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A Summary of Communications Technologies Supporting Roadway Weather Information Systems

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Final Report
June 2010

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Aurora is an international program of collaborative research, development and deployment in the field of road and weather information systems (RWIS), serving the interests and needs of public agencies. The Aurora vision is to deploy RWIS to integrate state-of-the-art road and weather forecasting technologies with coordinated, multi-agency weather monitoring infrastructures. It is hoped this will facilitate advanced road condition and weather monitoring and forecasting capabilities for efficient highway maintenance, and the provision of real-time information to travelers.

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16. Abstract

Public agencies typically operate Roadway Weather Information Systems (RWISs), which provide transportation managers and maintenance crews with a key source of timely and accurate weather information for guiding operations during adverse weather events.

Jurisdictions employ a variety of local area and wide area communications schemes to centrally collect and aggregate environmental data from spatially-distributed RWIS sensors. We were interested in determining best practices and gaining further understanding of the commonly-deployed communications schemes in use for North American RWIS systems. The objectives of this study were to present and describe the categories of communications systems enabling the transmission of field-collected environmental data to centralized data collection and management facilities; review the types of data collected by the various sensors deployed within participating jurisdictions; and detail the communications requirements and communications solutions deployed to meet the constraints imposed by these collected data products.

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A SUMMARY OF COMMUNICATIONS TECHNOLOGIES SUPPORTING ROADWAY WEATHER INFORMATION SYSTEMS

Final Report
June 2010

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BACKGROUND

Adverse winter weather conditions present operational capacity and safety problems to travelers utilizing the nation's transportation infrastructure. To counter such threats, transportation system managers attack adverse roadway conditions with a variety of countermeasures, applying a hierarchy of traveler information systems, chemical anti-ice agents, surface-friction-increasing granular materials, and, ultimately, road closures.

For the most-effective application of such countermeasures in the fight against winter weather, it is desirable for transportation managers to have accurate and close-to-real time information about the weather events threatening transportation corridors within their jurisdiction. To provide this information, managers rely on a range of public and private data sources, such as Internet weather sites, local and national television broadcasts, National Weather Service bulletins, and private prediction services.

Also common among jurisdictions is the deployment of environmental sensor networks alongside travel corridors. Such a system of instrumentation is commonly called a Roadway Weather Information System (RWIS), and is typically operated by a public agency with requisite deployment and operational assistance from a short list of private-sector vendors. We found that RWIS stations provide transportation managers and maintenance crews with a key source of timely and accurate weather information for guiding operations during adverse weather events.

Jurisdictions employ a variety of local area and wide area communications schemes to centrally collect and aggregate environmental data from spatially-distributed RWIS sensors. We are interested in determining best practices and gaining further understanding of the commonly-deployed communications schemes in use for North American RWIS systems. It is hoped that such a study will accomplish the following objectives:

- Present and describe the categories of communications systems enabling the transmission of field-collected environmental data to centralized data collection and management facilities.
- Review the types of data collected by the various sensors deployed within participating jurisdictions.
- Detail the communications requirements and communications solutions deployed to meet the constraints imposed by these collected data products.

RWIS ARCHITECTURE SUMMARY

To provide a common frame of reference and system vocabulary, we describe and classify the components of a typical RWIS installation and categorize the types of data collected by roadside instrumentation. The typical sensor suite we describe will also serve as a useful reference for making comparisons between the RWIS devices and networks encountered in our research. Figure 1 shows a block diagram detailing our typical reference model.

At the core of every RWIS deployment is the field-deployed network of environmental sensors. We'll refer to the entire collection of sensors and hardware for a single location as a Remote Processing Unit (RPU). A number of spatially-distributed RPUs are deployed using a coverage strategy that maximizes the environmental data available for key travel corridors within a jurisdiction, while adhering to the constraints of a fixed deployment and maintenance budget.

In Figure 1, beginning from the left side, we show the local environment in which the RPU is deployed to collect environmental data. Focusing on the sub-components of the RPU shown in the figure, we show a typical RPU consisting of sensing hardware for the following data collection categories:

- Sub-surface
- Surface
- Atmospheric
- Video/image capture

Sensors are under the control of the RPU central processing unit (CPU), which also manages the communication of collected data to centralized collection and management services. In the diagram, the RPU is shown receiving electrical power from the local power grid. This sub-system provides the power necessary for all sensors, CPU, and communications.

Following the flow of communications (over a private or public communications network), we depict communicated environmental data being staged to a centralized collection point by collection and management services. Here, data are stored into a repository supporting any required downstream data management, reporting, and analysis applications.

Typical reporting and analysis applications include activities such as weather event prediction, real time information for winter storm-fighting activities, traveler information systems, and pavement temperature modeling/calibration. Management activities consist of typical information system functions of data backup, integrity, availability, and confidentiality (if appropriate).

