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FINAL REPORT

AUTONOMOUS MONITORING STATION PILOT PROJECT USING DIGITAL PCS (1XRTT) DATA NETWORK

Prepared for

ENTERPRISE
Ontario Ministry of Transportation
Transportation Development Centre of Transport Canada

October 2006

Delcan
TRANSPORTATION • INFORMATION TECHNOLOGY • WATER

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16. Abstract

The Autonomous Monitoring Station (AMS) concept is based on the use of a general-purpose controller to support multiple ITS field components. The primary goal of this project was to demonstrate the feasibility of using low-cost wireless communications and solar power to deploy autonomous road monitoring stations in remote sites.

Three sites were equipped and monitored along Highway 21 in southwestern Ontario during winter 2005-06. Visibility sensors and vehicle detectors collected visibility levels and traffic conditions (volume and speed) and summarized data every fifteen minutes. When visibility deteriorated below a predefined threshold, video images were collected and transmitted to the central database server for comparison to field observations.

The system developed and tested proved to be reliable and cost effective to support road operators in rural areas. Further AMS system research and development is recommended, including providing more automated alerts in poor visibility conditions and improving the user interface for operational use.

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16. Résumé

Le concept de station de surveillance autonome (AMS, Autonomous Monitoring Station) se fonde sur le recours à un contrôleur universel pour gérer plusieurs composants STI en site isolé. Le principal objectif de ce projet était de démontrer la faisabilité d'utiliser les communications sans fil et l'énergie solaire, ressources relativement peu coûteuses, pour déployer des stations autonomes de surveillance des routes en zone éloignée.

Trois sites situés le long de la route 21, dans le sud-ouest de l'Ontario, ont été équipés du système et surveillés pendant l'hiver 2005-2006. Les capteurs de visibilité et les détecteurs de véhicules recueillaient les données sur les niveaux de visibilité et les conditions de la circulation (nombre et vitesse des véhicules), et résumaient ces données toutes les 15 minutes. Lorsque la visibilité descendait sous un seuil prédéfini, des images vidéo étaient prises et transmises au serveur de base de données central, pour comparaison avec les observations faites sur le terrain.

Le système développé et mis à l'essai s'est révélé fiable et économique pour appuyer les services routiers en zones rurales. Il est recommandé de poursuivre la recherche et le développement sur le système AMS, pour notamment automatiser davantage les alertes dans des conditions de visibilité réduite et améliorer l'interface utilisateur en vue d'une utilisation opérationnelle du système.

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EXECUTIVE SUMMARY

Background

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 operating and maintenance costs.

The concept of the Autonomous Monitoring Station (AMS)[1] Pilot Project, which originated from an initiative by the Ministry of Transportation of Ontario (MTO) to use a general purpose controller to support multiple ITS field components, was to demonstrate the feasibility of using low-cost wireless communication and solar power to deploy remote visibility monitoring stations for rural ITS applications.

The project was conceived following the earlier ENTERPRISE study undertaken in 2004 by MTO, Transport Canada and Delcan which demonstrated that the commercial digital wireless PCS Network (1xRTT) could be used for urban traffic signal control[2].

The AMS Pilot Project was a cooperative effort with active support from the Ontario Provincial Police (OPP), MTO, and Transport Canada. Members of ENTERPRISE provided direction and financial support. Delcan was responsible for software development, procurement and systems integration.

In order to meet the requirements of this pilot project, it was necessary to utilize a general purpose controller which could monitor a variety of sensors and communicate using a wireless commercial data network at remote locations. Other key requirements of the AMS pilot project:

- communications to be provided through a wireless network, ubiquitously available along rural roadways,
- an “off the grid” power solution , and
- standard ITS controllers to interface with standard field monitoring and control devices.

The system needed to use open technological solutions and be compatible with the ITS Architecture for Canada.

System Overview

The locations selected for the pilot project were along Highway 21, adjacent to Lake Huron in southwestern Ontario, which is subject to severe winter white-out conditions caused by blowing snow. The locations were recommended by the South Bruce Detachment of the OPP and South West Region of MTO based upon their knowledge of

1 Also known as Total Monitoring Station (TMS)
2 Test of Personal Communication Service (PCS) Data Services for Traffic Signal Control, ENTERPRISE, May 2004 (Transport Canada report TP 14279E)

the regions and road conditions. The AMS were installed in the fall of 2005 and data was collected during the winter of 2005 – 2006.

A key component of the AMS 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 AMS, is a valuable new, but practical application. The major advantages of a 1xRTT network (versus typical dedicated lease lines) are rapid deployment time and reduced lease costs.

In order to address the power requirement of AMS in rural areas, where conventional power may not be readily available , the pilot project used solar power.

Visibility sensors provided a qualitative measure of visibility. Vehicle detectors monitored the number of vehicles and their speed. Field controllers monitored the visibility levels and traffic conditions. Data was summarized in 15-minute intervals and transmitted via the wireless IP network to a database server. When winter snow conditions caused visibility to deteriorate below a predefined threshold, video images were collected and transmitted to the central database server.

The data collected by the AMS was available to researchers and operating agencies through a browser interface via the Internet.

The OPP and MTO District staff took field visibility observations during the course of their normal duties. These observations were entered into the database and provided a benchmark for evaluation.

Challenges

A number of challenges were faced, including installation and setup under severe early winter conditions. A key aspect of the project was to determine how accurately the readings from visibility sensors could reflect the driver's perspective of visibility along the roadway.

The height of the sensor is a key consideration. Since the ideal height, at driver's' eye level, is not practical, the impact of less than ideal mounting heights was explored. In addition the sensors measure the particles in a small volume of air which could be subject to rapidly changing conditions. Therefore, trying to assess the validity of sensor data was another key challenge for the project team.

Another challenge was to manage the expectations of users of the system. The pilot project was set up to research the concept and to determine the requirements for deployable operational systems. Users found value during the pilot testing period in the system and tried to use the system to support their operations. Although the their interest was gratifying, the user interface was not intended for or suitable for operations. This resulted in some frustration, in particular with a "clunky" viewer for the video clips.

Conclusion

The AMS Pilot Project demonstrated the technical capability of deploying wireless communication and solar power with a low-cost interface to different combinations of field devices and sensors.

The project also showcased how ITS equipment can be cost effectively deployed to monitor adverse driving conditions and provide automatic warning to assist road operators in rural areas.

The conclusions of the pilot project were:

- the wireless communications technology and solar power will support remote Autonomous Monitoring Stations reliably
- visibility sensors and traffic detector can be used to provide alerts to the public and provide a tool for operating agencies
- fully automatic alerts and road closures are not practical and human intervention and operator decisions will still be required.

Recommendation

Further research and development of the AMS system is recommended to develop an updated system focussing on operational support.

The following improvements to the browser-based user interface are recommended:

- a video player fully integrated into the browser for single or double click activation
- alarm / alert windows to allow operators to track outstanding events
- simple entry window for "observations"
- immediate access to real-time sensor data as well as a severity index.

It is recognized that visibility can not be addressed simply by using visibility sensors. It is recommended that a visibility severity index based on data collected from visibility sensors, traffic sensors and anemometers be explored.

Deployment of the updated AMS system is recommended for the 2007-08 winter season.

SOMMAIRE

Contexte

Il existe un besoin reconnu de systèmes fiables et précis pour surveiller l'état des routes et les conditions environnementales et alerter les automobilistes en conséquence, en zones rurales. Or, les routes où ces systèmes sont nécessaires sont souvent isolées et mal desservies par les réseaux de téléphonie et d'électricité classiques. Et là où ces services sont offerts, l'investissement initial pour le raccordement, et les coûts annuels d'exploitation et d'entretien, sont élevés.

Le projet pilote de station de surveillance autonome (AMS, *Autonomous Monitoring Station*)[1] émane d'une initiative du ministère des Transports de l'Ontario (MTO), qui consistait à utiliser un contrôleur universel pour la gestion de plusieurs composants STI en site isolé. Il avait pour objet de démontrer la faisabilité d'utiliser les communications sans fil et l'énergie solaire, ressources relativement peu coûteuses, pour déployer des stations éloignées de surveillance de la visibilité, qui font partie des applications STI en zones rurales.

Le projet s'inscrit dans la foulée de l'étude ENTERPRISE réalisée en 2004 par le MTO, Transports Canada et Delcan, qui a démontré la possibilité d'utiliser le réseau numérique commercial sans fil SCP (1xRTT) pour la régulation de la signalisation routière en zone urbaine[2].

Le projet pilote AMS est un effort coopératif qui a reçu le soutien actif de la Police provinciale de l'Ontario (PPO), du MTO et de Transports Canada. Les membres de ENTERPRISE ont assuré la direction du projet et y ont contribué financièrement. Delcan était responsable du développement logiciel, de l'achat du matériel et de l'intégration des systèmes.

Le projet a nécessité le recours à un contrôleur universel capable de surveiller divers types de capteurs et de communiquer par un réseau de données commercial sans fil à partir de sites éloignés. Voici les autres exigences auxquelles devait répondre le projet pilote AMS :

- communications assurées par un réseau sans fil ayant une forte présence en zone rurale;
- réseau électrique autonome;
- contrôleurs STI standard, interfaçables avec des dispositifs standard de surveillance et de commande en site isolé.

Le système devait utiliser des solutions technologiques ouvertes et être compatible avec l'architecture STI pour le Canada.

[1] aussi connu comme *Total Monitoring Station (TMS)*
[2] *Test of Personal Communication Service (PCS) Data Services for Traffic Signal Control*, ENTERPRISE, mai 2004 (rapport TP 14279E de Transports Canada)

Aperçu du système

Les endroits choisis pour le projet pilote étaient situés le long de la route 21, à proximité du lac Huron, dans le sud-ouest de l'Ontario. Il s'agit d'une route sujette à des conditions de visibilité nulle, en hiver, en raison de la poudrerie. Ces endroits avaient été recommandés par le détachement de South Bruce de la PPO et la région Sud Ouest du MTO, qui connaissent bien la région et les conditions routières qu'on y rencontre. Les AMS ont été installées à l'automne 2005 et les données ont été colligées pendant l'hiver 2005-2006.

Un élément clé de l'AMS est le recours à un réseau numérique commercial de communications sans fil (1xRTT). Même si les capteurs de surveillance sont relativement courants dans les STI, l'utilisation de la technologie 1xRTT, avec le réseau point-à-point à fonctionnement automatique via l'AMS, est une application à la fois novatrice et pratique. Les principaux avantages d'un réseau 1xRTT (par opposition aux lignes spécialisées louées habituelles) sont la rapidité de déploiement et les coûts de location réduits.

Pour alimenter en énergie électrique l'AMS dans des zones rurales où les réseaux d'électricité classiques ne sont pas toujours présents, le projet pilote a eu recours à l'énergie solaire.

Les capteurs de visibilité donnaient une mesure qualitative de la visibilité. Les détecteurs de véhicules surveillaient le nombre de véhicules et leur vitesse. Les contrôleurs sur le terrain recueillaient les données sur les niveaux de visibilité et les conditions de la circulation. Ces données étaient résumées toutes les 15 minutes et transmises sur le réseau IP sans fil à un serveur de base de données. Lorsque des précipitations de neige faisaient descendre la visibilité au dessous d'un seuil prédéterminé, des images vidéo étaient prises et transmises au serveur de base de données central.

Les données recueillies par l'AMS étaient mises à la disposition des chercheurs et des exploitants au moyen d'un navigateur Internet.

Des membres du personnel de la PPO et du district du MTO faisaient des observations de la visibilité sur le terrain, dans le cadre de leurs tâches habituelles. Ces observations étaient entrées dans la base de données et servaient de points repère pour l'évaluation du système.

Défis

Le projet s'est buté à certaines difficultés, dont l'installation et le montage des systèmes qui ont dû se faire dans les conditions rigoureuses d'un hiver hâtif. Un aspect clé du projet était de déterminer dans quelle mesure les lectures des capteurs de visibilité correspondaient à ce que voyait le conducteur sur la route.

La hauteur du capteur était un facteur très important. Comme il n'était pas possible d'installer les capteurs à la hauteur idéale, soit celle des yeux du conducteur, l'effet de hauteurs de montage non optimales a été étudié. De plus, les capteurs mesuraient les particules dans un petit volume d'air, qui était soumis à des conditions susceptibles de changer très rapidement. Par conséquent, évaluer la validité des données des capteurs constituait un autre défi de taille pour l'équipe de projet.

Une difficulté d'un autre ordre a consisté à ne pas décevoir les attentes des utilisateurs du système. Le projet pilote visait à explorer le concept et à déterminer les exigences de systèmes opérationnels, déployables. Mais les utilisateurs, ayant trouvé le système utile pendant l'essai pilote, ont tenté de l'utiliser à des fins «opérationnelles». Or, tout gratifiant qu'ait été un tel intérêt, l'interface utilisateur n'avait pas été conçue pour des fins opérationnelles, et ne convenait pas à de telles fins. Cela a mené à une certaine frustration, notamment au sujet d'un lecteur vidéo «chancelant».

Conclusion

Le projet pilote d'AMS a démontré la faisabilité technique de recourir aux communications sans fil et à l'énergie solaire pour établir à peu de frais des liaisons entre différentes combinaisons de dispositifs et de capteurs sur le terrain.

Le projet a également servi de vitrine pour la possibilité de déployer de façon économique un matériel STI capable de surveiller les mauvaises conditions routières et d'émettre des avertissements automatiques aux usagers de la route, dans des zones rurales.

Les conclusions tirées du projet pilote sont les suivantes :

- la technologie de communications sans fil et l'énergie solaire peuvent soutenir de façon fiable les stations de surveillance autonomes
- les capteurs de visibilité et les détecteurs de véhicules peuvent donner des avertissements au public et servir d'outil aux exploitants
- il n'est pas envisageable d'automatiser complètement l'émission des avertissements et les fermetures de routes; l'intervention humaine et les décisions des exploitants demeureront nécessaires.

Recommandations

Il est recommandé de poursuivre la recherche et le développement sur le système AMS, en vue d'axer davantage le système sur le soutien opérationnel.

Il est recommandé d'apporter les améliorations suivantes à l'interface utilisateur par navigateur Web :

- un lecteur vidéo parfaitement intégré au navigateur, activé par un clic ou deux
- fenêtres d'alarme/alerte pour permettre aux exploitants de suivre les événements exceptionnels
- fenêtre d'entrée simple pour les «observations»
- accès immédiat aux données en temps réel des capteurs, de même qu'à un indice de danger.

Il est reconnu que les capteurs de visibilité seuls ne suffisent pas à rendre compte des conditions de visibilité. Il est recommandé d'explorer l'idée d'un indice de danger (lié à la visibilité restreinte) fondé sur les données recueillies à l'aide de capteurs de visibilité, de détecteurs de véhicules et d'anémomètres.

Le déploiement du système AMS perfectionné est recommandé pour l'hiver 2007 2008.

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APPENDIX

1 INTRODUCTION & PROJECT OBJECTIVES

The Autonomous Monitoring Station[1] Pilot Project was undertaken to demonstrate a practical deployment of remote monitoring stations for rural ITS applications. In order to meet the requirements for the remote deployment:

- communications must be provided through a wireless network ubiquitously available along rural roadways,
- an “off the grid” power solution is necessary, and
- standard controllers used for ITS supporting interface to standard ITS monitoring and control field devices must be used.

In Ontario there are a significant number of locations where driver’s visibility is a known issue, with poor visibility resulting in accidents and frequent road closures due to inclement weather. A suitable application, with a proven need was visibility monitoring and generation of alerts. In order to determine “visibility thresholds” research and analyses of measured data would be required; Autonomous Monitoring Stations are a suitable tool to collect these data.

The communication technology selected was 1xRTT, (single carrier radio transmission technology) which provides 3rd generation digital voice and Internet protocol (IP) data services on the cellular network. The potential to use1xRTT for ITS applications was identified and investigate through a previous ENTERPRISE Study[2]. This study showed that the use of 1xRTT would be possible if the characteristics of the services were well understood. In order to power the AMS’s a solar power solution was selected with a fall back plan to the Ontario Hydro electric grid to ensure continuous operations. 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 Advanced Transportation Management Systems (ATMS), such as COMPASS,[3] along the 400 series highways throughout the major urban centres.

A project proposal was prepared for ENTERPRISE by Delcan and the Ministry of Transportation of Ontario (MTO). The project was designed as a private, public partnership with in kind goods and services from the private firms and funding from ENTERPRISE, MTO and Transport Canada. Bell Mobility provided communication services, SONY Canada provided a loan of IP cameras and Delcan provided computer hardware and in kind services.

The objectives of the pilot project were:

- To demonstrate and assess the practical use of digital PCS, 1xRTT, communications for rural ITS applications.
- To demonstrate and evaluate a low maintenance autonomous monitoring station (AMS) suitable for rural deployment powered by solar energy to support a light infrastructure deployment.

[1] Also known as Total Monitoring Station (TMS)
[2] Final Report, “Test of Personal Communication Service (PCS) Data Services for Traffic Signal Control”, May 2004, for ENTERPRISE (Transport Canada report TP 14279E).
[3] COMPASS is the ATMS deployed along Highway 401 throughout the greater Toronto area.

- To determine if, and under what conditions, visibility sensors and vehicle detectors can be used to provide useful roadway visibility information to the roadway authorities and motorists.

2 SYSTEM DESCRIPTION & IMPLEMENTATION

2.1 System Design

The system deployed for the pilot project consists of three AMS (labelled RTMS in Figure 2-1) 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 2.1 below.

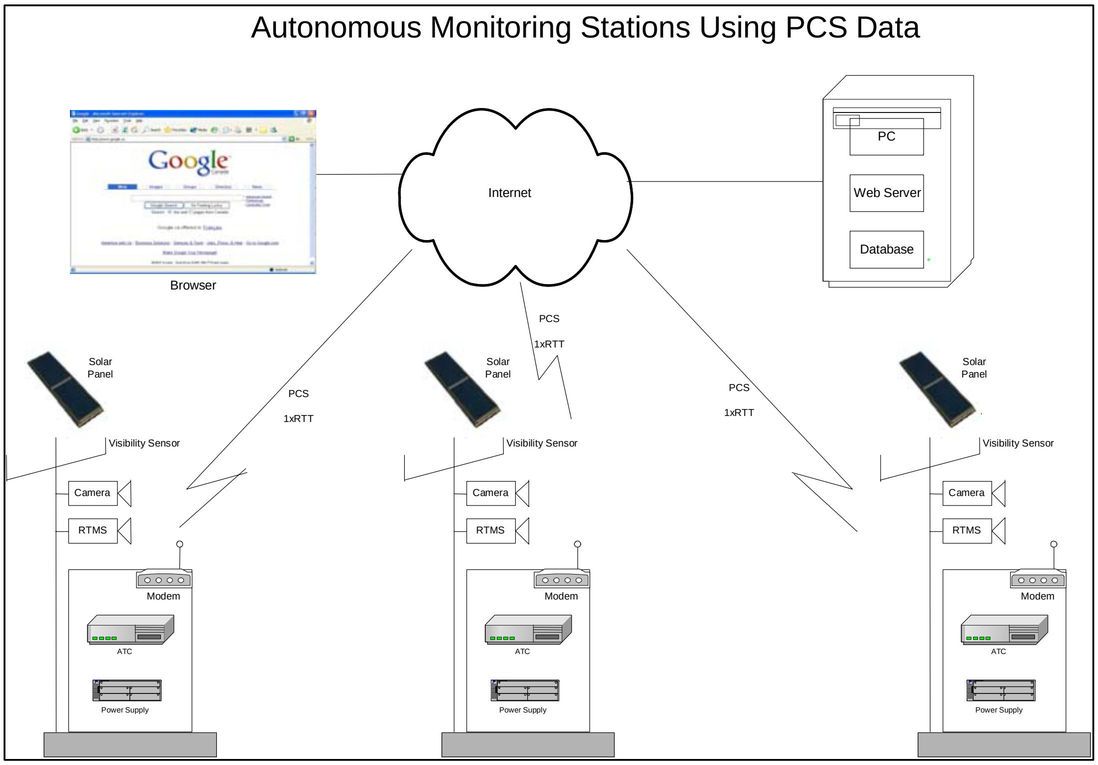


Figure 2-1 System Design Diagram

There were several important factors and constraints driving the AMS design. The design needed to provide a low cost solution with low maintenance requirements. In particular, due to the relatively remote location, site visits to adjust the AMS needed to be minimized. As much as possible the equipment used was familiar to the MTO maintenance forces that would be involved in the actual installation and maintenance activities of the AMS. Since the AMS would be powered through solar energy the design needed to minimize energy use. Recurrent communication costs in an operational system are also an important consideration. Although Bell Mobility provide free service during the test period the communication techniques were designed to meet the lowest tier of service offered.

Each station in the field consists of:

- an Advanced Transportation Controller (ATC),
- a visibility sensor,

- an overhead multi-lane vehicle detector,
- a video camera with an Internet protocol (IP) interface,
- an 1xRTT radio modem, and
- solar panels, batteries and associated charging system.

The ATC's communicate with each other and the central server through the 1xRTT network. Users can access the server and the ATC's through the Internet using a web browser.

2.2 Advanced Transportation Controller

The MTO qualified Advanced Transportation Controller (ATC) was selected as the main AMS control processor in the field. 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.

The ATC's have been modified to operate with lower power consumption and from a DC power supply. In order to operate efficiently with solar power each standard off-the-shelf ATC was fitted with DC-DC power conversion units. The ATC are configured to control camera pan, tilt and zoom (PTZ) which has high power consumption. This functionality was disabled to conserve power. The operating system was upgraded to the latest version of the real-time operating system QNX-6.

The ATCs are equipped with 3 serial ports and one 10-BaseT Ethernet interface. The visibility sensors and the RTMS traffic detectors were specified to provide their sensor data through ASCII protocols over a standard serial interface with the camera connected via the Ethernet interface. This serial arrangement simplified the overall sensor integration effort.

Figure 2-2 ATC and Cabinet

In order to conserve additional power the CCTV camera was normally powered off until a video clip was required. The CCTV camera required a 5V digital signal to activate a trigger to process the capturing and storing the video. This trigger is provided through the ATC's preconfigured digital I/O which is wired to an industrial standard I/O harness. Hood heaters used in the visibility sensors to control snow build up were also configured to be switch-able through the ATC's digital I/O.

Although the AMS's are designed to operate on solar power, to be prudent a standard power service was provided as a backup. Since the ATC had been converted to DC operation a commercial DC power supply was required. An interlocking relay provided an automatic switch to the output of this supply if the solar system failed.

An 1xRTT modem was installed in each AMS and a small antenna mounted above the cabinet. The modem provided the interface between Bell Mobility's network and the ATC in the cabinet. A link was provided to the server via the Internet.

To optimize data transfers to the central server over the PCS communications a special data collection task consolidates the data from the visibility sensor, the traffic detector and the CCTV video. The consolidated information package is communicated to the central server at 15 minute intervals.

All equipment including the batteries was arranged to be integrated into a single field cabinet. The MTO standard cabinet was selected as it provided all of the necessary mounting, standard 19" rails, and auxiliary power connections. Another major advantage was that MTO was already very familiar with its arrangement.

The cabinets were mounted on inverted poles driven into the ground fitted with standard mounting bases. This mounting arrangement did away with the conventional concrete pedestal design for a more rapid and less costly installation.

2.3 Visibility Sensor

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, refract a small amount of light into the sensor. The visibility is inversely proportional to the amount of refracted light detected at the sensor.

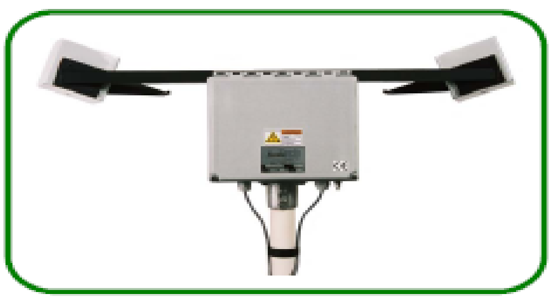


Figure 2-3 Visibility Sensor

The visibility sensor works on the principle of forward scattering. The design uses an active transmitter and an opposing receiver mounted at 42 degrees looking forward at a sample volume of air in front of the sensor arrangement. The emitter transmits infrared light into the sample volume and the detector receives any light that is scattered by any contaminants within the sample volume such as smoke, dust, haze, fog, rain and snow. The intensity of the signal is correlated to the extinction properties of the air sample. The sample volume is representative of the surrounding air near the sensor and therefore the sensor measures the extinction coefficient of the air and calculates the meteorological optical range (MOR) or visibility. The sensor electronics monitor MOR and produce an average "equivalent visibility" reading in meters every minute.

The sensor is designed for low maintenance and automatic operation. it uses "look down" geometry which reduces the window contamination and clogging from blowing snow. The sensor windows use continuous duty anti-dew heaters to provide consistent performance in varying weather conditions. Hood heaters are provided for both the transmitter and the receiver heads. To reduce the power consumption of the visibility sensor the hood heaters are wired to the ATC digital I/O and are manually controlled.

