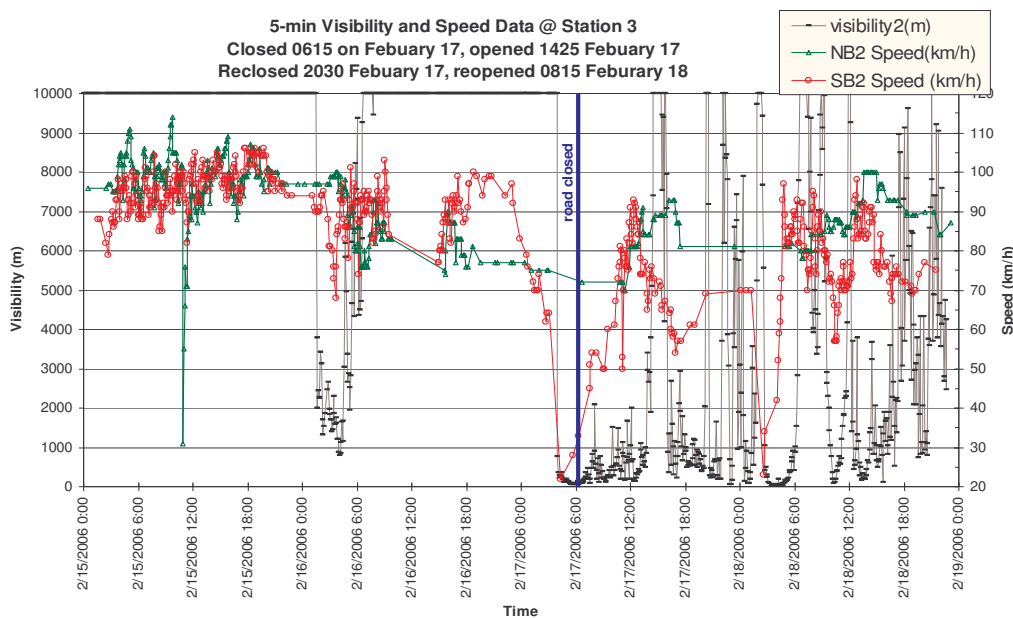
Visibility, Traffic and Manual Events cause video images to be generated and stored on the TMS Database Server. Since the "Events" are time stamped it is possible to view and assess the stored images of the roadway. Analysis of this data enabled the project team to determine that there was a strong co-relation between visibility readings, traffic

patterns and road conditions. However, a specific "visibility" threshold under which the road should be closed was not able to be defined.

In order to correlate measured sensor data with on-site assessments, the local OPP detachment and MTO regional road maintenance personnel were requested to provide field observations. The OPP and MTO, as part of their normal duties, patrol the area and identify poor road conditions. If conditions were poor when the patrollers drove by each TMS, observations of the road and visibility conditions were made. This information was relayed by radio to the associated radio operators who entered the observation in the TMS Database Server through the Internet. The database therefore contains a record of observed subjective data, measured sensor data and video streams which can be co-related based upon time and location.

These data are being analysed with a particular emphasis on the data obtained around the period of time when closures occurred. Figure 5.1[8] illustrates visibility and traffic data in February when a road closure was required.

Figure 5-1   Analysis of a Closure Event

The analysis showed a correlation between visibility measurements, traffic speed and observed data however there is not a direct relationship. As can be seen in Figure 5.1, traffic speed is sometimes relatively high considering the visibility sensor indicates very poor visibility. This has been attributed to the sensor height and location which does not always reflect visibility at the driver's eye level. In addition field observations have indicated that occasionally when the sensor readings indicate poor visibility, as opposed to very poor visibility (500 m to 1000 m for example), the actual field conditions may be worse. This is caused by blowing snow across the snow banks at the driver's eye level but below the sensor location.

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[8] Analysis by Raynald Ledoux, Transport Canada.

The conclusion of the analysis is that at road level visibility can be strongly indicated by data from visibility sensors and traffic sensors but this data is not, on its own, sufficient to warrant issuing alerts or taking other action such as opening or closing roads. A subjective evaluation is required using a visual observation either in the field or via an appropriately located camera.

Additional analyses of the data which, are being undertaken, indicate wind speed information may also be useful in determining visibility at the road level.

6. CONLCUSIONS AND RECOMMENDATIONS

The TMS Demonstration Project was designed to demonstrate technology suitable for deploying a general purpose ITS field controller in a rural environment and to determine if visibility and other sensors interfaced to that controller could be used to accurately determine visibility at the road level.

The TMS Demonstration Project successfully demonstrated:

- 1xRTT communication is reliable and consistently met the requirements of the TMS.
- The bandwidth required can be managed to maintain low monthly communication service charges.
- Solar power is a viable alternative for powering a variety of sensors and a general purpose controller using a reasonable size array of solar panels and number of batteries.
- A general purpose ATC is readily adaptable for lower power operation and provides the flexibility to interface with multiple types of sensors and control devices used in ITS.

The visibility experienced by a driver at road level is determined by several environmental conditions. The TMS Demonstration Project concluded that data from visibility sensors and anemometers can be used in conjunction with traffic data to predict when visibility conditions are likely poor. However, it was also determined that likely a visual observation, either by an observer in the field or via a video camera, is also required in order to make operational decisions.

The TMS Demonstration Project showed that the technology is viable and cost effective and the array of sensors used can provide meaningful information to operations personnel.

It is recommended that the TMS demonstration sites along Highway 21 be converted to operational sites. This will require upgrades to some of the sensors and the addition of an anemometer to each station. The user interface, pages on the web server, also need to be redeveloped from an operations perspective; as opposed to supporting a research and evaluation tool.

Total Monitoring Stations are a cost effective means of interfacing a wide variety of ITS sensors and control devices. They provide autonomous processing, control and monitoring while enabling peer to peer communications and user access through web services.