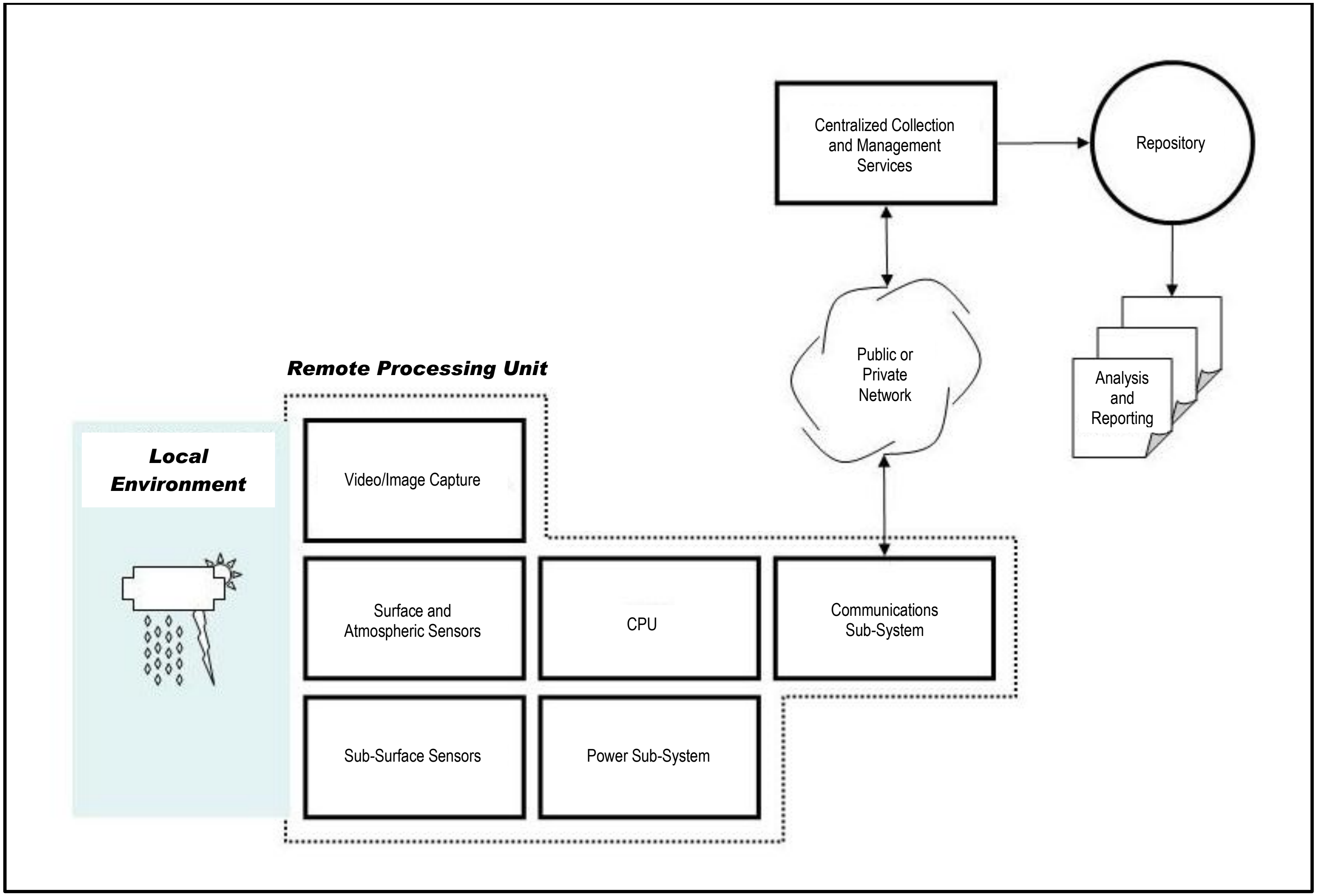

Figure 1. Typical RWIS architecture

COMMUNICATION TECHNOLOGY OVERVIEW

The jurisdictions in our study employed a variety of communications technologies for the transmission of roadside environmental data to centralized collection and management services. Technology variations not only exist from jurisdiction to jurisdiction, but they also exist within each jurisdiction.

We found the type of communications technology in use typically reflects what the most economical choice for a deploying agency was at the time of a rollout. Such decisions are logical when the costs of RWIS system rollouts are placed in the context of an agency decision-making process, governed by an adherence to a limited resource budget. Staged RWIS RPU rollouts also explain some of the variation in technology choice within a jurisdiction. The economics of technology choice was also heavily dependent upon geographic area size and terrain variations, the update frequency and timeliness required by decision support applications, and the types of sensors deployed within a jurisdiction.

We organize communications technologies into the following two categories:

- Land-line
- Wireless

Land-Line Communications

The jurisdictions we contacted that employ land-line communication technologies used predominantly dial-up and dedicated leased-line telephone circuits. Other examples we found in this category include fiber-optic facilities, digital subscriber line (DSL), and cable broadband networking technologies.

Dial-up telephone circuits offer a low-cost way to communicate with remote environmental sensors, but come with the trade-off of low data rate and the requirement to have access to the telephone system. The slower data rate of traditional public switched telephone network (PSTN) type dial-up facilities either do not permit or greatly hinder the collection of some types of environmental data, such as near real time sensor readings and video imagery streaming.