The sensor is mounted on a pole adjacent to the road. The mounting considerations are as follows:

- The sensor receive head must be oriented toward the north direction
- The sensor assembly must be at least 2.5 metres above the ground or expected snow depth in order to minimize interference from the ground scattering signal.
- The sensor (sample volume of air) must be near as possible to the actual or ideal measurement location

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 light levels (visibility) are less than a specified threshold, say 500 meters, a visibility event is generated and a video stream is captured and sent to the database server.

2.4 Traffic Detector

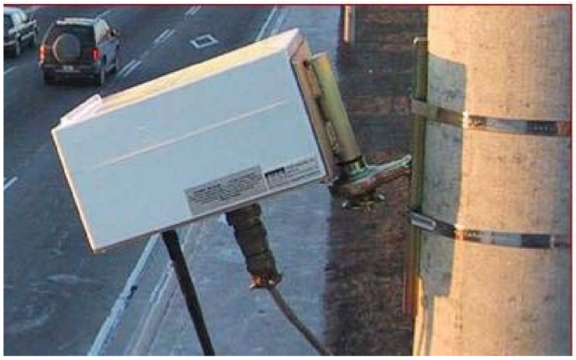


Figure 2-4 Traffic Detector

The RTMS traffic detector operates on the principal of ranging radar. The detector is an active device which emits pulses of microware energy and receives the reflected pulses. The unit measures the time difference between the emitted and the received signal and determines the likely position of the vehicle. In the cross fired configuration, where the beam of microwave energy is directed across the road and all its lanes, the position of the vehicle corresponds to a particular lane. The detector determines the presence of a vehicle in the appropriate position (lane). For the AMS installation on Highway 21 the RTMS units are configured in the cross fired mode looking across both lanes of traffic. The RTMS unit uses some signal processing to derive the traffic data such as volume, occupancy and speed on a lane by lane basis.

The detector is mounted on a pole adjacent to the roadway. The mounting restrictions in this case are as follows:

- Height above the road surface 5 m
- Beam angle 40°
- Distance away from the roadway 4.5 m

They were configured to produce individual vehicle presence (count), occupancy and speeds. These data were received by the ATC and summarized into 5 and 15 minute data sets.

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

2.5 CCTV Camera

The CCTV camera employed for this design is an integrated camera package that uses a standard CCD video camera with an MPEG 4 video compression and streaming software through IP protocol. All data including video, control, and configuration are communicated over IP protocols through the Ethernet interface. The camera configuration is provided through a http service and the streaming video is provided through a proprietary decoder.

Figure 2-5 IP Camera

An IP based CCTV camera was selected which would allow video clips to be generated on demand. The video compression and digital file storage are also managed by the camera and only require minimal configuration. This approach reduced the effort required to handle the video image data.

The IP encoded CCTV camera has two different interfaces to the ATC. The first interface is through a 10BaseT Ethernet interface and the second is through a digital I/O control interface. The camera unit is configured to record a video 5 second clip and transfer the video over the Ethernet interface to the ATC upon the activation of the camera digital I/O over the control interface. When an event is raised in the system, the ATC activates the CCTV camera digital I/O causing the capture and storage of a video clip. The system event could consist of a visibility event, traffic event, peer event (an event set by a peer AMS station) or manual event (manually triggered event).

To optimize data transfers to the central server over the PCS communications a special data collection task consolidates the data from the visibility sensor, the traffic detector and the CCTV video. The consolidated information package is communicated to the central server at 15 minute intervals.

The central server receives the sensor data from all three AMS stations and logs the data to a relational database management system (RDBMS). The historical data is made available through the internet

2.6 Solar Power System

Figure 2-6 Solar Planes and Pole Mounted

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.

2.7 Database Server

The database was located on one of Delcan's servers connected to the Internet. The server operates under Linux[4] and PostgreSQL[5], 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 AMS 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. These data which are based upon subjective observations in the field to be later co-related to the sensor data based upon a time and date record.

2.7.1 Browser Interface

Access to the database and AMS for the Pilot Project is provided via the Internet using a browser. The purpose of the user interface was to allow researchers to access data collected and for entering manual observations. It was designed as a tool for researchers and not intended for "highway operations" purposes. Additional requirements for operational purposes are discussed in section 4.1.6 of this report.

A series of simple pages were developed for the pilot project to allow access to the data and to enable project team members to access real time data and video clips for evaluation. Sample screens are illustrated below.

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

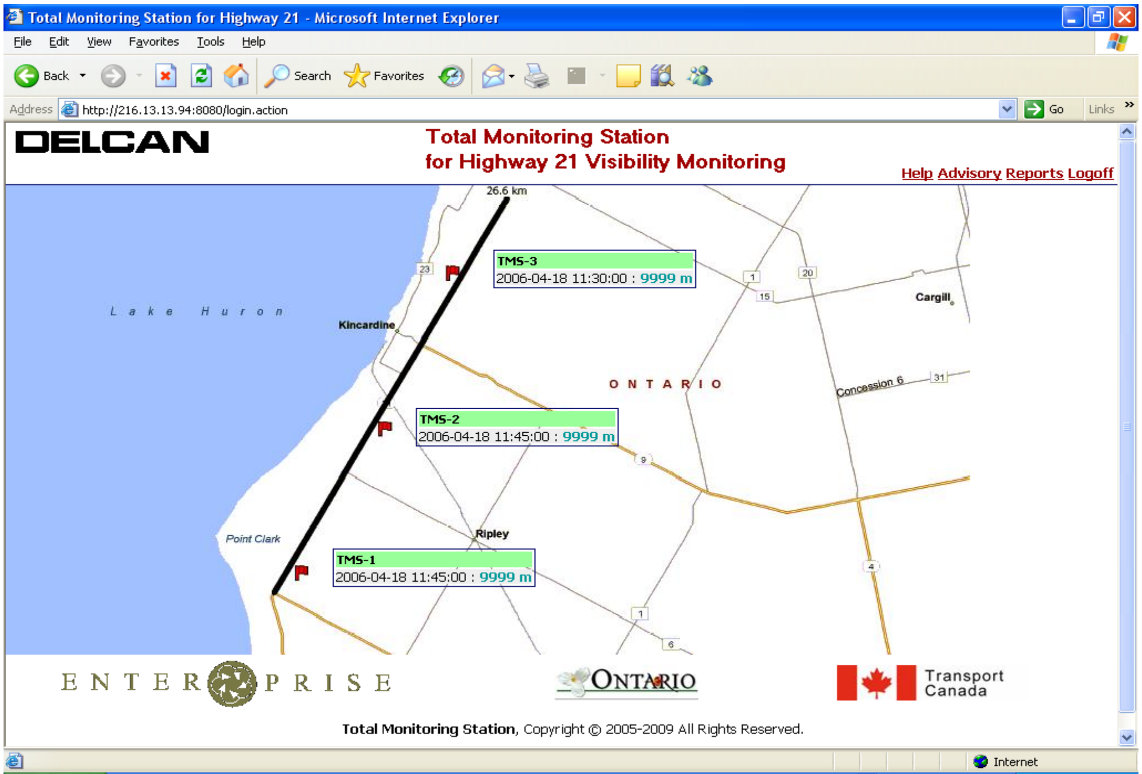


Figure 2-7 Browser Interface

2.7.1.1 Reports

A variety of data reports are available through the browser Interface. These data can be printed or exported for use in other databases and spreadsheets. Reports are available of data collected and system operational data.

Reports TRAFFIC_DATA_1HR

12 items found, displaying all items.**1**

start_time	tms_id	nb_vol	nb_occ	nb_speed	sb_vol	sb_occ	sb_speed
2006-04-18 01:00:00	3	1	1%	106	4	1%	101
2006-04-18 02:00:00	3	1	1%	108	3	1%	98
2006-04-18 03:00:00	3	1	1%	108	5	1%	104
2006-04-18 04:00:00	3	4	1%	110	1	1%	106
2006-04-18 05:00:00	3	12	1%	105	9	1%	94
2006-04-18 06:00:00	3	136	1%	105	26	1%	99
2006-04-18 07:00:00	3	126	1%	103	69	1%	99
2006-04-18 08:00:00	3	74	1%	91	109	1%	100
2006-04-18 09:00:00	3	61	1%	91	74	1%	96
2006-04-18 10:00:00	3	52	1%	89	52	1%	97
2006-04-18 11:00:00	3	58	1%	94	81	1%	94
2006-04-18 12:00:00	3	13	1%	97	19	1%	93

Export options: CSV | Excel | XML

Figure 2-8 Sample Traffic Data Report

Data Reports include:

- Traffic Data
- Visibility Data
- Visibility Events
- Traffic Events

Reports which are associated with systems operational data are:

- address
- AMS Station Status.

Reports EVENTS

179 items found, displaying 21 to 40.[First/Prev] 1, 2, 3, 4, 5, 6, 7, 8 [Next/Last]

event_id	event_time	tms_id	event_type	event_text	video
4121	2006-01-03 13:45:22	3	MANUAL	MANUAL	Show
4122	2006-01-03 13:45:32	3	MANUAL	MANUAL	Show
4123	2006-01-03 16:17:39	1	IPCHANGE	TMS_IP_CHANGE	
4124	2006-01-03 16:25:42	1	VIS_DATA	VIS_DATA_OFFLINE	
4125	2006-01-03 16:25:42	1	TRAF_DATA	TRAF_DATA_OFFLINE	
4126	2006-01-03 16:25:57	1	VIS_DATA	VIS_DATA_ONLINE	
4127	2006-01-03 16:25:57	1	TRAF_DATA	TRAF_DATA_ONLINE	
4128	2006-01-03 17:47:00	3	IPCHANGE	TMS_IP_CHANGE	
4129	2006-01-03 17:58:55	3	VIS_DATA	VIS_DATA_OFFLINE	
4130	2006-01-03 17:58:55	3	TRAF_DATA	TRAF_DATA_OFFLINE	
4131	2006-01-03 17:59:20	3	VIS_DATA	VIS_DATA_ONLINE	
4132	2006-01-03 17:59:20	3	TRAF_DATA	TRAF_DATA_ONLINE	
4133	2006-01-03 19:48:58	2	IPCHANGE	TMS_IP_CHANGE	
4134	2006-01-03 19:56:33	2	VIS_DATA	VIS_DATA_OFFLINE	
4135	2006-01-03 19:56:33	2	TRAF_DATA	TRAF_DATA_OFFLINE	
4136	2006-01-03 19:57:08	2	VIS_DATA	VIS_DATA_ONLINE	
4137	2006-01-03 19:57:08	2	TRAF_DATA	TRAF_DATA_ONLINE	
4138	2006-01-03 22:29:12	3	VIS_DATA	VIS_DATA_OFFLINE	
4139	2006-01-03 22:29:12	3	TRAF_DATA	TRAF_DATA_OFFLINE	
4140	2006-01-03 22:29:12	3	NODE	NODE_OFFLINE	

Export options: CSV | Excel | XML

Figure 2-9 Sample Event Report

The reports can be selected by type as well as range of data and time. The ability to export the data into MS Excel allows for easy reference, co-relation of data and evaluation of events during off-line a posteriori analysis.

2.8 Event Declaration

A variety of types of events which can occur based upon changes in system status, visibility conditions, traffic conditions and by operator command were planned and built into the ATC software and user interface.

2.8.1 System Status

The status of each of the stations is maintained in the database server. The events associated with station status are:

- communications failure
- IP address change
- node / controller status
- traffic sensor status
- visibility sensor status.

Communication status, node status and sensor status are displayed in real time via the browser interface. Historical data is stored in the database and is accessible through the report function of the user interface.

2.8.2 Visibility Events

There are two visibility thresholds set in the controller. These are to declare a poor visibility event and to clear a poor visibility event. The visibility thresholds are set in metres and hysteresis is provided to limit rapid changes in visibility state. The thresholds are adjustable parameters in the controllers; however under current pilot set-up, they are not adjustable through the user interface but only by adjusting the values in the ATC configuration file.

When a visibility event is declared the controller:

- issues a “peer” event (described below) to the other two AMS
- powers up the camera
- triggers the camera to capture a short video stream (3 to 5 seconds)
- encodes the video stream into MPEG 4 compressed video file with a date and time stamp
- sends the video file to the database server.

The server changes the state to indicate the visibility has fallen below the visibility threshold and stores the event and video file in the database.

Similarly when the visibility returns above the higher threshold a second event is created clearing the low visibility indication.

In the initial implementation only two video clips were generated; when the visibility dropped below the lower threshold and when it improved above the upper threshold. In order to obtain more data for analysis the system was modified partway through the project to capture video steams every 30 minutes when the visibility was between the two thresholds. This was done for evaluation purposes and would not likely be used in an operational deployment once visibility event detection is reliable.

2.8.3 Traffic Events

The traffic sensors monitor and average within a given time period:

- volume: number of vehicles which pass
- occupancy: percentage of time in which vehicles are in the detection zone
- speed: average speed is accumulated in the controller.

These data can be used to assess the level of congestion on the roadway which can be used to identify possible traffic incidents or queues. This assessment is done using a simple “automatic incident detection” (AID) algorithm. The AID algorithm is used by other highway applications to detect queues and incidences using a combination of occupancy and speed. Under conditions of high occupancy and low speed a queue can be detected and a traffic event created. The algorithm parameters are tuneable for different road configurations.

Similar to when a visibility event occurs, a peer traffic event is created and a video stream captured and sent to the server.

2.8.4 Peer Events

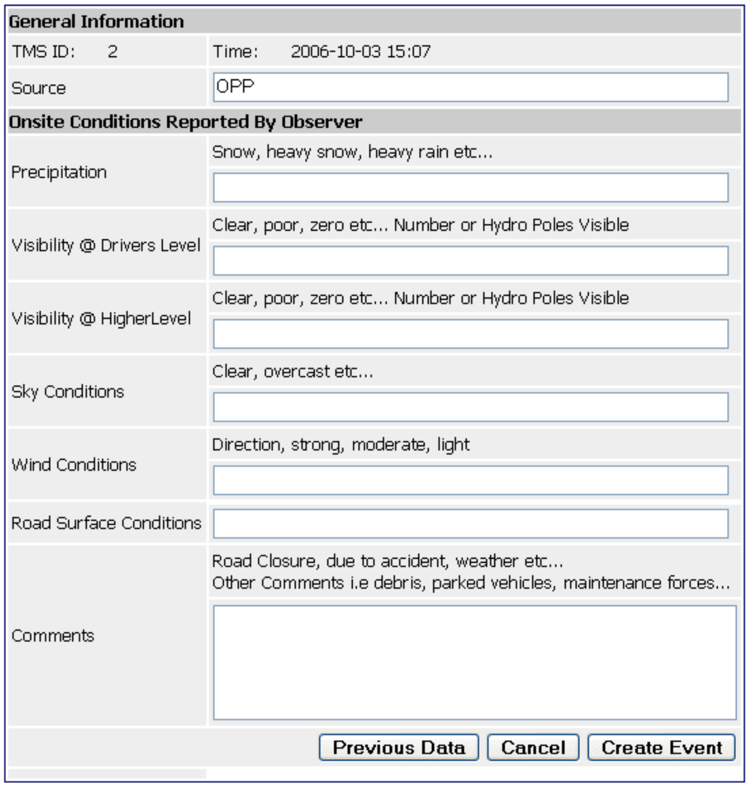
In order to assess the visibility at all three sites when visibility is poor at one location the concept of "peer events" was created. A visibility event at one station causes that station to communicate the relevant information to the other stations. Since each AMS is an autonomous unit with its own IP address on a network and each knows the IP addresses of the other stations this communication occurs without intervention of the central server. The role of the central server is to simply maintain the correct IP address tables in the controllers.

The stations receiving the information create a peer event. They collect sensor data, capture a video clip and assemble an event file which is sent to the central server.

The peer events can be analysed qualitatively as well as quantitatively to determine how localized the visibility conditions.

2.8.5 Manual Events

Manual events can also be created through the browser interface. In order to create manual events the user must be logged on with "operator" priority. Manual events are designed to help co-relate visible conditions in the field with measured conditions and video clips recorded. In the event of a road closure or a field observation report an operator clicks on the manual event icon and the Manual Event Form (Figure 2-10) appears.



General Information	
TMS ID: 2	Time: 2006-10-03 15:07
Source	OPP
Onsite Conditions Reported By Observer	
Precipitation	Snow, heavy snow, heavy rain etc...
Visibility @ Drivers Level	Clear, poor, zero etc... Number or Hydro Poles Visible
Visibility @ HigherLevel	Clear, poor, zero etc... Number or Hydro Poles Visible
Sky Conditions	Clear, overcast etc...
Wind Conditions	Direction, strong, moderate, light
Road Surface Conditions	
Comments	Road Closure, due to accident, weather etc... Other Comments i.e debris, parked vehicles, maintenance forces...
	Previous Data / Cancel / Create Event

Figure 2-10 AMS Manual Event Form

Using this form the operator enters the appropriate data and selects “Create Event” to cause a manual event at the selected AMS location.

The resulting event file with sensor data and associated video clip can then later be compared with the observed data. The data entered into the form is also stored in the database.

As well, a simple standalone script file was created which also allows an operator to create events through a single mouse click without filling in the form if time does not permit.

3 IMPLEMENTATION & DATA COLLECTION

3.1 Site Selection

The key criterion in selecting sites was identifying locations which would provide many opportunities to evaluate the sensors under conditions of poor visibility. In addition, the individual sites should not be subject to small local microclimates but, as much as possible, be representative of surrounding area.

The team was considering locations where fog or snow was known to create visibility problems. Locations along Highway 401, 400 and 402 were initially considered. However, MTO South West Region recommended Hwy 21 due to the frequent closures caused by blowing snow during the winter and the number of serious accidents. For example, during 2003 the highway was closed 16 times, 2004 closed 11 time and during the first half of 2005 5 times. In spite of the relatively remote location from the development team in Toronto it was an ideal location for sampling and testing purposes. Refer to the map in Figure 3-1 below.

Figure 3-1 Hwy 21 map

Highways in this area suffer from heavy winds and snow squalls coming off Lake Huron which cause frequent white out conditions as illustrated in the photograph in Figure 3-2 taken in November 2005 along Hwy 21.

Once the general study area was located it was necessary to select the actual locations. Six potential sites were identified along a 26 km section of the highway.

The 1xRTT radio communication coverage along the area was checked and confirmed to be excellent at all potential locations.

Figure 3-2 Hwy 21 taken on November 2005

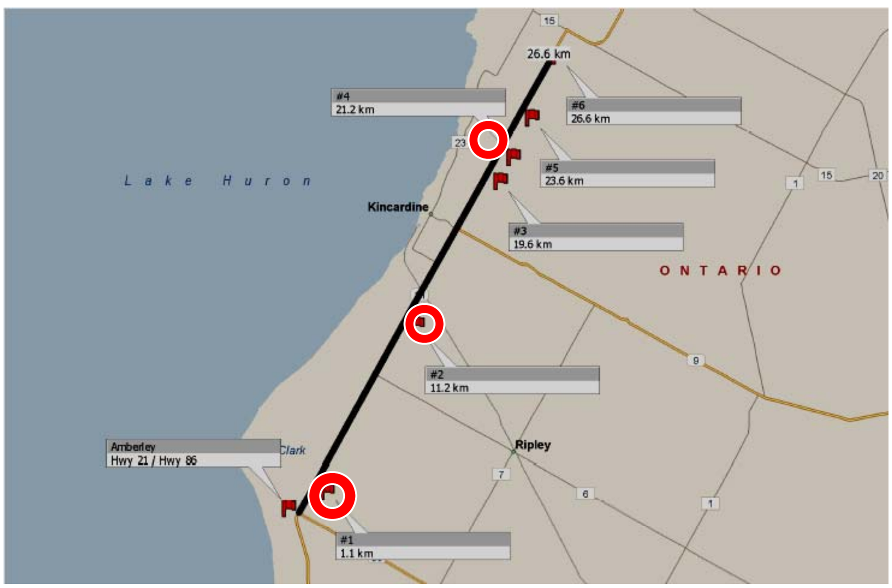


Figure 3-3 Three representative locations

Of the six sites identified three were selected (sites #1, #2 and #4) to be the best representative locations as identified in Figure 3-3.

3.2 Installation and Commissioning

The field equipment was relatively easy to install and verify. Prior to field installation a "dry" run was conducted at MTO's maintenance yard in Toronto to verify wiring, controller software, sensor setup and installation of the solar panels.

All sensors and solar collector equipment is pole mounted. The sensors were designed to be pole mounted and were delivered with the mounting details suitable for this arrangement. The four solar panels required to be broken up into two groups to be mounted on the same pole. The only item that required a special or custom mounting bracket was the CCTV camera. The dome camera required to be hung upside down away from the side of the pole.

The major design consideration for mounting was the proper placement of the sensor with respect to geometry and minimum height requirements stipulated by the manufacturer.

The installation required very little civil works and did not involve the disruption of the pavement surface. Each of the sites required only a culvert to bridge the drainage ditch for proper access during winter conditions.

In order to mount the standard, base mounted, MTO ATC cabinet a pole was driven into the ground and a base plate mounted over the end of the pole to support the ATC cabinet.

Weather conditions during the installation and commissioning were problematic. In spite of the "dry" run installation and previous testing some debugging of the wiring was required and minor updates to the controller software was necessary. Software updates and adjustments to sensor and algorithm parameters are performed via the communications link hence site visits are not required for this purpose.

The stations were commissioned November 15th and although data was collected it was not until December 21st that the final user interface was completed and all hardware and software issues resolved. Data was collected and evaluated from November 21 2005 through March 27th 2006.

3.3 Data Collection

3.3.1 Automatic Data Collection

In the previous sections, which described the system and associated sensors, the method of automatic data collection was described. This section reviews that information and provides a little more detail on the data collection and averaging processes followed.

The AMS-ATC controller interfaces to three sensors mounted on the pole. The Sentry visibility sensor unit, The EIS RTMS detector unit and the Sony IP encoded CCTV camera.

3.3.1.1 Visibility Sensor Data

The visibility sensor is configured to provide 60 second averaged meteorological range (MOR) extinction coefficient values every minute over an RS-232 communications to the ATC. The ATC averages this one minute MOR sampled data over a five minute period to obtain a visibility reading. This visibility reading is first compared against configurable threshold values to determine if a visibility event is to be raised. Then the data and the event information are passed to a central data collection process to be communicated to the central server.

3.3.1.2 Traffic Detector Data

The RTMS traffic detector is interfaced to the ATC through an RS-232 serial interface. The RTMS unit is configured to provide data over a fixed polling cycle for the north bound lane and south bound lane of traffic on the Highway 21. The unit provides average speed, occupancy and volume data for each of the two lanes. The traffic data is then averaged by the ATC over a five minute period and passed through a incident detection algorithm to determine if a traffic event is to be raised. Then the data and the event information are passed to a central data collection process to be communicated to the central server.

3.3.1.3 CCTV Camera Image Data

The IP encoded CCTV camera has two different interfaces to the ATC. The first interface is through a 10BaseT Ethernet interface and the second is through a digital I/O control interface. The camera unit is configured to record a video 5 second clip and transfer the video over the Ethernet interface to the ATC upon the activation of the camera digital I/O over the control interface. When an event is raised by the ATC, it activates the CCTV camera digital I/O causing the capture and storage of a video clip. The system event could consist of a visibility event, traffic event, peer event (an event set by a peer AMS station) or manual event (operator manually triggered event).

3.3.1.4 Data Communications

To optimize data transfers to the central server over the PCS communications a special data collection task consolidates the data from the visibility sensor, the traffic detector and the CCTV video. The consolidated information package is communicated to the central server at 15 minute intervals.

The central server receives the sensor data from all three AMS stations and logs the data to a relational database management system (RDBMS). The historical data is made available to the project team members through the browser interface.

3.3.2 Observations

In order to co-relate the data from the sensors and the video images captured by the system with actual visibility in the field observations were obtained from the OPP officers and MTO road patrollers.

The OPP officers driving past the stations were asked to radio in visibility and road information when they passed the AMS stations in the field. The radio operator in the control centre would then fill in the AMS Manual Event Form and create a manual event as discussed in Section 2.8.5. It was noted that in some cases the “observations” were identical at all three locations and the events had the same time stamp. The data recorded in these cases sometimes varied significantly in these cases. It suggests that a single observation may have been made and applied to all three locations in order to generate three “manual events” for comparison. The observations obtained through the OPP officers provided the most detailed and timely data for comparison.

The MTO Patrollers drive a predetermined route through the region and prepare a traffic conditions report at the end of the route and provide interim radio reports which are noted in the radio log. Since this information is not closely correlated to the time of passing a station or conditions specific to the station it was used to co-relate general road and weather conditions only.

Road closures are ordered by the OPP when conditions reach a point when road travel is considered unsafe. This can be due to visibility or a variety of other conditions including excessive snow or ice covered roads prior to maintenance activities. MTO causes the road to be closed or open based upon the OPP decisions. MTO utilises the reports from the Patrollers and road weather information stations to manage road maintenance. Once the conditions have improved and the maintenance forces have cleared the road the road can be re-opened. Since there could be a significant time lag between the time when conditions improve and road opening this needs to be considered when evaluating the data. This time lag will increase substantially for instance, if there are stranded vehicles which need to be removed prior to maintenance activities.

The field observations and the data recorded by the system were at times difficult to co-relate and verify. Section 4 of this report provides an analysis of this correlation and the methodology for collecting the field data evolved throughout the data collection phase. It is believed that further field observations during subsequent seasons will have more consistent results due to a more rigorous data collection methodology.

4 EVALUATION

Ultimately, the AMS role is to gather field information that can provide insight about driving conditions on a highway at remote locations in order to take decentralized decisions autonomously. The intended goal of complementing basic AMS traffic monitoring devices with a visibility sensing device is to generate visibility alerts based on visibility thresholds, traffic conditions and conditions at adjacent stations. If proven to be sufficiently reliable for the detection of poor visibility conditions, it can then be expanded to provide visibility alerts to operational agencies, media and travellers, etc. Peer-to-Peer (P2P) functionality between neighbouring AMS sites could increase the general reliability of the decision process as well as provide back up opportunities within the network of stations. As well as generate alerts, the AMS would provide alerts when condition improves. Thereby allow roads to be re-opened sooner and more efficiently.

This section of the report provides an evaluation of the results of the pilot project with respect to the three identified objectives. These are determine:

- the suitability and reliability of the 1xRTT communications infrastructure for this purpose,
- assess the feasibility and reliability of utilizing solar power and a general purpose ATC to support a variety of sensor technologies, and
- whether these technologies and sensors could be used to as a tool to meaningfully assess visibility along the roadway.

Section 4.1 provides an assessment of the technology deployed. Sections 4.2 discuss the methodology used to analyse the sensor data. The visibility and traffic data collected are analysed in Sections 4.3 and 4.4 respectively. An analysis of specific road closure events is presented in Section 4.5.

4.1 System Performance

System performance is considered as to be how well the hardware, software, sensors and communication service supported the collection of data and subsequence analysis.
System performance is impacted by equipment failures and limitations as well as software issues which may affect data collection. The evaluation period covers from November 21st, 2005 through March 27th, 2006.

4.1.1 Communications

The communications network operated nearly flawlessly. The signal levels were consistently strong and noticeable retransmissions or data loss did not occur.

The service utilizes dynamic IP addressing which required that the central server manage the IP address tables. The IP addresses are changed by the service provider typically every 12 hours. When this occurs the AMS node can not communicate and needs to initiate a process to obtain the new IP address Table. This results in a failure which typically caused a loss of 15 minutes loss of data twice a day. Although this is not significant, an operational system would incorporate a method of double buffering to ensure that the data is sent successfully after communications is restored.

During the course of the project a failure of one of the modems was experienced and it had to be replaced. This caused data loss from February 21, the time of failure, until February 24, when it was replaced. The failed modem showed signs of water damage which may have been caused when the cabinet door was opened for inspection or by snow blown in through the fan (disconnected) at the top of the cabinet.

The database server experienced intermittent problems accessing the Internet in the morning of February 22 which also resulted in the loss of some data before the fault was identified. In an operational system additional data could be stored on the AMS to protect against these sorts of normal occurrences.

The availability of the communication network approaches 100 %, particularly if the data losses which occur during IP address changes are eliminated.

4.1.2 ATC Hardware and Software

The ATC's utilized on the project are specially designed for operation in a highway environment and are specified to the full NEMA temperature range hence temperature related problems were not expected even though the heaters in the cabinets were removed to reduce the power consumption.

Prior to deployment one of the ATC's failed and had to be replaced. A second unit failed in the field and refused to start up. Prior to returning it to the manufacture it was tested in the office environment it was found to be able to operate. Environmental testing and qualification is particularly important in AMS installations where limited power precludes general cabinet heating.

The ATC software was designed to operate in an unattended environment and a number of processes are included to manage and recover from failure. Software revisions can be downloaded through the communications network and the AMS node rebooted. In addition parameters can be downloaded and implemented without rebooting the entire node. During the initial deployment it was determined that the failure recovery process was not robust enough. The associated processes were redesigned successfully to increase the reliability necessary for unattended operation.

An abnormality was noted on visibility data received on February 23rd and 24th . The readings were extremely high, beyond the maximum reading of 9999 m. This was caused by a temporary problem with the sensor, likely related to snow build up. It was also compounded by the averaging process which over weighted the very high, out of range readings. The averaging process was updated February 27th to mitigate the effect of this problem. It is noted that the visibility sensor is equipped with a hood heater which can be turned on at the server; however this was not tried during this single abnormal occurrence.

The ATC's and associated software operated very well after the initial start up was completed other than the ATC hardware failure noted above.

4.1.3 Visibility Sensors

The visibility sensors operated well with the only technical problem the abnormal readings discussed in the previous section.

The major issue with the visibility measurement is not with the sensor but the mounting location. Ideally the sensor should be mounted at the motorist's eye height; clearly this is not practical since they would be buried in snow and susceptible to vandalism. They also should be mounted as close to the road as practical. In future installations the sensors should be mounted at a consistent height as low as practical to address visibility issues closer to the ground. The impact of sensor height is discussed in the following sections of the evaluation report.

The visibility sensor measures MOR co-efficient which is a small number (<< 1) which is then converted to meters through an inverse relationship. A very low sample, representing excellent visibility, would have low accuracy which impact the sampling error. To improve the accuracy of averaging calculations; these calculations should be done in MOR with only the final number presented in metres.

In the event of snow build up it is necessary to activate the hood heaters. A mechanism to accomplish this automatically is preferable.

The visibility sensors operated very reliably with no unavailability attributable to them other than the issue of the abnormal readings at one location for about 20 hours.

4.1.4 Vehicle Detectors

The vehicle detectors operated with out any failures during the course of the pilot project.

However, it was necessary to re-calibrate them early on in the project to correctly match the vehicle location to specific lanes. In order to calibrate the unit traffic is required; the very limited traffic volume on Hwy 21 made this more difficult than normally would be the case. As well in a rural winter environment traffic does not always stay in the lanes since lane markers are often not visible. The units operated well with some problems with lane differentiation for the reasons described above.

A speed measurement abnormality was identified at AMS 1; southbound speeds were consistently below northbound. After a number of speed controlled drive by's it was determined that the speed was reasonably accurate. It was speculated that when southbound drivers approached the village of Amberley they start to slow down well in advance of the village.

4.1.5 Camera and Video Decoder

The cameras provided for the project by Sony had a number of desirable features. They provide both a day time colour setting and a monochrome night time low light setting with automatic switching. Integral to the camera is an MPEG 4 encoder as well as standard analog NTSC interface and the camera can be triggered with a digital signal to capture a video stream. The camera was supplied in a small environmental dome enclosure suitable for easy mounting.

A number of difficulties were experienced in the field which caused problems for the MTO users and to a certain extent the evaluators. These difficulties and possible resolution are discussed below.

MPEG 4 Decoder

The camera was tested prior to deployment using the vendor's software. However, since the database server and browser applications were not completed prior to initial deployment the software was not integrated into the interface. It was determined after many discussions with the supplier that there were some proprietary components of the MPEG 4 encoding scheme which prevented a tight integration with the browser.

The intended design was to allow users to select the desired video clip using the mouse and having the video stream played using a standard MPEG 4 browser plug in player. This would provide a user friendly interface. Instead it was necessary to download a small player application from the database server then download the video clip as video file. This video file could then be played using the player. The video player only needed to be downloaded once however the additional steps required to download the video file then display it using the player was aggravating. Members of the evaluation team who used the application frequently were able to put up with this inconvenience; however, infrequent users found it frustrating and in some cases gave up trying to view the images.

Although this solution is workable for the pilot project it is not suitable for operational deployment. A solution is to use a separate MPEG 4 encoder to encode the NTSC video into a standard format which can be viewed as designed through a standard browser with a single or double click.

Camera Icing

During the data collection phase of the project there were times when the camera or the dome housing appeared to be covered with a thin film of ice, providing very limited and unusable video. In order to overcome this problem intermittent heating of the camera housing or dome would be required. A scheme is necessary however to minimize the power consumption required to meet this requirement. It would be possible to cycle the heater on a periodic basis to remove the ice or upon operator command using the browser interface.

Camera Configuration

There are a variety of configurable options possible with the camera. These are set using a network connection to a computer and through a set of digital input points. Relevant options include how the camera is to switch between night and day modes. There was some difficulty in selecting the automatic mode and one camera appeared to lose configuration data. The camera can be switched between day and night modes using the contact closures which could be used to provide more operator control. As well a network bridge to the ATC could be used to set up or adjust the configuration remotely,

4.1.6 Database Server and Browser Interface

Database Server

The database server was based upon open source database software on a dedicated server running Linux. The database performance met all of the requirements and no hardware or software failures were reported. Data export features met all of the requirements of the evaluators. Certain data; such as the Manual Event Reports, required access to the database server and could not be exported through the browser interface however database users could easily access this data.

As noted in the section on communications Internet presence of the server was lost on some occasions due to intermittent failure of the link to the Internet Service Provider and due to firewall reconfigurations. Although these failures were considered minor during the evaluation period, in an operational system a mechanism to prevent loss of data is required. In addition, data in the database should be backed up on a regular basis in accordance with good practice.

Browser Interface

The browser interface was designed to provide the investigators access to the data for offline analysis and to provide a means for the OPP and MTO to enter observations. As such it served its function very well. However, as an operational tool there is clear lack of functionalities. These and lack of a user friendly means to access video images and data left the operators frustrated. In an operational system the following changes were identified by the users as required:

- the video interface needs to be integrated into the browser functionality (this was the largest single complaint)
- single click video with longer video stream when requested
- alarms and alerts are required which advise an operator when abnormal conditions occur and when they are cleared
- display of current conditions directly on the map interface (i.e. it should not be necessary to directly access the station or reports) as only visibility data is currently provided
- Field Reports and Road Closure Data to be displayed on the main screen when relevant
- future capability to interface with dynamic message signs for alerts and road closure advisory.

As can be seen these requirements are focused upon making the system into an operational system. As well the developers have identified a few modifications to enable an even more robust design. These include more remote configurability of communications, attached devices, amount of data stored and data redundancy in the controllers.

4.1.7 Solar Power

An important aspect of the pilot project was to demonstrate that a solar power source could be successfully utilized for the AMS using conventional ATC's and sensors.

The design minimised power consumption by disconnecting inactive components of the ATC and by powering off sensors when not in use. Specifically the camera was powered off when not in use. Heaters for the visibility sensors were connected to digital outputs of the ATC and only activated if required. As noted in the previous section of the report it may be necessary to install and activate heaters to clear the camera housing and snow build-up on the visibility sensor.

The power consumption of the ATC and sensors were measured and estimates were made on the duty cycle of the camera and modems. The sizes of the solar panels and storage batteries were based upon solar patterns for the region with sufficient power storage for a week of sunless days.

Since the investigation into the use of solar power was only one component of the study and power was available through the study area, back up power was available through the Hydro One, the power utility. The power was connected to a power supply through a relay network which would only connect primary power if power was not available via the batteries. The state of the relay, ac or solar, was available to be monitored at the server. Although a switch-over to the ac power did occur on one occasion it was likely caused by transients of the ac power during winter storms affecting the basic relay logic and not a result of depleted batteries.

The solar panels became snow covered by heavy blowing snow. The researchers were concerned that this would impact the capability of the solar charging system. In spite of very severe snow coverage no failures were experienced. It is speculated that the photo-optic conversion which occurs on the panel surface creates sufficient heat to clear the panel of snow once the storm finishes.

The solar panels provided reliable power throughout the winter and are clearly a viable method to power the AMS. The power calculations were developed based upon conservative design rules and hence some margin is to be anticipated. The actual power usage information is not available. The actual power consumption data would be useful to determine the available reserves to power heaters for the camera housing and visibility sensor hood for future testing set-ups.

The solar power system meets all of the system power requirements. However, although no failure was observed, the current set up does not provide data to establish reserves and sunlight conditions during the testing period. This monitoring setup (hence outside the AMS power consumption equation) could prove to allow for less expensive power supply equipment or additional sensing devices provision in the future.

4.2 General Analysis Methodology

During the initial stages of this pilot project, tools to collect data were developed within a 'minimal functionality' user interface (UI). These were designed to obtain organize and make available reliable data from visibility sensors and traffic sensors in order to generate a database to be scrutinized off line as opposed to a more thorough "online use operation centre" designed UI.

Visibility is a key factor that affects drivers' decision making under inclement weather conditions. On Highway 21 near Kincardine, drifting snow and whiteouts cause frequent road closures – 11 closures in 2003 and 16 in 2004 – as well as collisions. Using visibility sensors, combined with traffic sensors and video images, the relationship between poor visibility, traffic, and road closures is investigated in order to support the decision-making process for OPP and MTO regarding timely road closures.

Data analysis was done using Microsoft Excel spreadsheets to combine data on system events, visibility, traffic and images on a weekly basis. Chart preparation and analysis were selected to provide an initial insight into data correlation for development purposes. These results were also put in perspective using visibility events video images collected by the system. It was not planned for this project to rely highly on mathematical modeling but rather to provide an exploratory overview of the various parameters that could later feed into a more sophisticated modeling effort.

Four stages of data analysis and evaluation during the development and adjustment of the implemented system can be described as follows:

Stage 1 – Nov 15 to Dec 21, 2005

After the initial system start-up was completed and a few remaining system hardware and software problems were worked out, **data and their trends were investigated during the first weeks of data collection**.

Stage 2 – Dec 21, 2005 to Jan 30, 2006

As all stations were reported fully operational by the end of December and the latest version of the user interface was finalized, **evaluation and fine-tuning of thresholds for speed and visibility readings were explored.**

Stage 3 – Jan 31 to Feb 27, 2006

As the system was stable and bad weather events were observed, **data were explored and defined and the correlation environment was analyzed** with a view to finding a reliable and efficient advisory diagnosis tool for operational personnel.

Stage 4 – Dec 21, 2005 to Mar 27, 2006

i. *Dec 21, 2005 to Mar 6, 2006*
An **exploratory threshold matrix** was tested based on previous findings for relevant sensing devices, and on a conceptual approach using a minimal number of sensors

for better power efficiency, bearing in mind that video image references will always remain a "must provide" support to OPP and MTO field personnel for confirmation and sound judgement/decision about highway closures.

ii. *Mar 7, 2005 to Mar 27, 2006*
Weather/traffic data collected were monitored and an **exploratory severity index was validated** based on visibility and wind speed. The need for other devices for the severity index development and efficient event flagging (read minimize false alarms expectancy) was investigated.

The results of these analyses are reviewed in the following sections.

4.3 Visibility Data Analysis

Section 4.3.1 gives an overview of visibility, its definition, data collection, and initial threshold settings. Section 4.3.2 consists of correlation of visibility sensor data with field observations, video images, human observations, and actual road closures. The purpose of this correlation is to understand how visibility data, combined with other information, can assist OPP and MTO in monitoring road closures for drifting snow and whiteout conditions.

4.3.1 Definition and Analysis of Visibility Data

Visibility, Forward-Scatter Visibility Sensors, and Measurement

The American Meteorological Society Glossary of Meteorology defines "visibility" as "the greatest distance in a given direction at which it is just possible to see and identify with the unaided eye (a) in the daytime, a prominent dark object against the sky at the horizon, and (b) at night, a known, preferably unfocused, moderately intense light source."

Visibility sensors (forward scatter) measure atmospheric visibility, also known as meteorological optical range (MOR) by determining the amount of light scattered by particles (smoke, dust, haze, fog, rain, and snow) in the air that passes through the optical sample volume. The infrared light is projected from the transmitter to illuminate the sensor's scatter volume. A 42-degree forward scatter angle is used to ensure performance over a wide range of particle sizes. MOR is then calculated based on received signal strength. When the air is clear, very little light is scattered since there are few particles in the sample volume, resulting in a small signal received by the sensor. As the number of particles in the sample volume increases, the amount of light detected by the receiver also increases. In short, visibility is a function of air particles content or air quality.

The definition of visibility and the function of visibility sensors determine two implications for highway applications. First, the same visibility will result given the same air quality, regardless of daytime or night time. However, a driver's visibility at night is also dependent on other factors, including ambient light. Second, the sensor measures visibility at the height of the sensor; for the data to be representative of driver visibility, the sensor has to be at or close to the driver's level.

Note to the reader: Implemented sensors have a limit of 10,000 meters. Hence all visibility conditions greater than 10,000 meters are reported as 9999 meters readings.

Initial Visibility Thresholds

A visibility threshold is the value beneath which driver behaviour and traffic are expected to be impacted significantly. If the visibility is above the threshold, there should not be much impact on driving or traffic; if visibility falls below the threshold, especially with respect to minimal stopping sight distance (SSD), drivers would need to drive cautiously or even slow down to avoid collisions.

The MTO defines visibility as 'fair to poor' when a driver' range of vision is reduced to 500 m or less and 'Nil' when it is less than 50 m. Hence, the initial 'poor' visibility threshold was set at 500 m and a 'clear' threshold was set at 550 m. When visibility drops below 500 m, a "poor visibility" event is logged by the system; and a "clear visibility" event is later logged when visibility climbs back above 550 m.

A short video clip is automatically collected and archived for every declared visibility event. Some weeks into the project, the system was updated to ensure a more thorough comparison of field conditions between the logs of 'poor' and 'clear' events. Additional images were collected at 30 minute intervals during poor visibility periods. The manual triggering function also allows system operators to capture additional videos at any given time.

Data Averaging Reporting Basis – 5-min average data

The team met with Environment Canada and confirmed that 5 minute averages are normally representative of visibility values with sufficient details, without too much fluctuation. The visibility data collection was based on this time value. A few weeks into the field implementation of the project, traffic data were also archived on this basis as opposed to the usual 15 minutes engineering practice. This allowed for a more cohesive analysis of the data collected.

Bad data

Occasionally, out of range data were reported. For one instance, data were out of range continuously for about 20 hours, on February 23, 2006. This is discussed in a previous section of the report

4.3.2 Correlation of Visibility Sensor Readings with Field Observations

The purposes of correlating sensor data with observed data are:

- Assess how closely the sensor data compare with human observation.
- Based on sensor data, interpret what information OPP used in making road closure decisions, i.e., how low did visibility drop? For how long? What other factors were considered?
- Establish visibility thresholds to assist OPP in making decisions about road closures in an informed and timely manner.

4.3.2.1 Visibility Sensor Readings and Field Visit Observations Comparison

Figures 4-1 to 4-5 show photos taken during a field visit on December 21, 2005, between 11:40 a.m. and 12:45 p.m.. It was observed that visibility was poor or nil when passing through drifted sections, at driver's level. For example, Figure 4-4 shows that the lower part of the departing vehicle was about 2 hydro poles away, which is equivalent to about 100 meters.

During the same period, the lowest/highest 5 minute visibility values were recorded at 500m/767m, 715m/2417m and 905m/1197m respectively at Site #1, Site #2, and Site #3.

Two conclusions are obvious from the field observations made on Dec 21st and were confirmed with subsequent comparison of sensor data and camera images:

- First, visibility varies significantly depending on locations along the road. It is poorer in the presence of lateral snow banks and strong east-west oriented wind causing snow drifting at about 2m above the road pavement **(Figure 4-1)**.
- Second, visibility can be significantly lower at driver eye level – about 1.3 meters above the ground – due to drifting snow, compared with readings from visibility sensors mounted at greater heights (4.5 m at site #1, 5.0 m at site #2, and 7.4 m at site #3). From qualitative observations, a 500 meter sensor reading – if drifting snow is occurring – could correlate to visibility of 100m on the ground.

Because the site equipment set-up was designed to evaluate 3 sites in a Peer-to-Peer wireless approach, it was decided to proceed with this implementation and data gathering and analysis. As mounting heights greater than 3 m are a pre-requisite because of snow accumulation and possible vandalism along highways, it should be noted that prior to any operational deployment a test bed type of implementation should explore the relation of 3 to 5 m mounting height readings compared to driver eye level readings under various weather conditions and snow bank heights.

From further visual examination of visibility sensor data, it appears that clusters of data often form when visibility falls below about 1000m. As shown in **Appendix A – Chart 4.1**, visibility dropped below 1000m between 05:00- 05:40 and 07:35- 09:45 on February 3, then again from February 4 at 16:25 for persistent periods into February 5. These clusters point out the occurrence of a different regime of visibility behaviour and the fact that a 1000 m sensor reading could be indicative of the occurrence of poor to nil visibility conditions. Hence, based on this observation and the observed difference between 5-7 m high readings and driver eye level visibility, visibility sensor thresholds needed to be reconsidered.

On February 3, 2006 onwards, the system visibility thresholds were changed to 1000 m to log "poor visibility" events and 1200 m to log that "good/fairer visibility" had resumed.

Figure 4-1 Drifting snow causing poor Visibility at driver's level: Dec 21, 2005, 11:45

Figure 4-2 December 21, 2005

Figure 4-3 Dec 21, looking south while a car approaches site 1 (left side of the Photo); hydro poles visibles

Figure 4-4 December 21, 2005, 12:34 near site 3, looking south

Figure 4-5 December 21, 2005

4.3.2.2 Correlation with OPP/MTO field input – Visibility

Table 4-1 summarizes field input provided by OPP. This information was noted during field patrols and later provided to us. A total of 28 observations were recorded by OPP during February 2006. Detailed data is provided in **Appendix A – Table 4-B**

When comparing visibility sensor data with OPP field observations a ‘logged’ status is set for a reported event:

- when OPP reports low/nil visibility (0-300 m) while sensor data register below the threshold of 1000 m;
- when the lowest visibility readings within an hour’s time (+/- 30 minutes from the OPP reported time stamp) register below the threshold of 1000 m readings. The purpose of this check is to void any time lag that may exist between the OPP field input and visibility reading time stamps.

Other events are considered ‘unlogged’ since below threshold values are not logged by the system for these OPP patrol reported poor visibility event.

Table 4-1 Summary of OPP observations correlated with Visibility Sensor readings

Logged/Unlogged	# of records	%
Logged	14	50%
Logged within an hour	3	11%
Unlogged within an hour	11	39%
Total observations reported	28	100%

Overall, 50% of the OPP field observations corresponded to logged ‘poor visibility’ events, i.e., at the time OPP reported poor/nil visibility (0-300 m), visibility sensor data showed values below the threshold (1000 m). Taking into account the check within an hour’s time, an additional 11% of reported cases were logged. The 39% remaining ‘poor visibility’ episodes reported by OPP field observations show visibility values between 2100 m and ‘9999 plus’ m at the time.

Two conclusions can be drawn from these results and previous observations:

- First, numerous unconfirmed cases point again to potential discrepancies between sensor readings at mounting heights and field observations at driver eye level. A possible explanation of the discrepancies is the fact that OPP provides an overall assessment of the highway rather than specific AMS site observations.
- Second, experienced field operations observers may have gotten used to the harsh conditions along highway 21. This was somewhat confirmed during field visiting on December 21, 2005. Figures 4-1 to 4-5 show what could appear to be difficult driving conditions in the opinion of many less experienced drivers. Sensors reported 500 to 700 m visibility readings. Yet, on site, local MTO representatives reported the situation not too severe at that point in time. As we will see later in this report, vehicle speed data at these particular time do not automatically show significant immediate reductions, as though local drivers also felt somewhat comfortable with driving

conditions, in contrast with much harsher conditions when significant speed reduction were clearly observed.

The road conditions vary quite dramatically from location to location and although data is recorded for all three AMS locations it is likely that the observation made at one location, or on the average, was applied to all three locations. The Manual Event form allows data to be copied from the previous entry which may have compounded this question.

4.3.2.3 Correlation with Road Closures

There were 7 road closures in winter 2006**. Appendix A – Charts 4.2, 4.3, 4.4, 4.5, 4.6, 4.7** show the 5-minute visibility and traffic speed data at station 2 during road closures.

Table 4-2 summarizes visibility data at station AMS2 prior to OPP road closures:

- On Jan 18, ***70%*** of visibility readings were reported below 1000 m over a period of ***2 hours*** prior to road closure.
- On Jan 25, Feb 5, Feb 17 (2 episodes) and Feb 23, at least ***13.5 hou***rs elapsed between the time visibility first dropped below 1000 m and the highway closure; over that period, ***24% to 56%*** of the visibility readings were below 1000 m.; 2 hours prior to closure a significant (50%-70%) portion of the readings were below 1000 m.
- On Feb 25, the visibility data did ***not*** indicate any readings below 1000 m and yet the highway was closed. At station AMS1 only a few readings below 1000 m were noted at that time.

Table 4-2 Summary of visibility data prior to road closures in 2006 winter

Date of road closure	Time elapsed between first visibility drop below 1000 m and initial road closure (hh:mm)	Lowest visibility prior to road closure (m)	% of visibility less than 500 m prior to road closure	% of visibility less than 1000 m prior to road closure
Jan 18, 2006	1:55	286	57%	70%
Jan 25, 2006	18:30	262	8%	24%
Feb 5, 2006	26:15	80	40%	56%
Feb 17, 2006	13:30	111	21%	38%
Feb 23, 2006	16:50	66	21%	24%
Feb 25, 2006	20:05	595	0%	1 %

It appears that trend analysis of visibility data would be helpful for decision support but it is not shown to be sufficiently reliable in itself. Although these few event records confirm that trends in visibility sensor readings – even at 5-7 m mounting heights – can be fair indicators of conditions justifying potential closure, other reasons can demand/trigger road closure, such as pavement conditions, drifting snow, and whiteouts that cause poor/nil visibility at driver level but may not be reflected at the sensor's height.

Since roads are closured for a variety of reasons other than visibility the degree of co-relation appears to be reasonable.

4.3.2.4 Correlation with Video Images

Ultimately, video images will always be preferred to confirm driving conditions and 'poor' visibility events. During the evaluation period, video images were used to compare visibility readings with human observations, in order to assess how accurately videos can be used to visually confirm poor visibility conditions. **Appendix A – Table 4-A** presents, in chronological order, a summary that merges various pieces of information relating to the evaluation of visibility at all AMS stations. Observations are summarized as follows:

- Initial daytime images for AMS3 were of poor quality because of some camera "auto adjustment to daytime" functionality problems. Once corrected, images were of useable quality and still provided night time views because of nearby yard lightning.
- Night time images for sites AMS1 and AMS2 could not supply visual information unless vehicles were passing by and providing artificial lighting at the time of video capture.
- The camera lens protective cover got iced up a few times rendering captured images of poor quality and limited usefulness.
- Significant discrepancies (sensor readings in the 7000 m to 9999 m range and OPP reports below 500 m) were usually linked to blowing snow conditions with, in some cases, heavy snow fall. Images for these cases appear to be of "poor" to "fair" visibility.
- Lower range discrepancies (sensor readings in the 500 m to 1500 m range and OPP reporting in the 0-150 m range) are usually linked to blowing snow conditions with, in some cases, strong winds and slippery road conditions. Images for these cases show either partially snow-covered roadways or an iced-up protective lens cover.
- Discrepancies under clear conditions (sensor readings in the 500 m to 1000 m range and OPP reporting clear conditions) were usually linked to images of covered skies (fair visibility) and snow-covered roadways.

One major issue arises from our observations in regards to the nature of the IP camera and its limited capacity for image reporting in situations during poor light conditions. At night, which represents most of a 24 hour day period in winter, the camera at site 3 could show images because of the presence of a nearby truck yard light pole. Although only short range visibility was ensured, this light was sufficient to provide some night time assessment of weather conditions and precipitation as well as pavement conditions. Future testing site selection should take into account existing local highway/street lighting to help extend the observation period. An alternative could be to initiate a video recording triggered by a moving vehicle as it has been observed in several videos that vehicle lighting is very helpful in providing a brief indication of weather conditions and precipitation as well as pavement conditions. An alternative camera type (infrared more specifically) should also be considered to mitigate this situation.

In Summary

- Visibility sensor readings at 5-7 m mounting heights appear to be 5 to 10 times greater than human observation visibility estimates at driver eye level, based on field visits and OPP observations.

- For our site specific observations and mounting heights, visibility readings below 1000 m could be related to poor/nil visibility at driver eye level and hence 1000 m was considered a logging threshold for poor visibility.
- 61% of OPP observations of poor/nil visibility conditions in February 2006 confirmed visibility sensor data logging below threshold (1000 m) values within an hour of the observation time. 39% of OPP reported poor/nil visibility conditions in February 2006 are matched with visibility sensor data greater than 1000 m. Overall assessment by field personnel of visibility at driver eye level over a section of highway may differ from site specific and 5-7 m mounting height readings and images.
- Possible identified visibility patterns prior to highway closure could be tested over time: at least 24% of visibility readings below threshold over a 13.5 hour period, and at least 70% visibility readings below threshold over a 2 hour period.
- Visibility is only one of that factors that trigger road closure. For instance, the visibility sensor data was not indicative of closure on February 25. Other factors such as heavy precipitation, drifting snow due to high winds, road conditions, or accidents may have triggered the closure; but these are beyond the scope of the visibility and traffic sensors tested.

For precipitation identification, the availability of more sophisticated visibility sensors providing precipitation type and severity could be used to obtain more weather related information. Recently some roadway condition sensors based on ultrasonic technology have been made commercially available and may prove to be helpful.

4.4 Traffic Data Analysis

It is expected that drivers will slow down as visibility is reduced. The purpose of analyzing the relationship between traffic data – speed specifically – and visibility is to evaluate visibility thresholds based on driver speed selection behaviour.

4.4.1 Analysis of Traffic Data

Highway 21 is a 2-lane rural highway with a posted speed of 80 km/h between Amberley and Kincardine. The highest AADT (Annual Average Daily Traffic) (2002) was below 10,000 vpd (Vehicles Per Day). Under normal winter conditions, traffic speeds average about 105 km/h.

4.4.2 Correlation of Speed with Visibility Data

Prior to road closure, speed drop trends are consistent with visibility reduction, as shown in **Appendix A – Chart 4.8** On February 4, over a period of 30 hours prior to road closure, southbound speeds dropped from an average of 105 km/h to an average of about 75 km/h while visibility felt below 1000 m. In the northbound direction, average speed decreased from 105 km/h to 35 km/h at highway closure time.

Figure 4-6 Feb 17, 2006 at 12 :13 p.m.

Sometimes, speed dropped independently of reduction in visibility. As shown in **Appendix A – Chart 4.9**, between 6:30 and 16:45 on February 16 (road closed at 6:15 on February 17), average speed dropped to about 95 km/h but average visibility remained at '9999'. Factors other than visibility may have caused the speed drop, such as road conditions, drifting snow, as shown on Feb 17th video image or accidents.

In summary

1 Speed drop occurred at about the same time that visibility dropped below threshold. As such, speed reduction patterns can be an indicator of deteriorating driving conditions impacting driver behaviour. As for incident detection on urban expressways, the speed/occupancy relationship appears to be an additional key factor that could provide assistance with road closure decision-making based on existing algorithms.
2 At certain times prior to closure, speed variation patterns can be significantly atypical in duration and severity. Major differences between northbound and southbound directions are also noted. This may have something to do with the low volume traffic conditions.
3 On February 16, speed dropped without any reduction in visibility and subsequently the road was closed. This suggests that visibility and traffic sensors together remain an incomplete set of indicators to pinpoint the development of difficult driving conditions. Other indicators such as wind and road conditions would complement road closure monitoring.

4.5 Analysis of Road Weather Events

Previously exposed visibility readings at 5-7 m mounting heights have been shown to be too variable and did not give an accurate representation of driving conditions. Consequently, it does not appear advisable to base decisions regarding road closures or openings solely on these visibility readings. It became evident that more weather-related measurements needed to be included to better explain our observations and results.

No weather detection devices were included in the AMS equipment that was set up. Weather data availability can be provided from the Road Weather Information System (RWIS) station network database. Although not a specific AMS site selection criterion, two RWIS stations are present in the vicinity of the HW 21 AMS site corridor along Lake Huron.

- Station SW-12 is located just south of Amberley (at Regional road 86, just south of AMS1 and about 10 km south of AMS2).
- Station SW-06 is located south of Port Elgin (about 12 km north of AMS3, between Concession roads 4 and 6).

As the weather monitoring instruments at these stations are typically located at least 6.5 m above ground, their readings are very similar to what could be expected at the top of a AMS site pole. Archive data from these RWIS were made available to us and were downloaded online on a weekly basis. Wind speed was initially considered the most useful variable for analysis as it generates drifting snow, which has the worst and greatest negative known impact on driving conditions for roadway users in the area under observation.

As the three site system became fully operational, a massive amount of data was available for analysis. Data from all three stations were monitored and reported in the format of a collection of weekly charts (Monday to Sunday) separate from this report. RWIS data were also separately downloaded and merged into chart-generating spreadsheets.

Although all three AMS sites were monitored, section 4.5.1 only deals with data from AMS1, because it was the only one close to an RWIS station. Furthermore, we concentrated our analysis on highway closure periods.

4.5.1 AMS and RWIS Readings during Road Closure Occurrences

Data from the field, once charted, pointed out general periods during which Highway 21 was closed in the form of a clear reduction in traffic data. Cooperation from OPP and MTO regional personnel was helpful in providing a precise time window for each reported event. Manual reports prepared by field personnel for bad weather periods, as well as their comments on the weather conditions and closure status, were made available.

Table 4.3 presents a list of all the reported highway closures for the months of January, February and March of 2006.

Note to the reader
As this section of Highway 21 has a long and strong history of bad weather and adverse driving conditions, local authorities and OPP as well as MTO field personnel keep a close watch on weather forecasts and are very active in the field when bad conditions are expected. Hence we made the assumption that each and every field-justified road closure was reported. Consequently, when similar conditions are monitored during a different period, it is assumed that observed field conditions (the "whole picture" so to speak) did not justify highway closure.

Table 4-3 List of reported HW-21 closures (Feb-Mar 2006)

Date and Time of Reported Closure			Reporting Sources (1)	Comments, References, AMS Observations
Closure Episode	From	To		
1	Jan 18, 2006, 05:00	Jan 18, 2006, 10:17	MTO Patrols	Chart 4.10
2	Jan 25, 2006, 03:30	Jan 25, 2006, 09:30	MTO Patrols	Chart 4.11
3	Feb 5, 2006, 18:40	Feb 7, 2006, 16:58	OPP, MTO Patrols	Chart 4.12 and 4.13
4	Feb 17, 2006, 06:00	Feb 17, 2006, 14:12	OPP, MTO Patrols	Chart 4.14 – Episode 1
5	Feb 17, 2006, 20:31	Feb 18, 2006, 07:58	OPP, MTO Patrols	Chart 4.14 – Episode 2
6	Feb 23, 2006 21:23	Feb 24, 2006 06:00	OPP, MTO Patrols	Chart 4.16 – Episode 1
7	Feb 25, 2006 18:11	Feb 26, 2006 02:09	OPP, MTO Patrols	Chart 4.16 – Episode 2

(1) OPP reports covered only February 2006

The following sections, 4.5.2 to 4.5.4, analyze in more depth the correlation between stations (concurring/opposing observations and advisory information) and discuss Peer-to-Peer operation potentiality. Finally, section 4.6.5 explores the potential for a severity index for road condition monitoring and decision support.

4.5.2 Correlation of AMS1 and RWIS Readings during Closure Occurrences

4.5.2.1 Closure 1

The first closure event reported for January 18 between 05:00 and 10:17 (**Appendix A – Chart 4.10**) shows the presence of two combining factors.

- Presence of wind speeds over 35 km/h (lower orange dotted line) for a sustained period prior to the event (about 10 hours).
- Presence of visibility lower than 1000 m (upper magenta dotted line) prior to (for about 2 hours) and almost throughout the event north of Amberley where AMS1 is located.

During the worst part of this event, the only images available were taken in the morning at 06:44. At that time, under vehicle rear lighting, the roadway appears mostly snow-covered and the weather shows precipitation. Shortly after the reopening of the highway, snow was smeared on poles, a sign of blowing snow under mild conditions. The roadway was covered with chemically wet snow, showing two sets of wheel tracks only. At other times that week, although wind speeds increased over 35 km/h, no visibility readings lower than 1000 m were recorded.

Figure 4-7 Jan 18, 2006 15 06:44

Figure 4-8 Jan 18, 2006 at 11:01

4.5.2.2 Closure 2

The second closure event reported occurred on January 25 between 03:30 and 09:30 (**Appendix A – Chart 4.11**) and shows the presence of two combining factors.

- Presence of wind speeds over 35 km/h (orange dotted line) for a sustained period prior to the event (about 10 hours).
- Visibility lower than 1000 m (magenta dotted line) prior to (for about 2 hours) and almost throughout the event.

- As the worst part of this event occurred mostly during the night, the only images available were taken prior to the highway closure on the 24th. At that time, the roadway appeared partially snow-covered and wet.

Figure 4-9 Jan 24, 2006 at 12:15

Figure 4-10 Jan 24, 2006 at 14:09

Due to the lack of images for this specific period and based on the newly-identified 'poor' visibility threshold (1000 m.) from data of this event, the video image recording activation process (local and central software) was revised in the following weeks to increase the number of videos available from the start and throughout an event.

Analysis of the chart shows that, at other times during the week, these two conditions (higher wind speed and poor visibility) were never present concurrently.

4.5.2.3 Closure 3

The third closure event was reported on February 5 (**Appendix A – Chart 4.12**) at 18:40. AMS1 is located south of Kincardine. Wind speed crossed the 35 km/h threshold for the first time that week on the 5th at about 15:00. For the whole day on the 5th, the available images show an iced-up protective lens cover as a result of wind carrying sleet, freezing rain or snow throughout the day.

Visibility was then, and remained, under 1000 m and often under 500 m until 19:55 on the evening of the 6th **(Appendix A – Chart 4.13**). During that period, as wind speeds slowly decreased to cross under the 35 kph threshold, visibility increased from the 500-100 m range to the 3000-6000 m range.

Images for the morning of Feb 6 and throughout the day show a roadway well-covered with patches of snow and ice and snow drifts along both sides of the highway, a sign of drifting snow at road level.

Again, although at many other times during these two weeks each of these two conditions was present, they were never observed concurrently.

Figure 4-11 Feb 5, 2006 at 18:11

Figure 4-12 Feb 6, 2006 at 07:40

4.5.2.4 Closures 4 and 5

The fourth and fifth closures were reported on Feb 17 (**Appendix A – Chart 4.14**). The first episode lasted from 06:30 to 14:12 and the second episode from 20:31 to 07:58 in the morning of Feb 18.

The prelude to the first episode, wind speeds increasing over 35 km/h, lasted about 3 hours with visibility readings sharply dropping from the 3000-6000 m range to the 300-500 m range. Vehicle speeds consistently dropped an average of 15-20 km/h during that period. HW 21 was then closed and not reopened until visibility had consistently crossed back over the 1000 m threshold with winds lower than 35 km/h.

Figure 4-13 Feb 17, 2006 at 08:55

Images for this episode occasionally show an iced-up protective lens cover and some less ambiguous pictures show bad visibility conditions and a partially covered roadway.

The second episode built up during an extensive fair visibility period where values around 1000 m were frequently observed for 3.6 hours prior to the closure. Halfway through, a sharp additional vehicle speed drop of 15-20 km/h was observed (lower vehicle speeds than during the previous episode). Yet on the night of Feb 17 to 18 the roadway was only closed after about 5 hours of increased wind.

Figure 4-14 Feb 17, 2006 at 07:08

Figure 4-15 Feb 18, 2006 at 06:58

During the closure, visibility below 1000 m (often under 500 m) was observed and wind speeds remained consistently above 35 km/h with several periods of gusts. HW 21 was reopened very shortly after visibility got over 1000 m (less than 15 minutes afterwards) and wind speeds went below 35km/h (about 90 minutes prior to reopening).

Figure 4-16 Feb 18, 2006 at 08:20

During the second episode, the situation was a bit inconsistent: at HW 21 closure, as winds were increasing from 35 km/h to close to 65 km/h, visibility remained lower than 5000 to 6000 m but was mostly better than 1000 m. After the road was closed, wind speeds between 50 km/h to 60 km/h were observed and yet visibility remained better than 7000 m for the next two to three hours. About 2 hours prior to the reopening of HW 21, wind speeds were below the 35 km/h threshold and yet visibility readings remained significantly below the 1000 m threshold. Several hours after HW 21 reopening, many visibility readings lower than 1000 m were noted with wind speeds lower than 20 km/h. Images at the end of that second episode clearly show difficult driving conditions (snow-covered roadway and poor visibility) and an upgrading of visibility conditions starting at around 07:00.

At other times thoughout that week (**Appendix A – Chart 4.15**), although visibility was frequently reduced to the 1000 m threshold and wind speeds got over 35 km/h for some periods, these two conditions were concurrently combined for only a few very short periods (+/- 1 hour).

4.5.2.5 Closure 6

The sixth closure was reported on Feb 23 at 21:23 and this episode lasted up to 06:00 on Feb 24.

This event (**Appendix A – Chart 4.16**) is different from the previous ones. Prior to the closure, the only lower visibility episode noticed (about one hour in duration) was in the morning of the 23rd. During the day of the 23rd and the morning of the 24th, visibility readings were way out of range due to sensor calibration and averaging methods as discussed in previous sections of the report. Wind speeds were reported on the increase at the RWIS station but remained under the 35 km/h threshold. Images available during that period show fair visibility and a wet snow covered pavement. The actual report from the RWIS station indicated either "snow warning" or "chemically wet" for that period. Vehicle speeds were reduced significantly from an average of 110 km/h at around 14:00 to about 60 km/h at 20:00 in the evening of the 23rd.

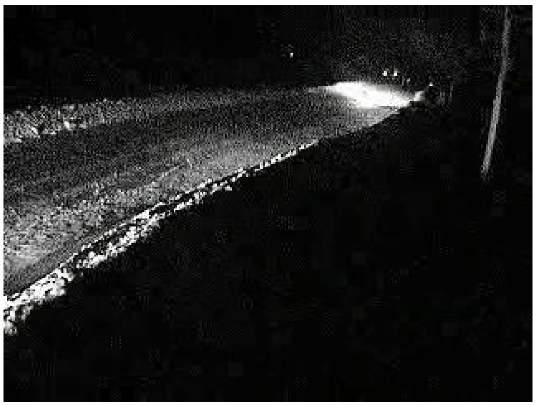


Figure 4-17 Feb 23, 2006 at 20:28

Figure 4-18 Feb 24, 2006 at 07:10

4.5.2.6 Closure 7

The seventh and final reported highway closure started on Feb 25 at 18:11 and lasted until 02:09 in the morning of the 26th. **Appendix A – Chart 4.16** shows again a typical patterns (usually fair visibility with wind speeds below 35 km/h and on the decrease) for this specific event pointing to pavement conditions causing driving difficulties.

Figure 4-19 Feb 25, 2006 at 17:35

Figure 4-20 Feb 25, 2006 at 17:58

These conditions can be inferred from available images prior to closure on the 25th and early in the morning of the 26th. During the late afternoon of the 25th, wind-driven snow rapidly covered the roadway within 30 minutes (17:35-17:58). As winds increased that evening, more snow was added as the first available image the following morning confirms. A combination of bad weather and pavement conditions played a key role in the decision of field personnel to temporarily close HW 21.

Figure 4-21 Feb 26, 2006 at 06:39

4.5.3 Correlation of AMS2 & AMS3 & RWIS Readings during Closure Occurrences

For this review we will concentrate on data for the week of Feb 13 to 20 and specifically on the two episodes (closures 4 and 5) that were analyzed previously for AMS1 (**Appendix A – Charts 12**).

4.5.3.1 AMS2 Location Observations

Although AMS2 (**Appendix A – Chart 4.17**) was less impacted overall by lower visibility conditions than AMS1 (many fluctuations and few values below 1000 m), the same trends and correlation were observed for both episodes on Feb 17 and 18. Visibility readings dropped within 3.0 hours to 3.6 hours prior to the upcoming closure. About 1.5 to 2 hours of visibility below 1000 m was monitored prior to closure. Observed vehicle speed reduction in the previous hours shows usually 2 to 4 hours of slowly decreasing average speed. Closure would coincide with lower visibility and higher wind speed thresholds occurring simultaneously and roadways would remain closed until visibility had consistently crossed back over the 1000 m threshold for about 1 hour. Difficulties with the camera lens cover being iced-up were noted.

Figure 4-22 Feb 17, 2006 at 09:36

Figure 4-23 Feb 17, 20060 at 10:44

Yet on the second episode during the night of the 17th to 18th, the roadway was closed even though visibility was reported as being above the threshold. It was only reopened during the morning after visibility readings had been above threshold conditions for about 1.5 hours. At that time, low visibility conditions remained in effect for one more hour at AMS 1 location. It is assumed that because of conditions in the vicinity of AMS1 site, MTO/OPP required closure of the road at that time based on dangerous driving conditions (pavement conditions and high crosswinds).

Wind speeds during this period were usually in correlation to visibility readings during the first episode – as wind speed increased visibility decreased. Road closures would occur usually after a 2-3 hour period of wind speed increase over 35 km/h. Similarly to the AMS1 site during the second episode, the situation was inconsistent: as winds increased over the 35 km/h threshold for almost 4 hours before the highway was closed, visibility remained lower than 5000 to 6000 m but was usually better than 1500 m. About 2 hours prior to the reopening of the highway, wind speeds were below the 35 km/h threshold and yet visibility readings remained below the 1000 m threshold during that period.

It can be assumed that in early episodes with the shortest time build-up (1-2 hours) snow was available for the wind to pick up. During subsequent episodes higher winds and longer build-up periods were needed due to the lack of snow (Hypothesis: lesser amount of snowfall, lesser amount of loose snow available or lesser amount of heavier snow on the ground or partially packed during the preceding wind drift episode).

4.5.3.2 AMS3 Location Observations

Although AMS3 (**Appendix A – Chart 4.18**) appears overall much less impacted by high winds [6] during the Feb 13 to 20 week, it does show significantly lower visibility conditions than AMS1 and AMS2. The same trends and correlation are observed for both episodes of Feb 17 and 18. Visibility readings dropped within 1.5 hours to 3.5 hours prior to the upcoming closure (about 1.5 to 2 hours of visibility below 1000 m – much lower than this actually – prior to closure). Observed vehicle speed reduction in the previous hours (charts show usually 2 to 4 hours of decreasing speed) was much sharper for the southbound direction. Closure coincided with lower visibility and just below or at the threshold value of 35 km/h for wind speeds. The roadway remained closed until visibility showed trends of crossing back over the 1000 m threshold for about 1 hour.

Figure 4-24 Feb 17, 2006 at 06:57

Figure 4-25 Feb 17, 2006 at 08:11

6 TMS3 wind speed data is from RWIS station SW-06 located about 12 km north of TMS3 site.

Some difficulties were occasionally noted with the camera lens cover being impacted by drifting snow. Many pictures confirmed more severe wind and drifting snow impeding driving conditions compared to the two other locations. Clearly, specific corridor features are present in the vicinity of AMS3 and the Port Elgin RWIS station wind speed data, although the closest RWIS station, are not representative of these specific weather-impacting characteristics.

In Summary

Comparing the evolution of wind speeds and visibility distances amongst all three sites showed that speeds were much higher at AMS1 and AMS2, yet visibility was consistently worse at AMS3. These findings appear to confirm that other variables (presence of falling snow, presence of loose snow in the nearby fields and specific wind corridor features, amongst others things) are present and play an important role in the driving conditions of AMS3. We must consider including specific wind measuring devices at AMS stations to minimize any bias in the analysis of future AMS data.

4.5.4 Peer-to-Peer Correlation of Wind Speeds and Visibility Distances

Peer-to-Peer (P2P) use of data was a specific exploratory task for this project. As vehicle speeds proved not to be consistently impacted by driving conditions, our analysis concentrated on the visibility data. A comparison was made on visibility ratios between site pairs**. Appendix A – Chart 4.19** shows the possible ratio combinations amongst all 3 sites for all valid (out-of-range values removed) visibility readings for the Feb 4, 2006 to Mar 6, 2006 period.

If a perfect correlation for visibility between stations existed, ratio values of 1.0 would be mostly observed.

Appendix A – Chart 4.19 does show a concentration of points along the Y=1 line. A more detailed look at numbers shows that of the 20471 plotted points in this chart, 15703 (76.7%) are within a range of 0.5 to 2.0 (plus 100%, minus 50% difference). In general, this shows a fair correlation. Yet a vast majority of these values were collected under good visibility conditions when visibility values were much more than the 1000 m threshold, generally into the 5000-9999 m range. Furthermore, the periods in the chart showing the greatest variability in ratios usually correspond to bad or less clement weather events. Higher variability patterns in a P2P monitoring network may prove to be an indicator of local adverse driving conditions worthy of further investigation.

Poor conditions being of the greatest interest to us for decision support, **Appendix A – Chart 4.20** only shows values for ratios where at least one of the visibility readings is lower than 1000 m. These points do show the expected dispersion patterns during short periods of time when poor visibility events are observed. The initial concentration of values along the Y=1 line is now absent. The only exception shown being for Feb 6, 2006 for which the AMS1/AMS2 ratio shows several values close to Y=1. For the remaining days of the analysis period, values are significantly scarce regardless of the concerned ratio. Overall, out of the 2293 points on the chart, only 446 (18.6%) are within the <0.5,2.0> boundaries. More than 55% of these cases are related to the AMS1/AMS2 co-relation.

A closer look at ratios for visibility data during the Feb 16 to Feb 19 (**Appendix A – Chart 4.21**) closure event does not show any correlation building. This particular chart does highlight quite clearly the significantly different visibility readings observed at site AMS3 compared to the two other sites.

A sensitivity analysis of the value for maximum visibility cut-off is presented in **Table 4.4** It shows a severe reduction (from 76.7% to 50.4%) in the number of values within the reasonable boundaries of <0.5 to 2.0> at the 5000 m value. If only poor visibility conditions (1000 m or less) are kept as the analysis sample, this reasonable portion decreases to a 18.6% value – more than four out of five values are outside these boundaries. AMS1/AMS2 ratios do increase the share of cases within these boundaries, showing that a stronger correlation might be built between AMS1 and AMS2 than any combination with AMS3.

Table 4-4 Summary of ratios within reasonable limits for AMS visibility co-relation

Low value for visibility cut-off (m)	Total number of ratios Count	Within <0.5,2.0> Ratio values Count	% within <0.5,2.0>	AMS1/AMS2 correlation portion within sample
All values	20471	15703	77%	36%
9990	9606	4839	50%	42%
5000	6499	1732	27%	49%
3000	5109	1225	24%	51%
2000	4076	913	22%	51%
1000	2393	446	19%	56%

We can safely assume that some local weather (micro-climate) appears to be present at AMS3 site, which significantly distinguishes it from the two southern sites. Overall Peer-to-Peer (P2P) relationships for driving conditions in this corridor do not show results of having a station reliably backing up a neighbouring one. This is probably related to the specific truly harsh and highly variable weather conditions encountered along Lake Huron. It also confirms that during initial AMS pilot site identification, the most badly impacted sites were selected and they were significantly different in nature hence covering significantly different highway sections for closure purpose as intended.

The weather specific conditions of AMS site locations under consideration would have to be assessed in detail (micro-climate, wind corridor, presence of tree lines or buildings) to ensure they best represent typical situations over an area and how it relates to its neighbouring AMS and RWIS stations. Where needed, the distance between stations could be reduced to ensure a better correlation between stations. Nevertheless, this first analysis of the collected data does provide enough material to encourage development of a bare basics “stage alarm/decision support tool” for field supervisors, as will be described in the next section. To the extent that the selection of stations provides for sufficient meteorological variations, the P2P visibility data could be useful indicators of bad weather events and the geographical importance of the concerned area.

4.5.5 Driving Conditions "Severity Index" Exploratory Evaluation

Supported by the apparent relevance of visibility and vehicle speed, we introduced at an early stage of the project the rudimentary concept of a driving conditions "Severity Index" using a matrix based on vehicle speed and visibility distances. As wind speeds became a more relevant indicator, we revisited this matrix content (**Table 4.5**).

Figure 4-26 Feb 18, 2006 at 10:32

Appendix A – Chart 4.22 presents a test at AMS1 for the week of Feb 13 to Feb 20. Severity Indexes were added to the previously presented data chart for that period. Severity Index values (dark blue moving average line) on the chart appear to be good indicators for upcoming driving conditions problems and show an alert level throughout both closure periods. Hence early episodes of poor visibility events and higher wind speeds flag closure periods. Yet some "false alarms" would have been declared later on the morning of the 19th as a sustained high index is shown from 09:30 to 12:30. Yet the highway was reopened at 08:15 that morning.

Table 4-5 Severity index Matrix Based on Visibility and Wind Speed

Visibility (m)	Wind Speed (kph)																	Posted Speed Limit							
at 5-7 meters height	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
10000	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	5	5	5	5	10	10	10	10
9500	[illegible]	[illegible]	[illegible]	0	0	0	0	0	0	2	2	2	2	2	2	2	2	5	5	5	5	10	10	10	10
9000	[illegible]	[illegible]	[illegible]	0	0	0	0	2	2	2	2	2	2	2	2	2	5	5	5	5	5	10	10	10	10
8500	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5	10	10	10	10
8000	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5	5	10	10	10	10
7500	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5	5	10	10	10	10
7000	0	0	0	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5	5	5	10	10	10	10
6500	0	0	0	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5	5	5	10	10	10	10
6000	0	0	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5	5	5	5	10	10	10	10
5500	0	0	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5	5	5	5	[illegible]	[illegible]	[illegible]	[illegible]
5000	0	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5	5	5	5	10	10	10	10	10
4500	0	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5	5	5	5	10	10	10	10	10
4000	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5	5	5	5	10	10	10	10	10	10
3500	2	2	2	2	2	2	2	2	2	2	2	5	5	5	5	5	5	5	5	10	10	20	20	20	20
3000	[illegible]	[illegible]	[illegible]	12	12	12	12	12	[illegible]	[illegible]	[illegible]	15	15	15	15	15	15	15	20	20	20	20	20	20	20
2500	[illegible]	[illegible]	[illegible]	12	12	12	12	12	[illegible]	[illegible]	[illegible]	15	15	15	15	15	15	15	20	20	20	20	20	20	20
2000	[illegible]	[illegible]	[illegible]	22	22	22	22	22	[illegible]	[illegible]	[illegible]	25	25	25	25	25	25	30	30	30	30	30	30	30	30
1500	[illegible]	[illegible]	[illegible]	22	22	22	22	22	[illegible]	[illegible]	[illegible]	25	25	25	25	25	25	30	30	30	30	35	35	35	35
1000	[illegible]	[illegible]	[illegible]	32	32	32	32	32	32	32	32	32	32	32	35	35	35	35	35	35	35	35	35	35	35
500	[illegible]	[illegible]	[illegible]	32	32	32	32	35	35	35	35	[illegible]	[illegible]	[illegible]	35	35	35	35	35	35	35	35	35	35	35
200	32	32	32	32	32	35	35	35	35	35	35	[illegible]	[illegible]	[illegible]	35	35	35	35	35	35	35	35	35	35	35
100	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
50	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35

Top Conditions
OPP Speed control?
MTO Stand-By?
OPP Incident? MTO Maintenance?
MTO Maintenance?
OPP Incident? MTO Maintenance?
OPP Incident? MTO Maintenance?
OPP Closure? MTO On Alert?

Figure 4-27 Feb 18, 2006 at 12:29

Images for that period show fair to poor visibility at 10:32 (similar to image at 06:58 in section 4.5.2 of the text, in reference to closures 4 and 5) with a clear distinction of better visibility conditions observed at 12:29. Throughout that period, the roadway appears seriously snow covered. The RWIS system at Amberley reported a snow warning in effect until the evening of the 18th. Perhaps driving conditions had been evaluated in the field as having improved so much from the previous worst episodes that field personnel felt comfortable reopening the highway. Consequently, the index would have kept field personnel online and proved a relevant "local watch dog" after the highway was reopened. Additionally, use of variable message signs to keep drivers on the alert could have been toggled remotely to do the same throughout the morning period once the highway was reopened.

5 CONCLUSIONS

The AMS Pilot Project was designed to evaluate the use of 1xRTT communications and solar power to support the collection of visibility and traffic data in rural locations. The project clearly showed that technology is available to cost effectively provide communication services and power to remote locations to support the collection of data by autonomous data collection stations.

The second component of the project was to analysis the usefulness of data collected from visibility sensors and traffic to provide information regarding visibility observed by motorists using the highway. The conclusion of the study regarding this component was more ambiguous based on the available AMS sensors and site set-up. There is a clear relationship between the measured visibility levels and visibility conditions experienced by motorists; however there are a variety of other factors which affect the conditions at road level.

The primary issue is sensor location. It is not possible to mount sensors at the eye level of the motorist; hence there will always be inconsistencies between the measured readings and the situation on the ground. This can be minimized by mounting the sensors as low as physically possible considering snow banks, vandalism and other concerns. As well the quantitative values obtained from the sensors need to be interpreted to provide a more valuable indication of the actual situations.

It was also shown that there is a strong correlation between visibility and wind speed in the presence of a layer of unpacked snow. Site visits showed clearly the results of heavy winds blowing snow from adjacent fields across the road. The resulting tunnel creates very poor visibility but primarily at the level of the snow banks. Therefore wind speed is an important component in assessing visibility.

The pilot project does show that motorist do reduce speed when visibility deteriorates, however under conditions of low traffic volume this reduction in speed is substantially less than would be expected for safe driving.

It is concluded that a simple visibility measurement system will not be sufficient to provide automatic road closure or visibility advisories on its own. However, a system which considers visibility measurements, traffic speed and wind speed as well as rate of change of these parameters can be used to develop a tool for operating agencies supporting alertness helping them take action regarding road closures and motorist advisories.

The co-relationship between these parameters can be used to further explore and develop a “severity” index which can be used to generate alerts during conditions of poor visibility. Cameras can be effectively used to visually assess the situation and dispatch observers and maintenance forces as appropriate.

6 RECOMMENDATIONS

The AMS Pilot project has shown that the use of 1xRTT communications and solar power can effectively be used to collect visibility and traffic data from remote rural locations. In order to effectively use this data additional investigations are required to develop a decision support tool to enable operating agencies to generate visibility alerts and facilitate road closure and opening decisions.

It is recommended that an operational system be developed to incorporate the following additional components:

- a browser based user interface designed to meet operational requirements
  - single click integrated video viewer
  - decision support system to asses visibility, traffic and wind speed in order to generate alarms
  - alarm window
  - improved diagnostics and remote configuration setup
- camera MPEG 4 encoder which meets open standard requirements
- visibility sensor locations adjusted
- integrated wind sensor
- remotely controlled heaters for camera dome and visibility sensor hood to better manage the environmental conditions
- additional local data storage to minimize data lose due to communications errors and IP changes.

The updated AMS should be redeployed during a similar winter season (planned for 2007/2008) and calibrated using manual observations from the OPP and MTO maintenance forces.

The concept of the AMS for visibility monitoring has been demonstrated to be effective, however additional work is required in order to deploy operational systems and decision support tools. It is recommended that:

- a tested site is implemented to better monitor the influence of the visibility sensor mounting height in regards with driver eye level reading.
- provide actual power consumption monitoring to better evaluate available reserves under various power requirements schemes (heaters timed period etc.) and sunlight conditions.
- provide local lighting of test sites during the night time to insure 24 hours per day coverage with IP cameras. Alternatively explore IR camera if needed
- evaluate new roadway pavement condition sonar sensors as they become available and additional section of roadway with different conditions be considered.

APPENDIX A

Chart 4.1 – Visibility Data at Station AMS2 (5 minutes readings)

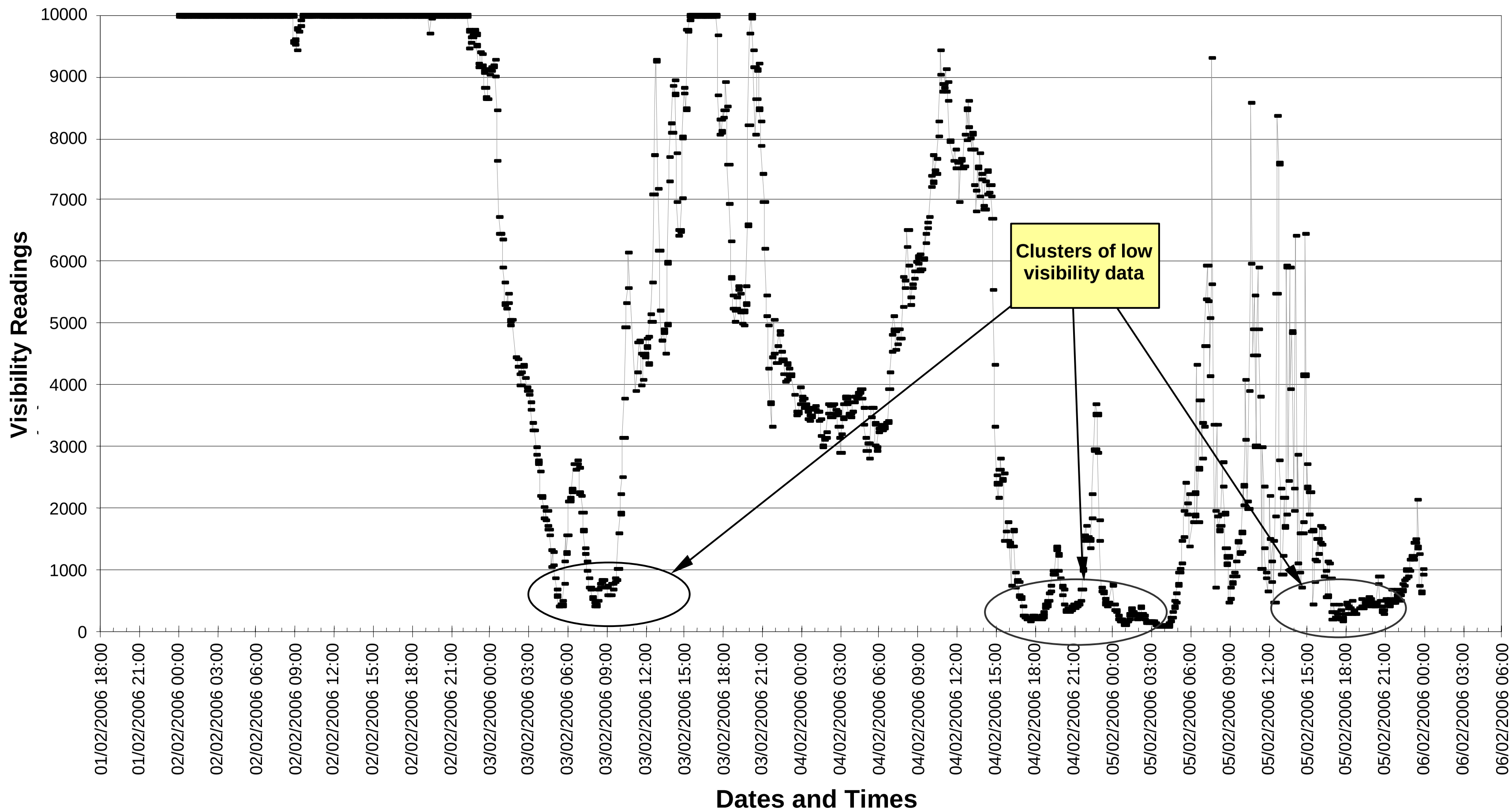
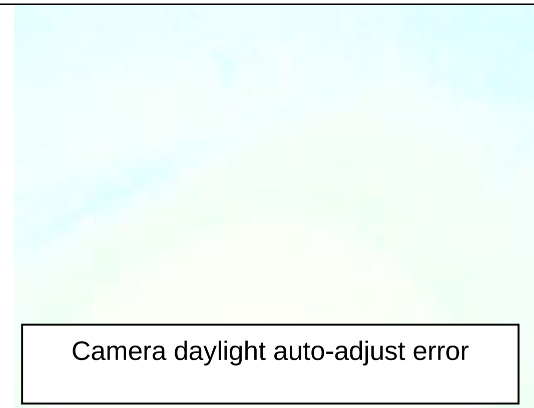


Table 4-A Comparison between Visibility Data, Field Observation and Video Images

Date	Time	Natural light conditions	Station	Visibility sensor (m)	OPP/MTO (1 pole ~ 50 m)	Video	Comments
2006-05-02	03:41	Night	3	**9999**	**100**		Heavy snow; strong wind building; road not closed, OPP/MTO monitoring
2006-05-02	03:46	Night	2	94	50-100	Too dark, no artificial light available	Blowing snow; strong wind building; road not closed, OPP/MTO monitoring
2006-05-02	03:49	Night	1	218	50-100	Too dark, no artificial light available	Blowing snow; strong wind building; road not closed, OPP/MTO monitoring
2006-05-02	05:44	Night	3	**9999**	**50-100**		Blowing snow; strong wind building; road not closed, media advisory out to use caution/do not drive

Date	Time	Natural light conditions	Station	Visibility sensor (m)	OPP/MTO (1 pole ~ 50 m)	Video	Comments
2006-05-02	05:45	Night	2	**2082**	**50-100**	Too dark, no artificial light available	Blowing snow; strong wind building; road not closed, media advisory out to use caution/do not drive
2006-05-02	05:45	Night	1	**2242**	**50-100**	Too dark, no artificial light available	Blowing snow; strong wind building; road not closed, media advisory out to use caution/do not drive
2006-05-02	16:25	Daylight	3	**9999**	**250-300**		Strong wind; drifting; roads open

Date	Time	Natural light conditions	Station	Visibility sensor (m)	OPP/MTO (1 pole ~ 50 m)	Video	Comments
2006-05-02	16:25	Daylight	2	581	250-300		Strong wind; drifting; roads open
2006-05-02	16:25	Daylight	1	**1830**	**250-300**	 Camera lens cover ice-covered	Strong wind; drifting; roads open

Date	Time	Natural light conditions	Station	Visibility sensor (m)	OPP/MTO (1 pole ~ 50 m)	Video	Comments
2006-06-02	10:57	Daylight	1	700			
2006-06-02	10:58	Daylight	2	790			

Date	Time	Natural light conditions	Station	Visibility sensor (m)	OPP/MTO (1 pole ~ 50 m)	Video	Comments
2006-06-02	10:59	Daylight	3	9999			
2006-06-02	16:30	Daylight	3	**9999**	**0-50**		Blowing snow; road closed Feb 6 at 18:40 to Feb 7 17:00

Date	Time	Natural light conditions	Station	Visibility sensor (m)	OPP/MTO (1 pole ~ 50 m)	Video	Comments
2006-06-02	16:30	Daylight	2	**679**	**0-50**		Blowing snow; road closed Feb 6 at 18:40 to Feb 7 17:00
2006-06-02	16:30	Daylight	1	**884**	**0-50**		Blowing snow; road closed Feb 6 at 18:40 to Feb 7 17:00

Date	Time	Natural light conditions	Station	Visibility sensor (m)	OPP/MTO (1 pole ~ 50 m)	Video	Comments
02/13/2006	02:34	Night	3	541	50-100		Blowing snow
02/13/2006	02:35	Night	2	**9999**	**50-100**		Blowing snow

Date	Time	Natural light conditions	Station	Visibility sensor (m)	OPP/MTO (1 pole ~ 50 m)	Video	Comments
02/13/2006	02:35	Night	1	**9999**	**50-100**		Blowing snow
02/13/2006	07:52	Daylight	3	1039	150		Heavy snow; blowing northerly

Date	Time	Natural light conditions	Station	Visibility sensor (m)	OPP/MTO (1 pole ~ 50 m)	Video	Comments
02/13/2006	07:52	Daylight	2	694	150		Heavy snow; blowing northerly
02/13/2006	07:53	Daylight	1	**6769**	**150**		Heavy snow; blowing northerly

Date	Time	Natural light conditions	Station	Visibility sensor (m)	OPP/MTO (1 pole ~ 50 m)	Video	Comments
02/17/2006	07:04	Daylight	3	84	0		Road closed Feb 17 at 06:00; blowing snow, whiteout conditions, strong easterly wind, road icy/slippery
02/17/2006	07:04	Daylight	2	573	0		Road closed Feb 17 at 06:00; blowing snow, whiteout conditions, strong easterly wind, road icy/slippery

Date	Time	Natural light conditions	Station	Visibility sensor (m)	OPP/MTO (1 pole ~ 50 m)	Video	Comments
02/17/2006	07:04	Daylight	1	178	0		Road closed Feb 17 at 06:00; blowing snow, whiteout conditions, strong easterly wind, road icy/slippery
02/17/2006	10:39	Daylight	3	230	100		Road closed Feb 17 at 06:00; blowing snow, whiteout conditions, NW wind, road getting snow covered

Date	Time	Natural light conditions	Station	Visibility sensor (m)	OPP/MTO (1 pole ~ 50 m)	Video	Comments
02/17/2006	14:25	Daylight	3	**451**	**clear**		Road just opened
02/17/2006	14:25	Daylight	2	2213	clear		

Date	Time	Natural light conditions	Station	Visibility sensor (m)	OPP/MTO (1 pole ~ 50 m)	Video	Comments
02/17/2006	14:25	Daylight	1	2305	clear		
02/23/2006	13:35	Daylight	3	**9999**	**150**		Heavy snow, strong SW wind, slippery, wet, slushy

Date	Time	Natural light conditions	Station	Visibility sensor (m)	OPP/MTO (1 pole ~ 50 m)	Video	Comments
02/23/2006	13:35	Daylight	2	469	150		Heavy snow, strong SW wind, slippery, wet, slushy
02/23/2006	13:35	Daylight	1	**542000**	**150**		Heavy snow, strong SW wind, slippery, wet, slushy

Table 4-B Comparison between Visibility Data and OPP Field Observations

Date	Time	Daylight/Night	Stn	Visibility – Sensor Data (m)	Visibility – OPP/MTO Field Observation (m) 1 pole ~ 50m	Visibility – Lowest/Highest 30 min Before and After (m)	Comments
02/05/2006	3:41	Night	3	9999 [1]	100	9999	Heavy snow; strong wind building; road not closed, OPP/MTO monitoring
02/05/2006	3:46	Night	2	94	50-100		Blowing snow; strong wind building; road not closed, OPP/MTO monitoring
02/05/2006	3:49	Night	1	218	50-100		Blowing snow; strong wind building; road not closed, OPP/MTO monitoring
02/05/2006	5:44	Night	3	9999	50-100	9999	Blowing snow; strong wind building; road not closed, media advisory out to use caution/do not drive
02/05/2006	5:45	Night	2	2082	50-100	1129	Blowing snow; strong wind building; road not closed, media advisory out to use caution/do not drive
02/05/2006	5:45	Night	1	2242	50-100	1635	Blowing snow; strong wind building; road not closed, media advisory out to use caution/do not drive
02/05/2006	16:25	Daylight	3	9999	250-300	9999	Strong wind; drifting; roads open
02/05/2006	16:25	Daylight	2	581	250-300	225	Strong wind; drifting; roads open
02/05/2006	16:25	Daylight	1	***1830*** [2]	***250-300***	***220***	Strong wind; drifting; roads open
02/06/2006	16:30	Daylight	3	9999	0-50	9999	Blowing snow; road closed Feb 6 18:40 – Feb 7 17:00
02/06/2006	16:30	Daylight	2	679	0-50		Blowing snow; road closed Feb 6 18:40 – Feb 7 17:00
02/06/2006	16:30	Daylight	1	884	0-50		Blowing snow; road closed Feb 6 18:40 – Feb 7 17:00
02/13/2006	2:34	Night	3	541	50-100	177	Blowing snow
02/13/2006	2:35	Night	2	9999	50-100	5695	Blowing snow
02/13/2006	2:35	Night	1	9999	50-100	9872	Blowing snow
02/13/2006	7:52	Daylight	3	***1039***	***150***	***216***	Heavy snow; blowing northerly
02/13/2006	7:52	Daylight	2	694	150	613	Heavy snow; blowing northerly
02/13/2006	7:53	Daylight	1	6769	150	1132	Heavy snow; blowing northerly
02/17/2006	7:04	Daylight	3	84	0		Road closed Feb 17 06:00; blowing snow, whiteout conditions, strong easterly wind, road icy/slippery

Date	Time	Daylight/Night	Stn	Visibility – Sensor Data (m)	Visibility – OPP/MTO Field Observation (m) 1 pole ~ 50m	Visibility – Lowest/Highest 30 min Before and After (m)	Comments
02/17/2006	7:04	Daylight	2	573	0		Road closed Feb 17 06:00; blowing snow, whiteout conditions, strong easterly wind, road icy/slippery
02/17/2006	7:04	Daylight	1	178	0		Road closed Feb 17 06:00; blowing snow, whiteout conditions, strong easterly wind, road icy/slippery
02/17/2006	10:39	Daylight	3	230	100		Road closed Feb 17 06:00; blowing snow, whiteout conditions, nw wind, road getting snow covered
02/17/2006	14:25	Daylight	3	***451***	***clear***	***1109***	Road just opened
02/17/2006	14:25	Daylight	2	2213	Clear		
02/17/2006	14:25	Daylight	1	2305	Clear		
02/23/2006	13:35	Daylight	3	9999	150	9999	Heavy snow, strong sw wind, slippery, wet, slushy
02/23/2006	13:35	Daylight	2	469	150	375	Heavy snow, strong sw wind, slippery, wet, slushy
02/23/2006	13:35	Daylight	1	542000	150	23400	Heavy snow, strong sw wind, slippery, wet, slushy

Notes:

1. Shaded cells denote when visibility sensor data do not match with OPP observations, i.e., visibility reading is greater than threshold (1000m) but OPP observed poor/nil visibility.
2. Italic bolded shaded cells denote where visibility sensor data do not match with OPP observations; but the lowest record within an hour window matches with OPP observation.

Chart 4.2 – Visibility and Speed Data
5-min Visibility and Speed Data at Station 2
Closed 05:00 January 18 – Opened 10:17 January 18

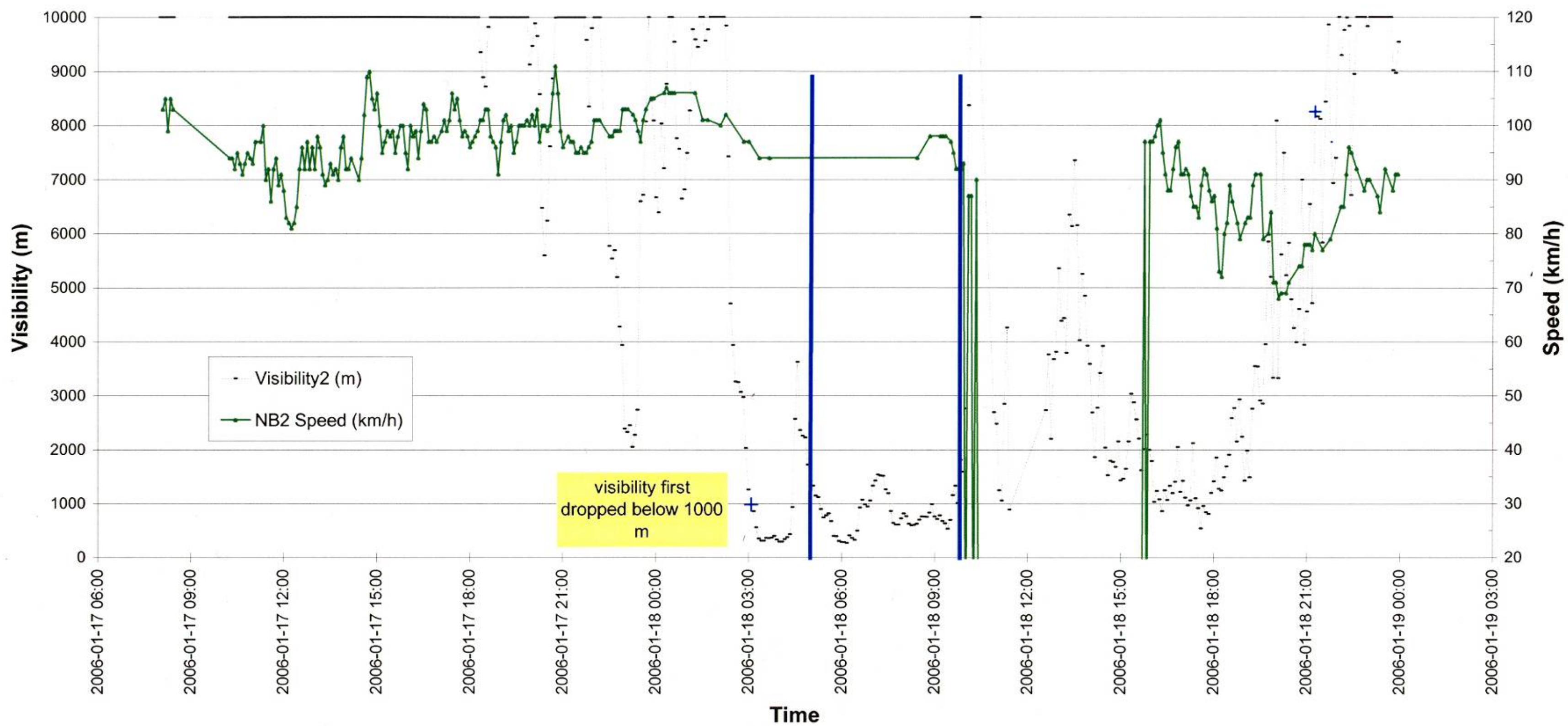


Chart 4.3 – Visibility and Speed Data
5-min Visibility and Speed Data at Station 2
Closed 05:00 January 25 – Opened 10:00 January 25

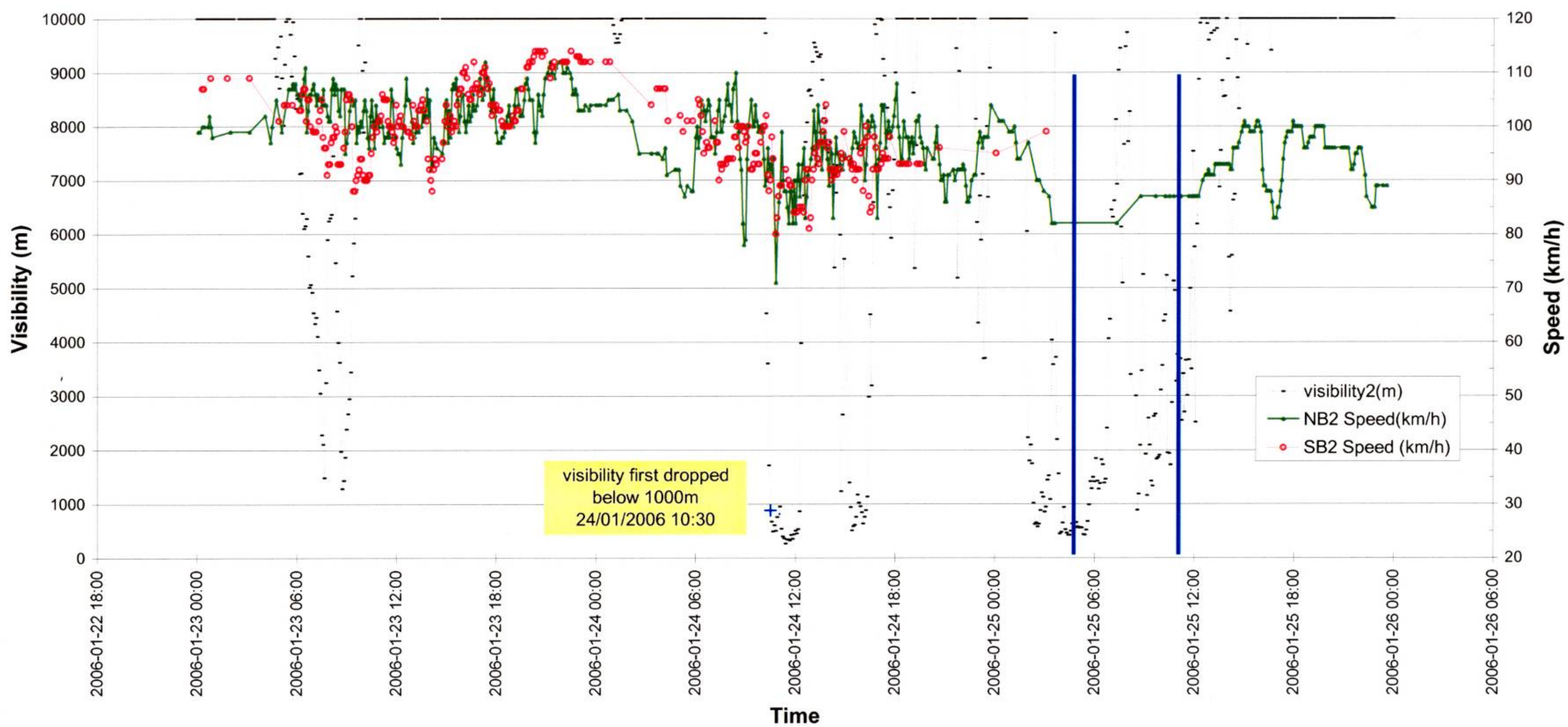


Chart 4.4 – Visibility and Speed Data
5-min Visibility and Speed Data at Station 2
Closed 18:40 on February 5, 2006 – Opened 17:00 on February 7, 2006

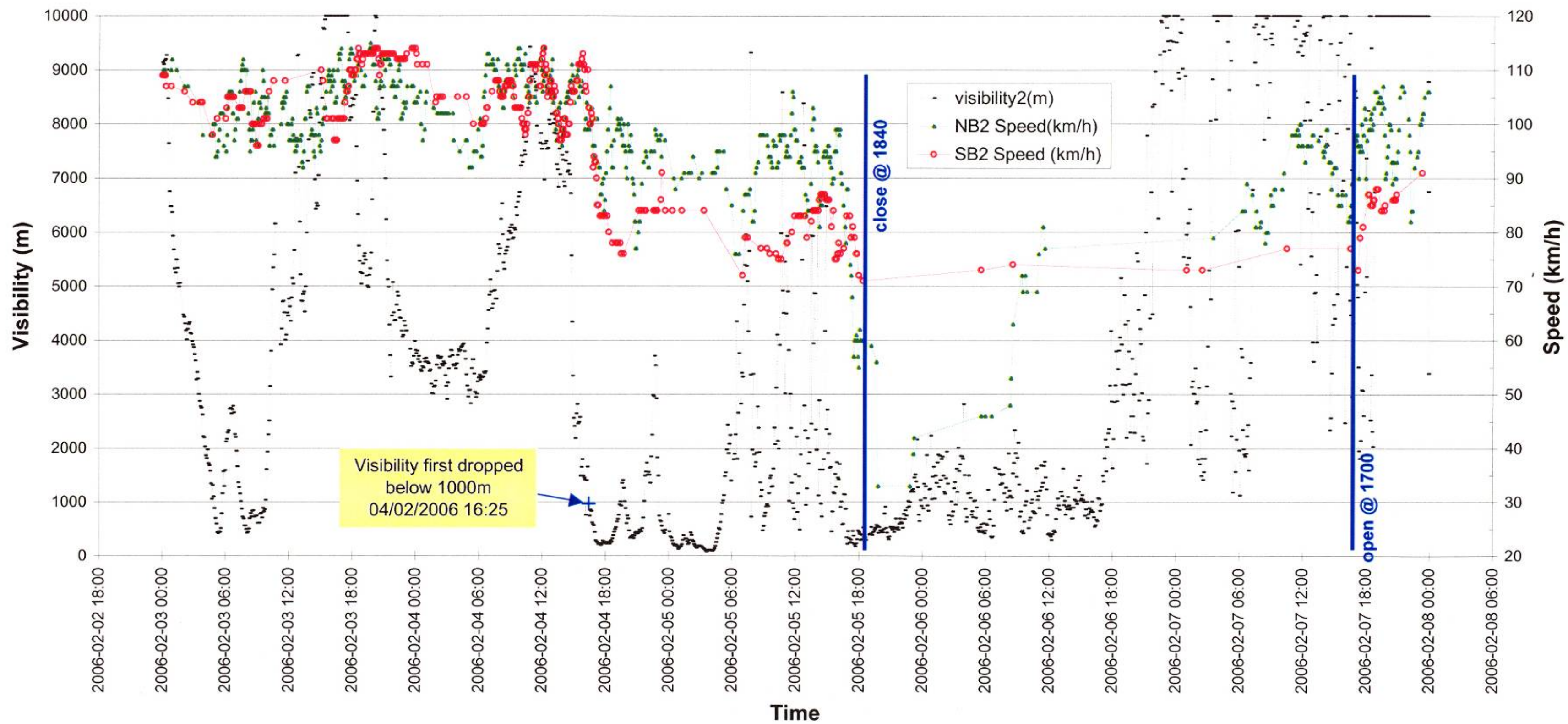


CHART 4.5 – Visibility and Speed Data
5-min Visibility and Speed Data at Station 2
Closed 06:15 on February 17, 2006 – Opened 14:25 on February 17
Reclosed 20:30 February 17 – Reopened 08:15 February 18

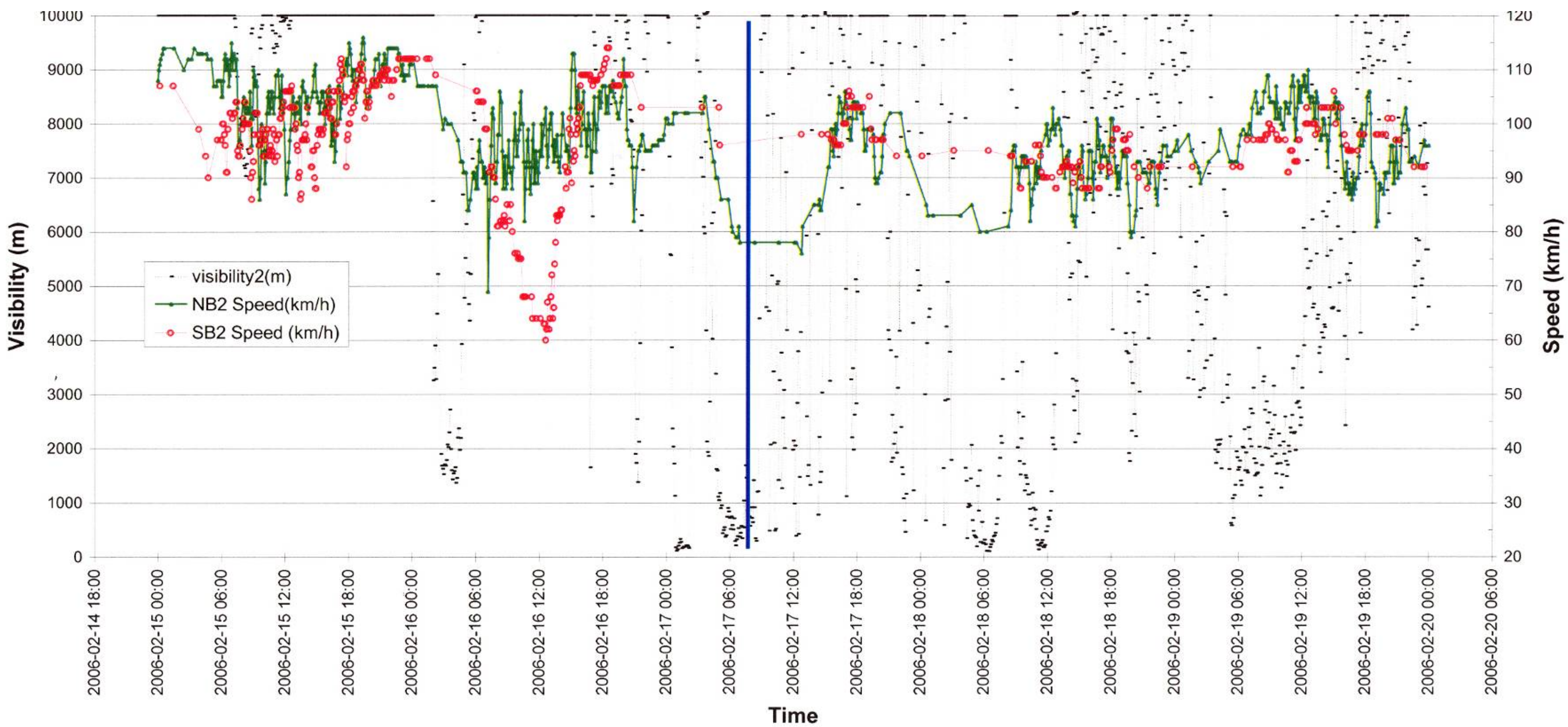


Chart 4.6 – Visibility and Speed Data
5-min Visibility and Speed Data at Station 2
Closed 21:23 on February 23 – Opened 06:00 on February 24

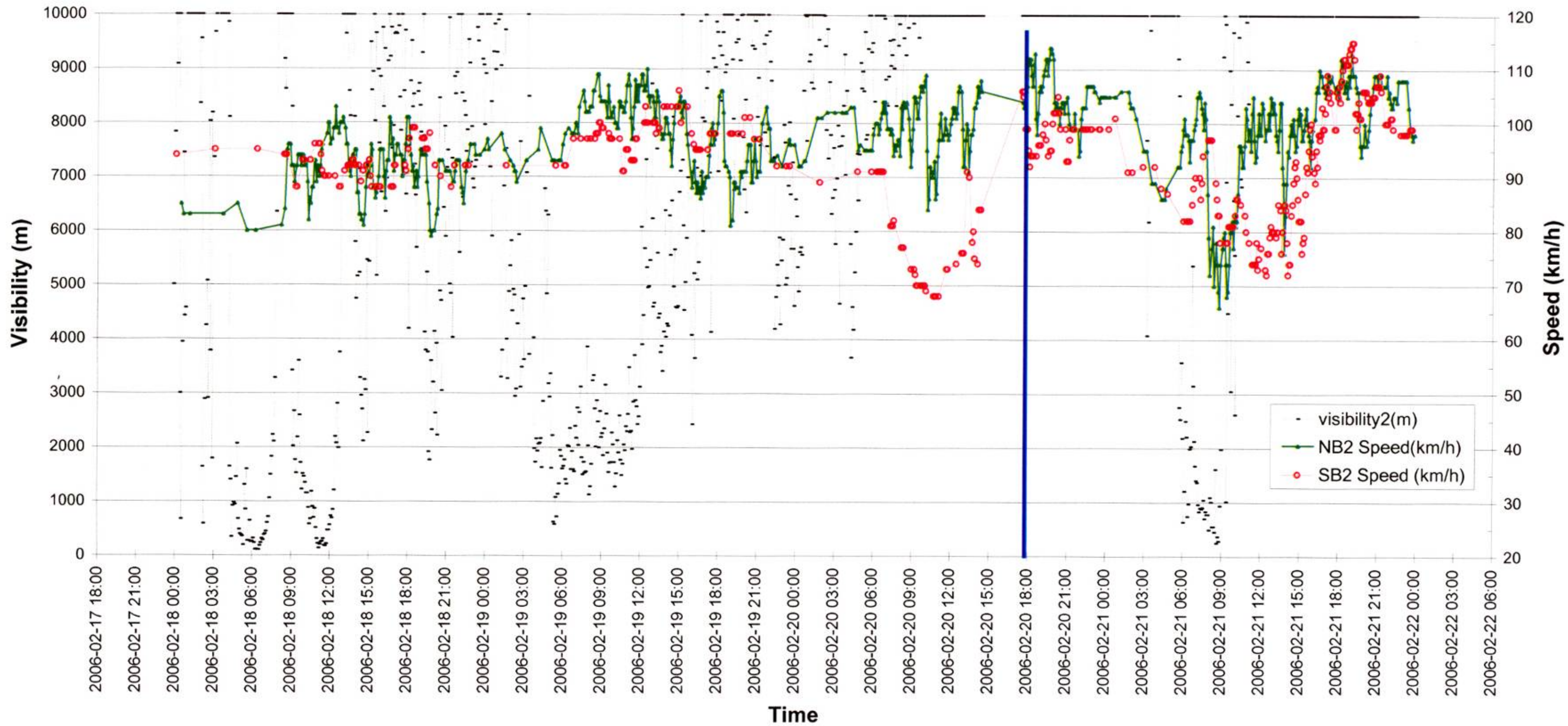


Chart 4.7 – Visibility and Speed Data
5-min Visibility and Speed Data at Station 2
Closed 18:11 on February 25 – Opened 02:09 on February 26

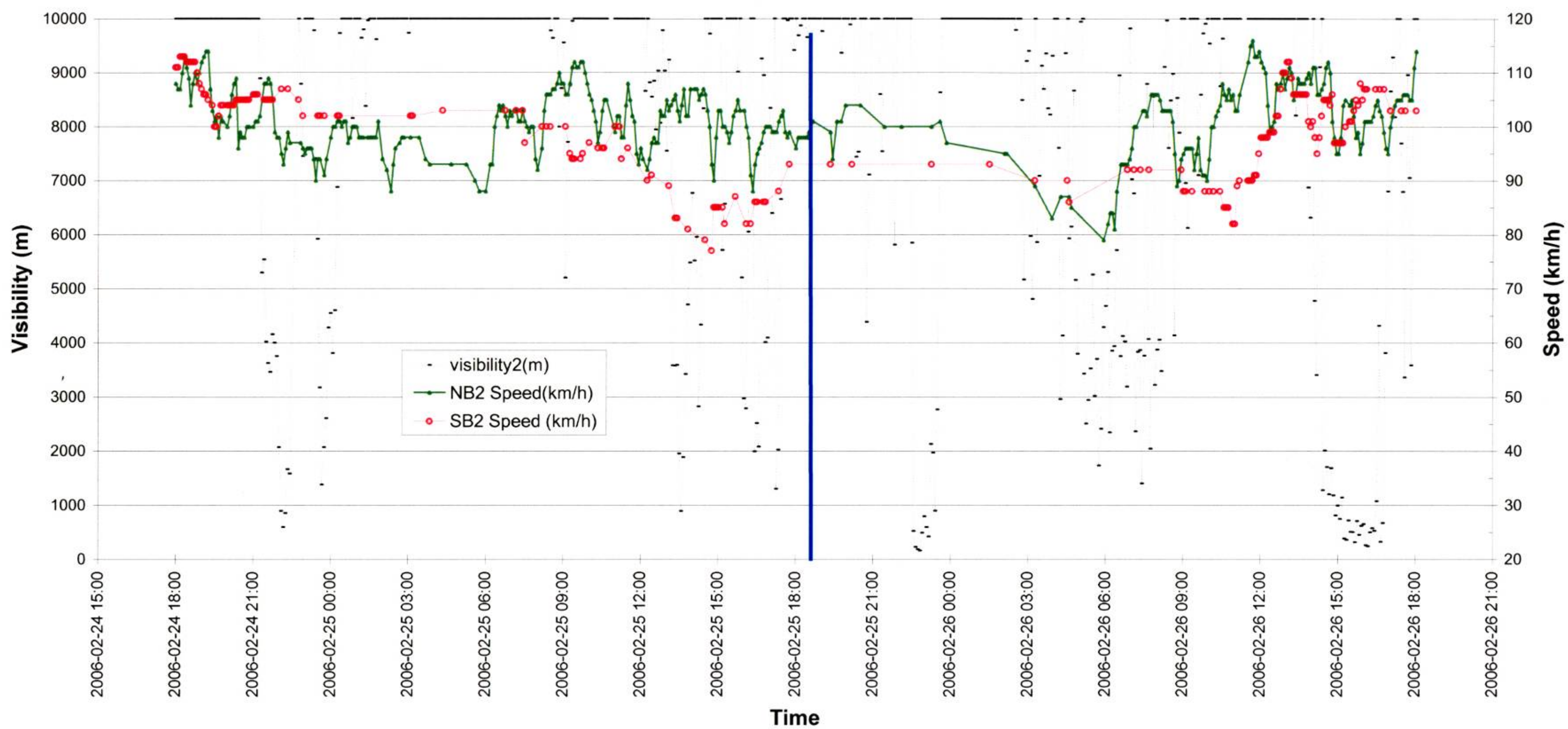


Chart 4.8 – Speed Drop vs. Visibility Drop Prior to Road Closure

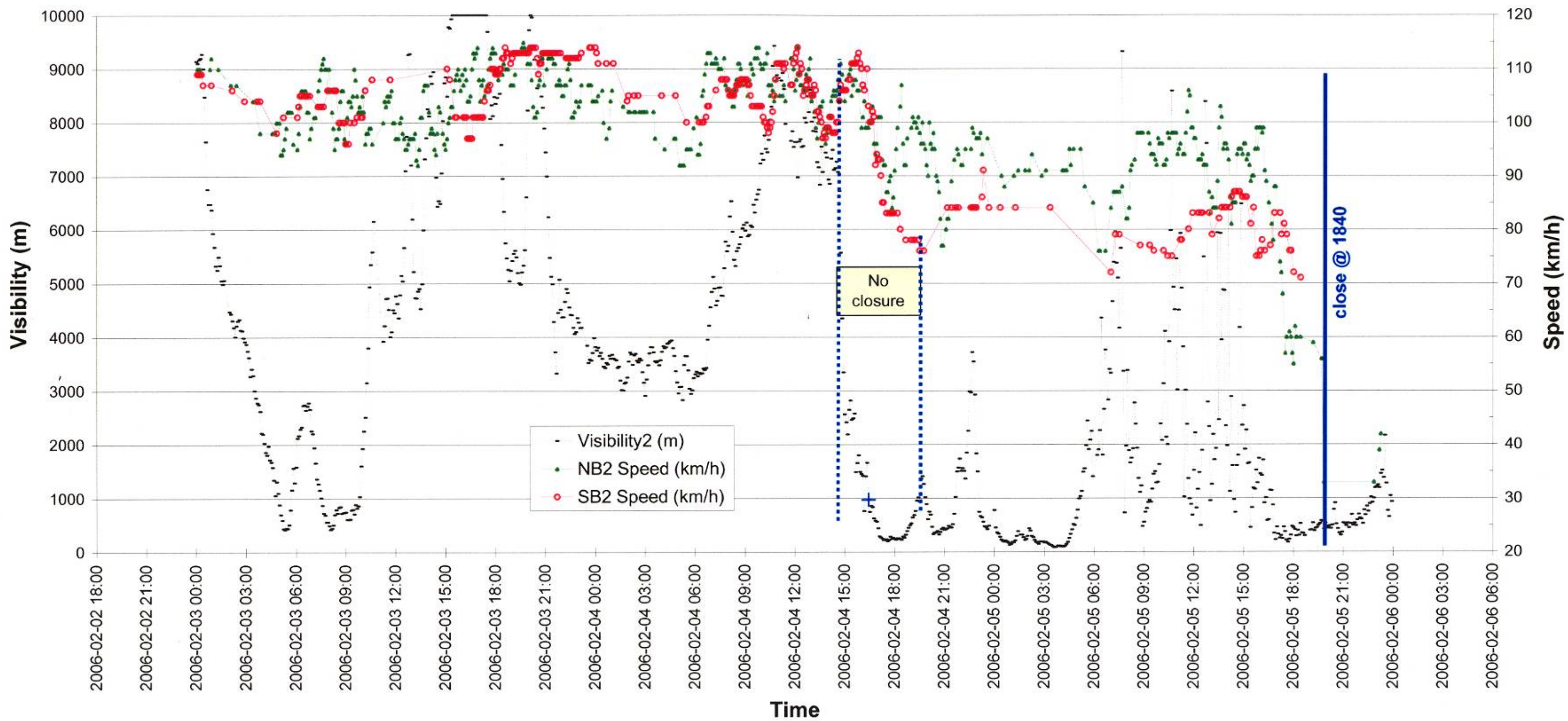


**Chart 4.9 – Speed Drop Without Visibility Drop
Prior to Feb 17 Closure**

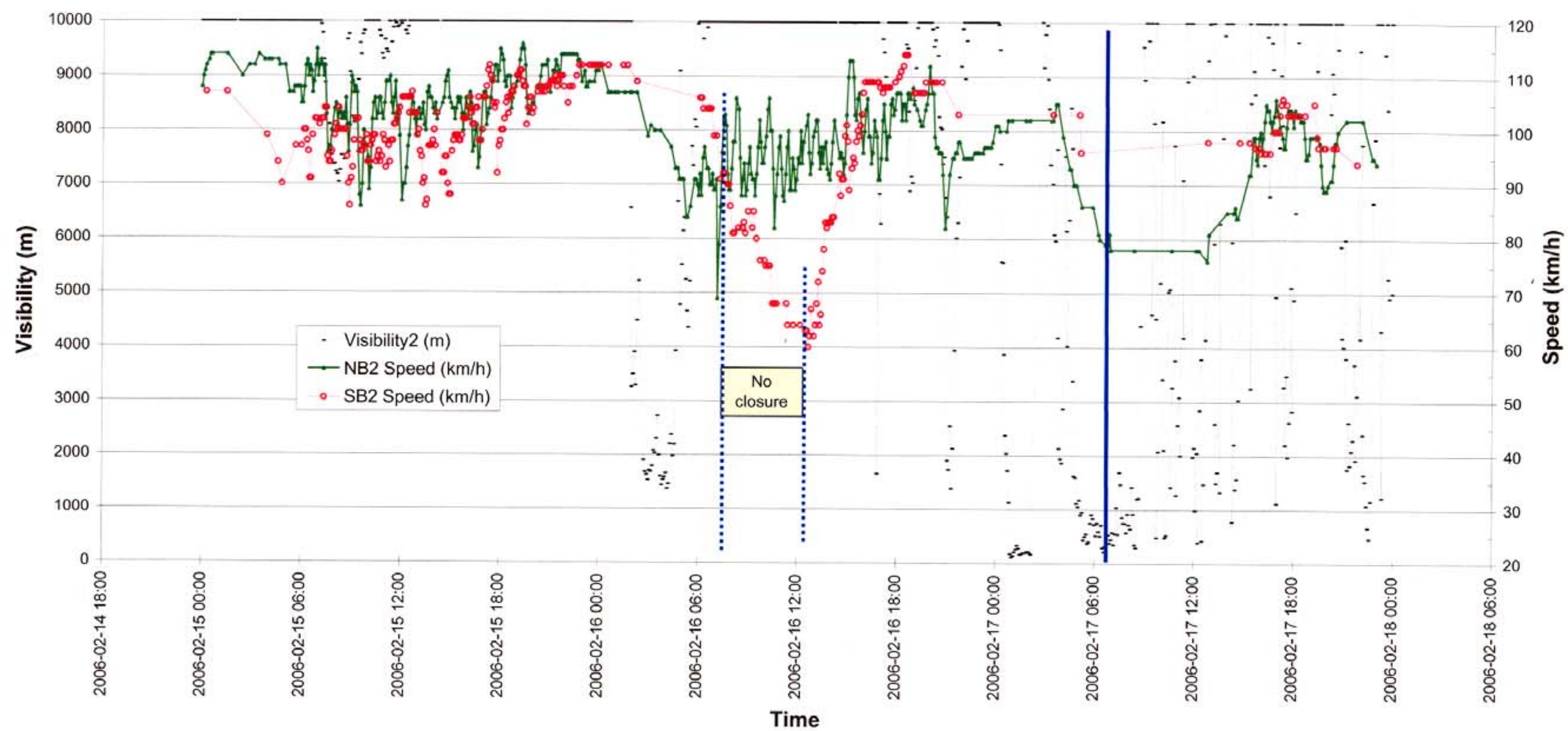


Chart 4.10 – Visibility vs Speed at AMS1 (Jan 11 to Jan 18, 2006)

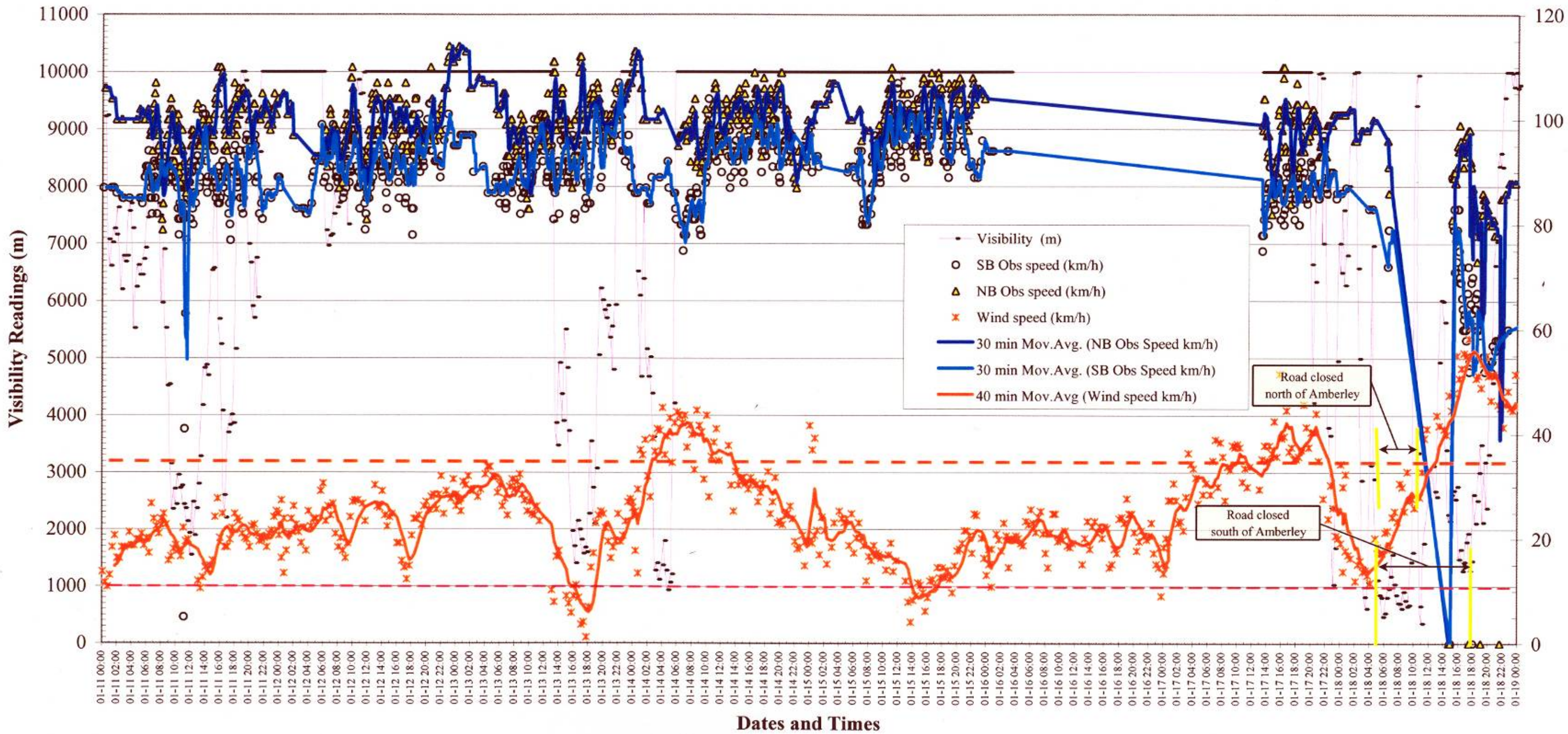


Chart 4.11 – Visibility vs Speed at AMS1 (Jan 23 to Jan 30, 2006)

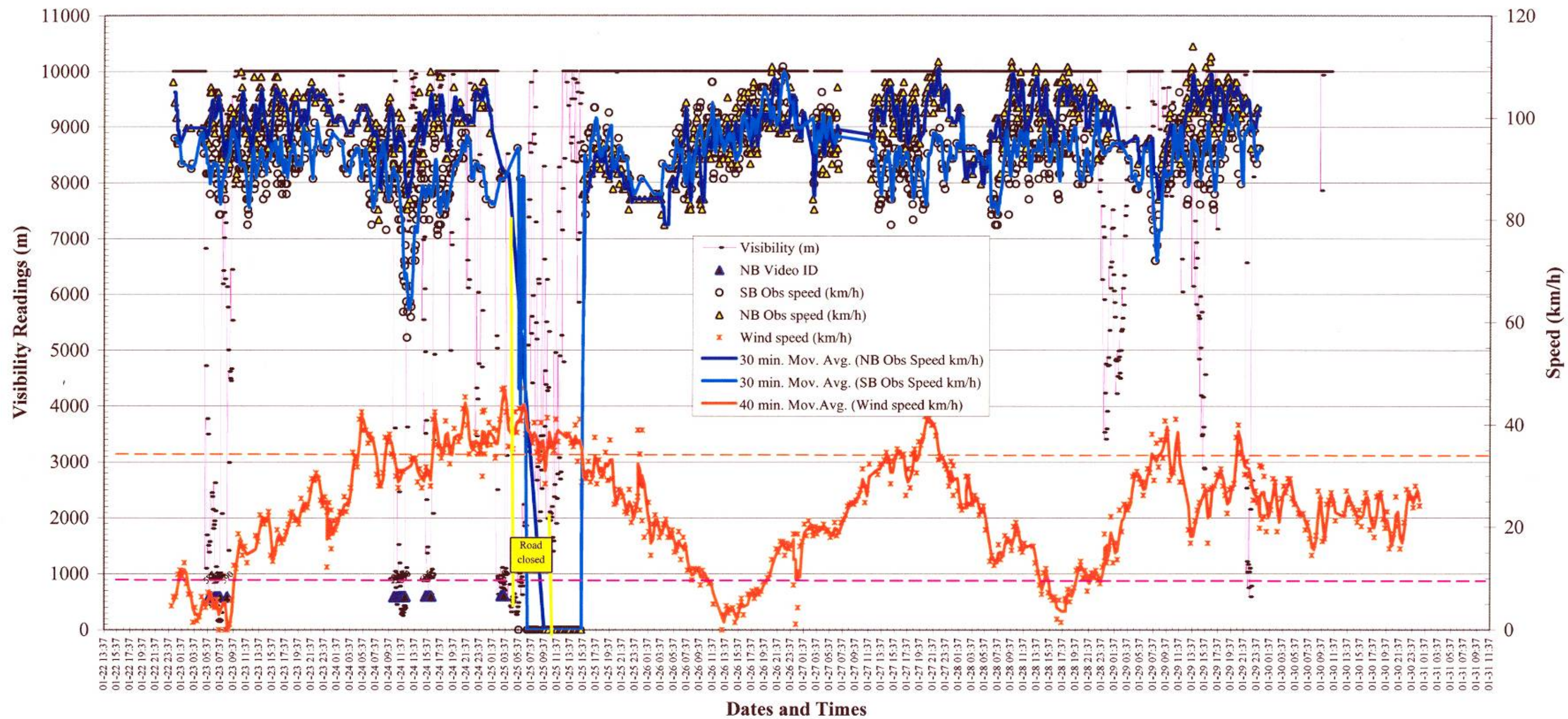


Chart 4.12 – Visibility vs Speed at AMS1 (Jan 30 to Feb 06, 2006)

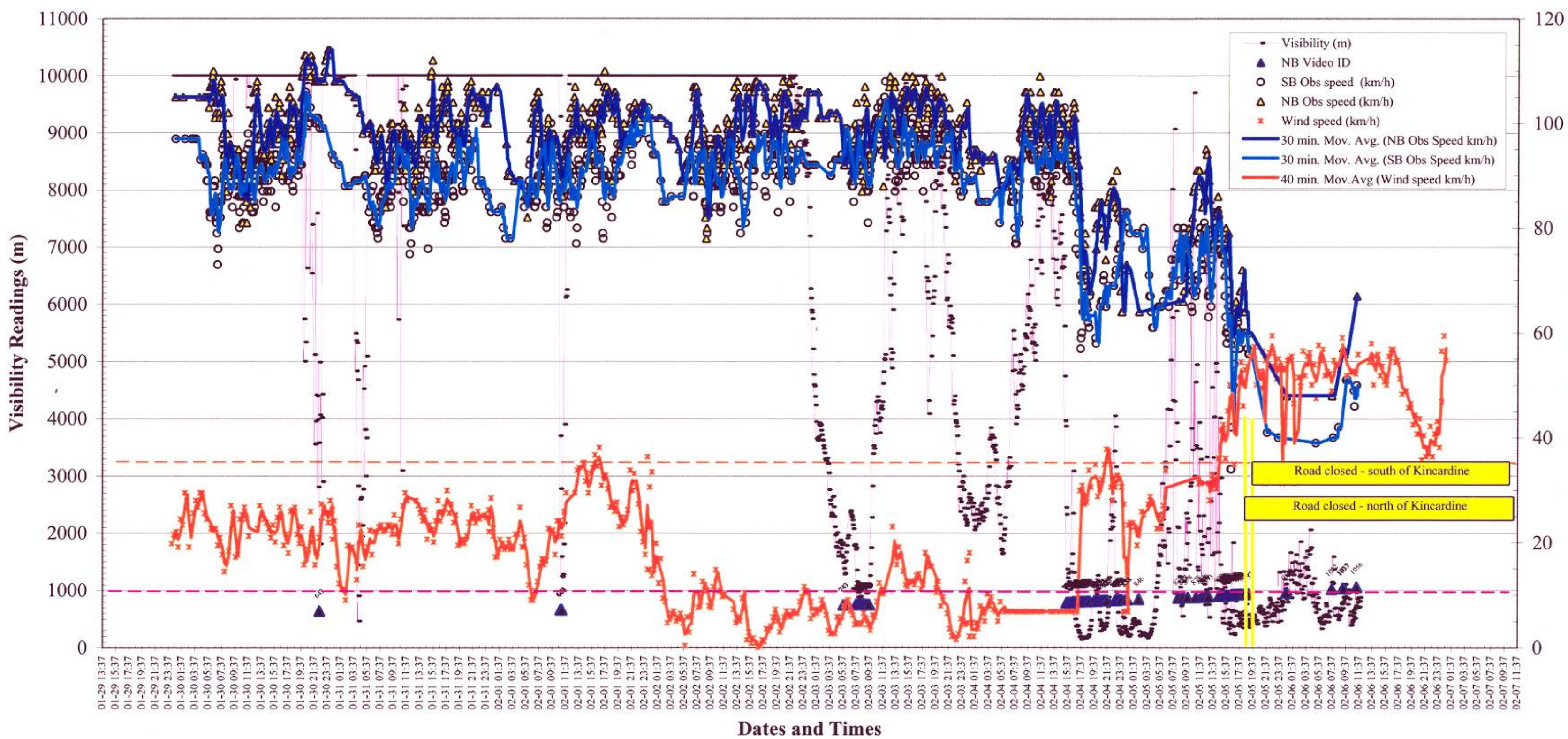


Chart 4.13 – Visibility vs Speed at AMS1 (Feb 06 to Feb 13, 2006)

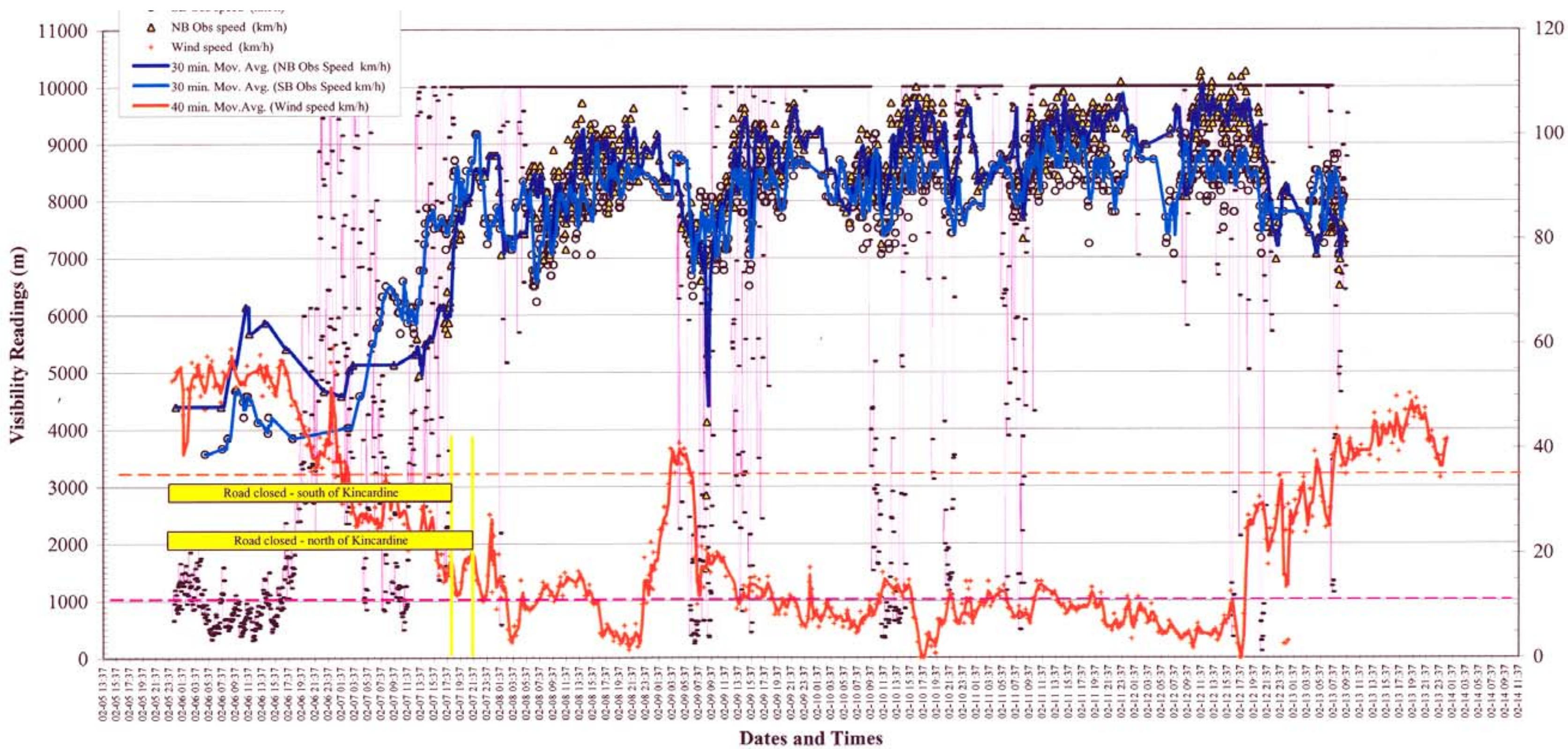


Chart 4.14 – Visibility vs Speed at AMS1 (Feb 16 to Feb 19, 2006)

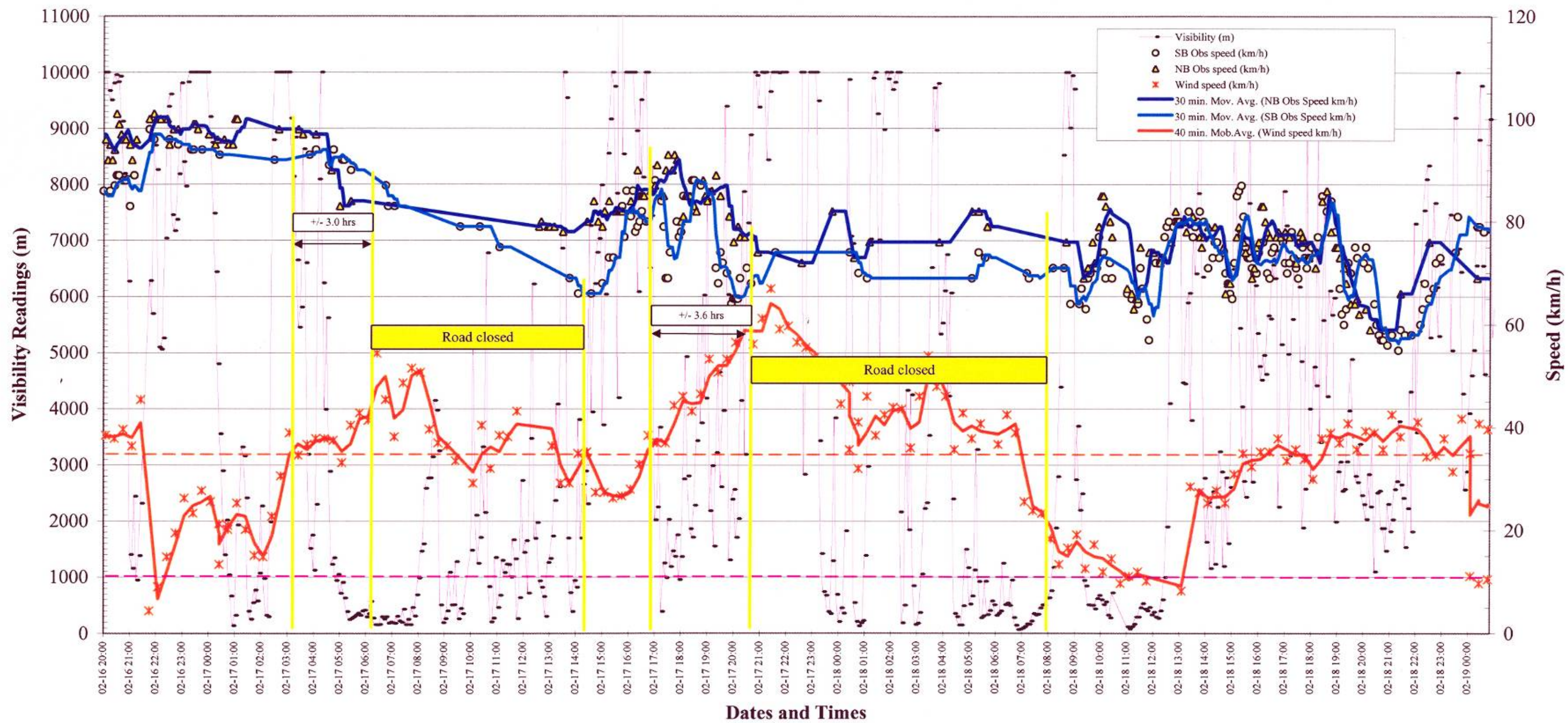


Chart 4.15 – Visibility vs Speed at AMS1 (Feb 13 to Feb 20, 2006)

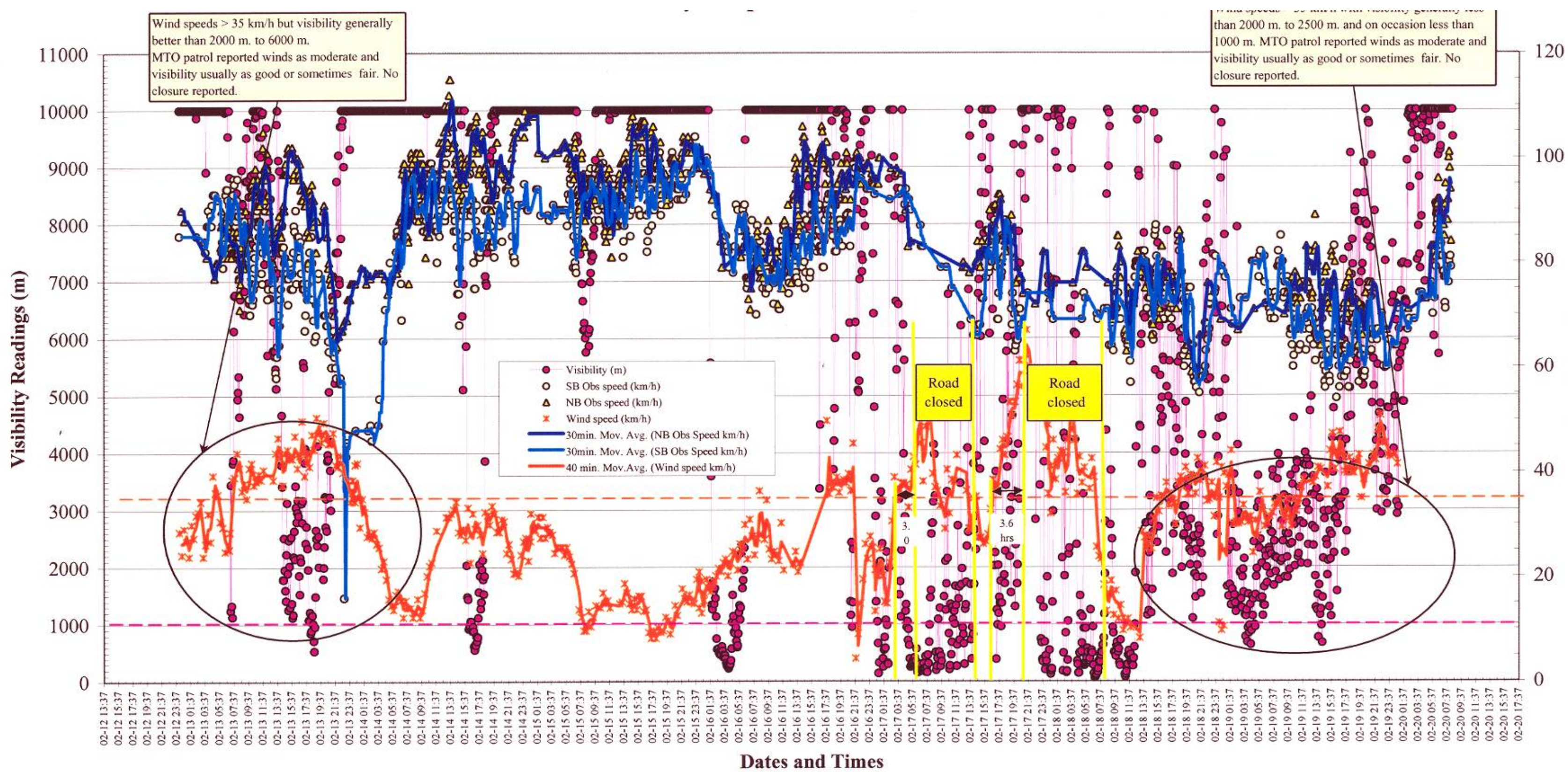


Chart 4.16 – Visibility vs Speed at AMS1 (Feb 20 to Feb 27, 2006)

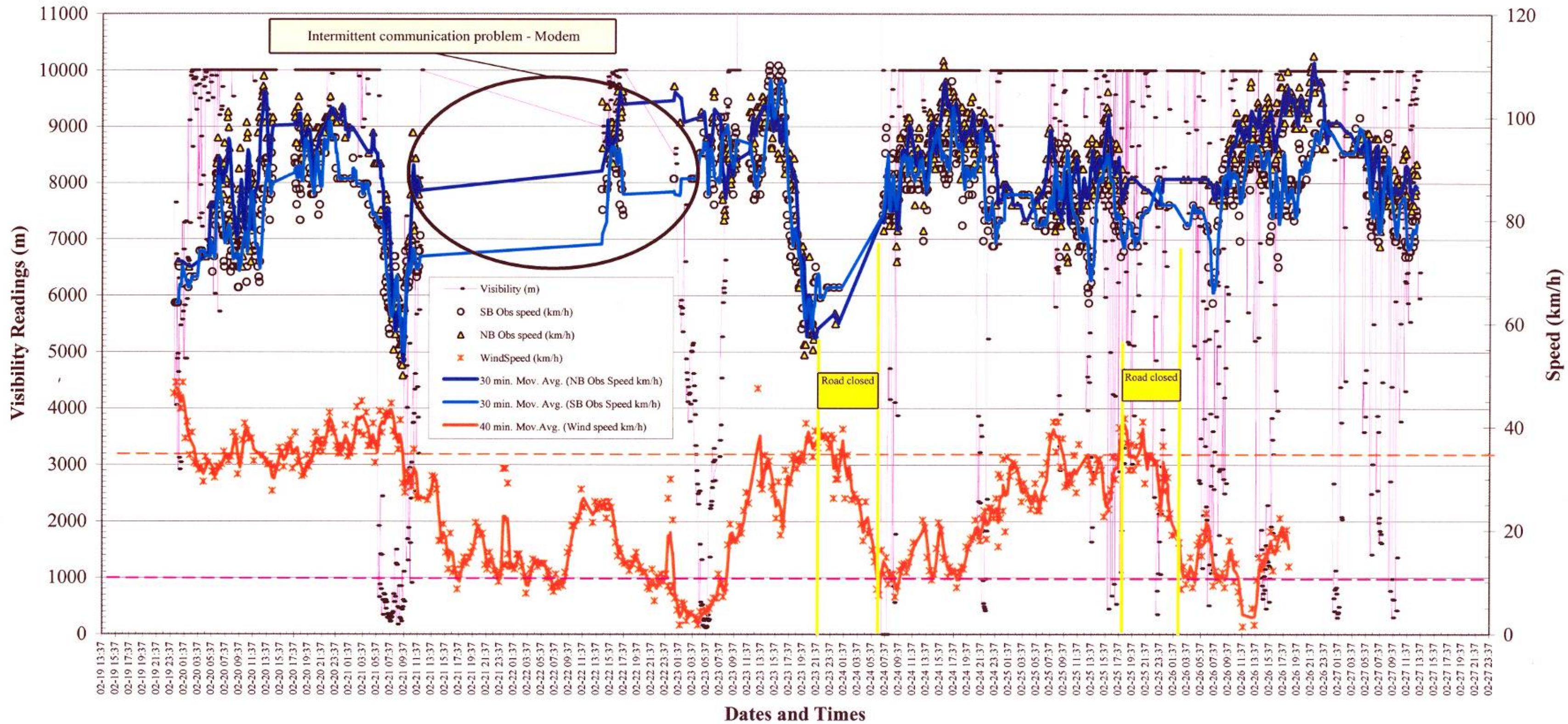


Chart 4.17 – Visibility vs Speed at AMS2 (Feb 16 to Feb 19, 2006)

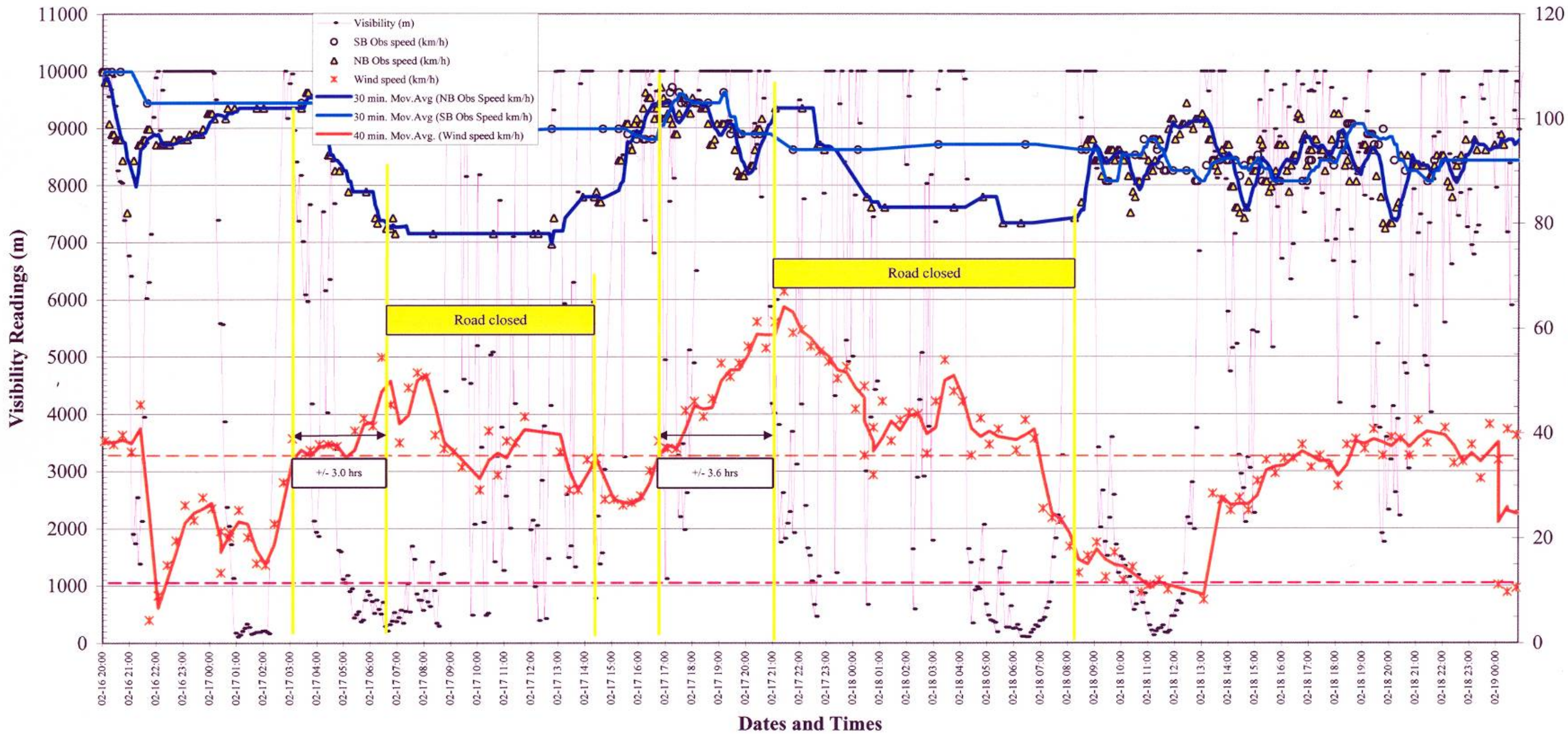


Chart 4.18 – Visibility vs Speed at AMS3 (Feb 16 to Feb 19, 2006)

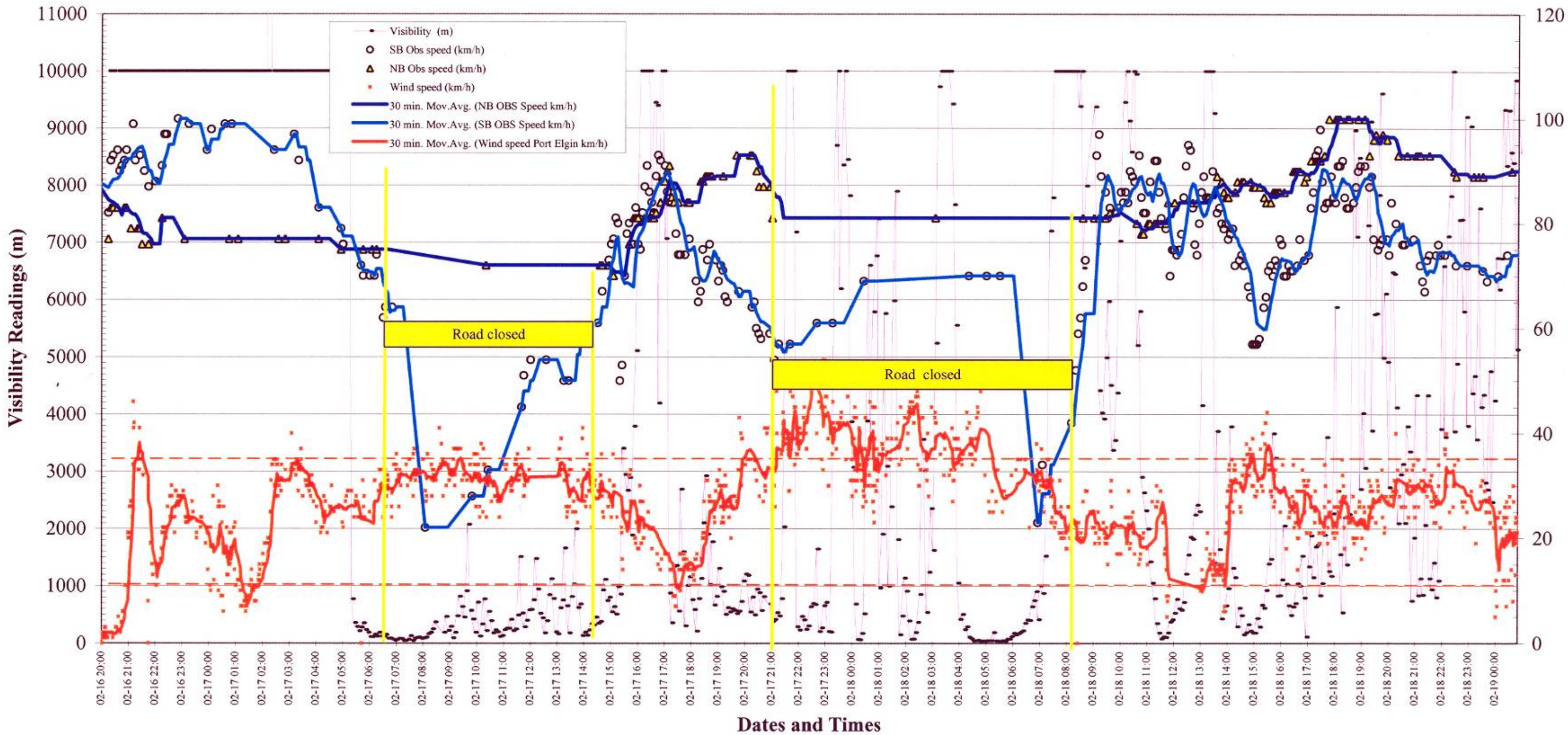
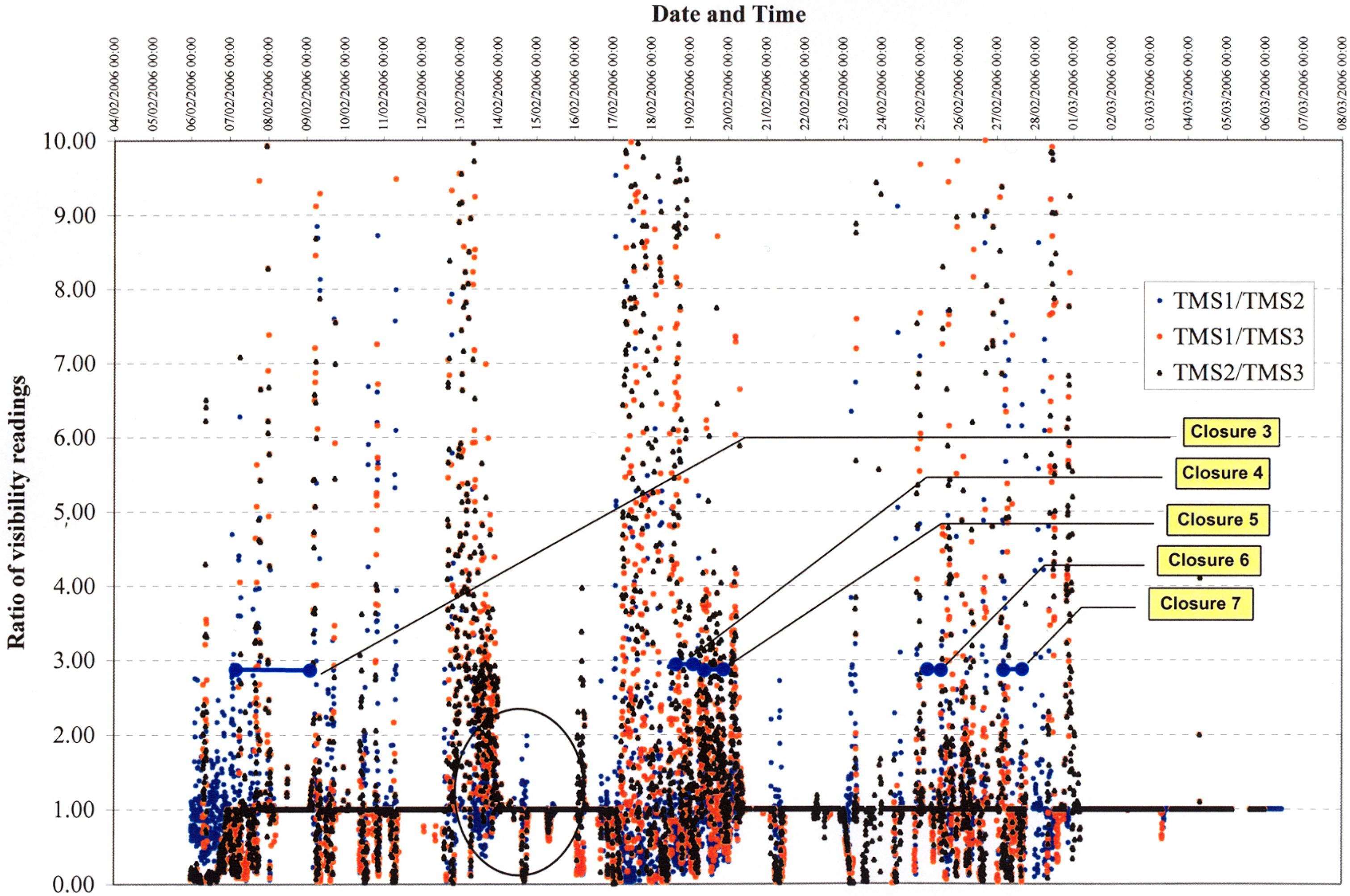
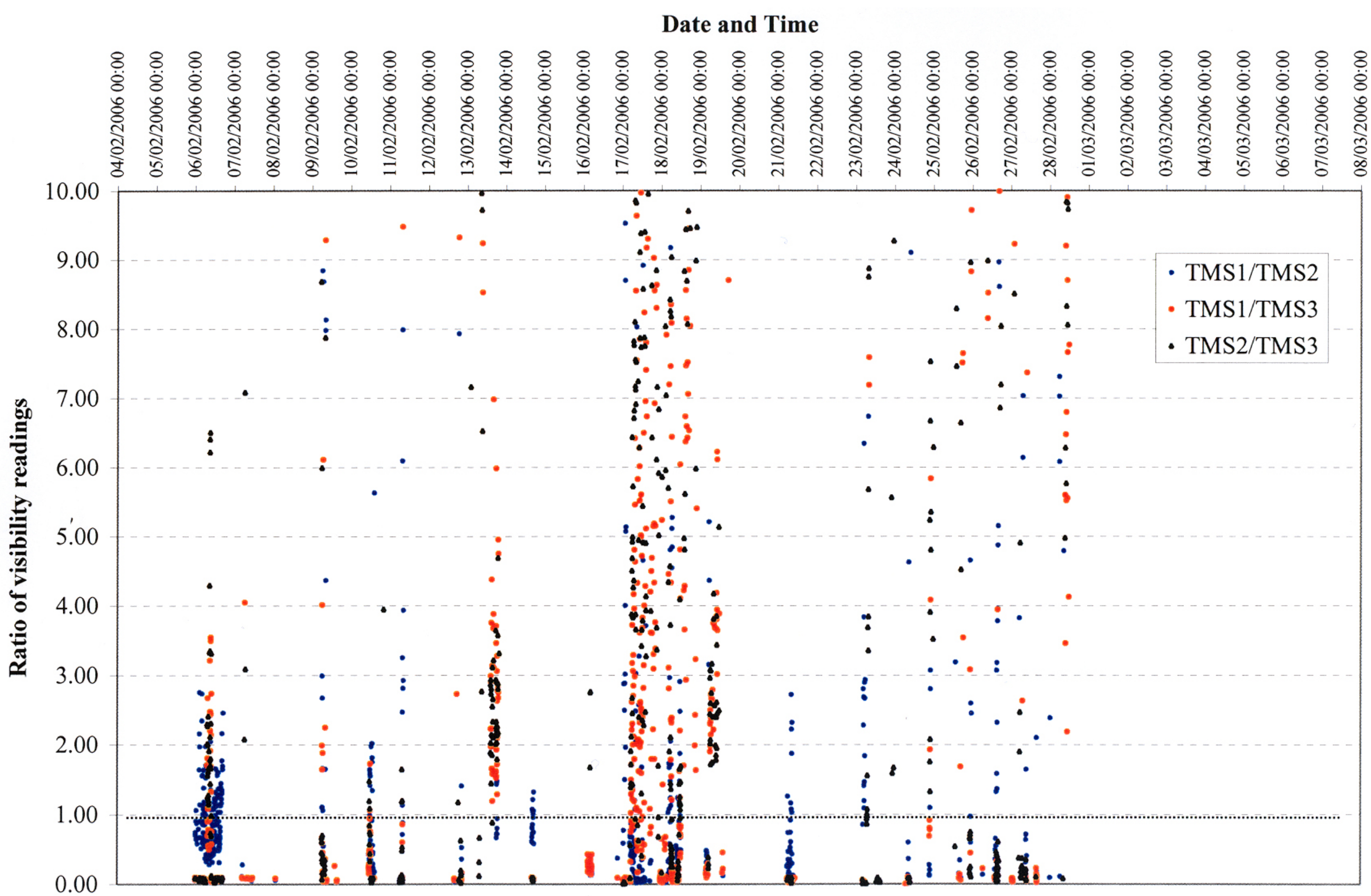


Chart 4.19 – P2P Visibility Comparison (Feb 04 to Mar 07, 2006)



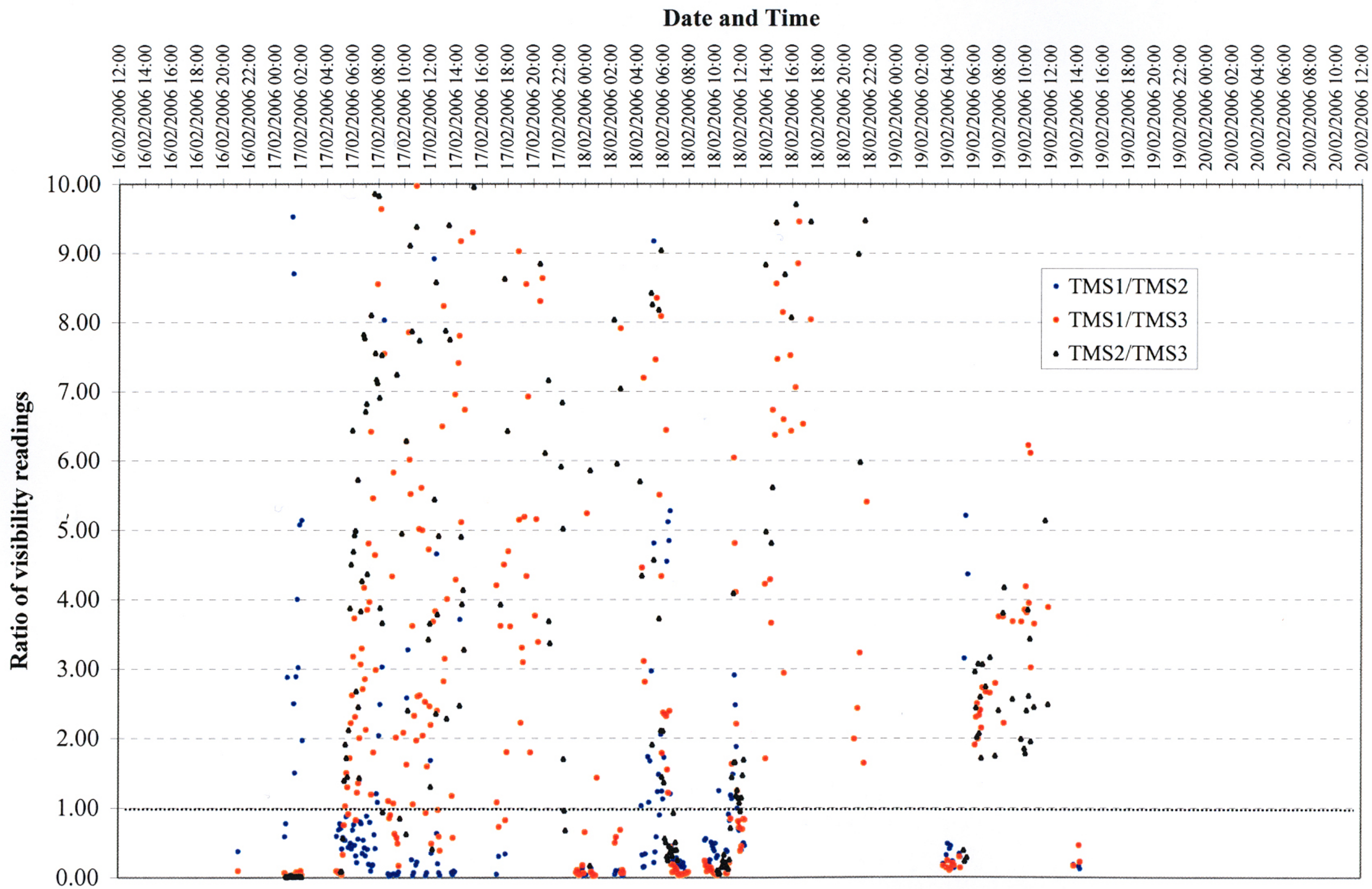
TMS = AMS

Chart 4.20 – P2P Visibility Comparison
(only ratios with at least 1 visibility reading <= 1000m.)



TMS = AMS

Chart 4.21 –PSP Visibility Comparison
(FEB 16 TO 19 – at least 1 visibility reading <=1000m.)



TMS = AMS

Chart 4.22 – Visibility/Wind Speed/Precipitation Based Indicators at AMS1 (Feb 17 to Feb 19, 2006)