The cycle time, or time it takes for a central polling point to dial-up all the sensors in a region, can also become a limiting factor in determining how often sensor information is made available to centralized collection and management services. However, at least one jurisdiction we interviewed (the Illinois Department of Transportation/IDOT) reports the capability of central collection services to dial up multiple sites in parallel with each other, due to dial-up modem redundancy in their server-side hardware architecture.

Dedicated leased-line circuits have the same physical location requirements, but may offer higher data rates, reduced cycle time, and increased data polling frequency. However, leased-line communications present a higher cost than dial-up communication lines.

The low cost of telephone lines and widespread availability make telephone circuits, especially dial-up, an easy choice for sensor-polling communications in many RWIS systems. However, long distance and interLATA charges can present cost problems to RWIS managers. (LATA stands for Local Access and Transport Area and interLATA calls are ones that are placed in one of these areas and received in another, requiring the use of an IXC Interexchange Carrier or IXC.)

To circumvent these charges, we found some jurisdictions forward-deploying communications servers local to a region (e.g. at a Department of Transportation/DOT District Engineering Office) to perform local rate (rather than long distance) dial-up polling functions on nearby RWIS sensor stations. These servers then communicate with central collection and management services using common Internet facilities already in place to serve other business functions required of the local branch office. This method of reducing operating costs is also found in use with all of the other communications technologies we describe as being used for the local first-hop, with final (e.g. backbone or back-haul) communications transport functionality depending on the Internet.

DSL and cable broadband technologies offering high speed, broadband data rates, “always-on” capability, and dedicated access to sensor data also fall into the land-line communications category. Both of these technologies have strict physical location requirements (e.g. DSL must be within a preset distance of a central office or collection network repeater node) and are most often found serving as the back-haul communications to central processing and management facilities in conjunction with a lower cost and less location restrictive first-hop technology, as we describe above.

The other form of land-line communications technologies we encountered in use by jurisdictions were fiber optics transmission facilities. Fiber optic transmission technologies feature the fastest data rates for high-demand applications. Dedicated, real time, high-resolution, streaming video applications are easily supported for RWIS, along with any number of sensor data types. Most often, fiber optic technology is found roadside as part of a regional Intelligent Transportation System (ITS) infrastructure. Typically, RWIS assets are integrated into ITS rollouts, along with other Advance Traveler Information System devices as part of an overall ITS traffic management plan.

Due to being part of an overall ITS design, it is more difficult to quantify the cost tradeoffs for these RWIS deployments’ traversing roadside fiber optics networks. In these cases, the RWIS is piggy-backed onto existing communications architecture at only a minor marginal cost to the overall design and implementation.

Wireless Communications

Jurisdictions we contacted employed a variety of wireless communications technologies. We found wireless technologies serving an increasingly prominent role in the first-hop from RPU to central collection and management facilities. The categories of wireless communications equipment in use by surveyed jurisdictions include wireless telephony devices (cellular modem, air-cards, etc.), dedicated (such as spread-spectrum) point-to-point communications equipment, and some usage of satellite transceivers in remote non-urban areas.

Cellular wireless technologies offer increasingly competitive service plans and mature service coverage areas in much of the continental US. Vendors providing cellular technologies offer both dedicated (continuous) and intermittent (e.g. dial-up) data communications services. The drawback to these services is the need for some sort of continuous service agreement; however, wireless coverage plans now approach land-line communications in cost and coverage area.

Competition to deliver smart-phone type mobile devices in the consumer and commercial markets has led to steady increases in data rate. The technology, and therefore the data rate, is categorized by what is called a "generation," or G, for short. Therefore, 3G simply translates to "third generation" below.

That said, the typical 2.5G data rates are 9.6 kilobits per second (kbps) to 256 kbps, with 3G offering considerably higher data rate packages, beginning at 384 kbps, with the potential for 7.2 megabits per second (Mbps) and higher with 3.5G and planned 4G rollouts in the near future. In short, current and near-future data rates offer supporting bandwidth for most any type of environmental sensing currently deployed by jurisdictions, including continuous sensor monitoring and (beginning with 3G/3.5G) streaming of some form of compressed video imagery.

Aside from cellular services, we found surveyed jurisdictions using a variety of other wireless solutions. A common element among these technologies is equipment, owned and maintained by the agency, which uses spread-spectrum technology as part of a wireless bridge or wireless local area network (WLAN) architecture. Spread spectrum methods allow for denser subscriber counts, reduced channel interference, and higher noise immunity, supporting greater range for a given transmission power.

The Industrial, Scientific, and Medical (ISM) bands of 900 megahertz (MHz), 2.4 gigahertz (GHz), and 5.8 GHz support a great variety of unlicensed wireless data link layer protocols providing jurisdictions a range of alternatives to cellular services for wireless communications with remote environmental sensors. Protocols in use range from proprietary vendor-specific protocols to standards-based protocols, such as 802.11 (WiFi), 802.15 (ZigBee), and 802.16 (WiMAX). Access methods such as these support both point-to-point and point-to-multi-point wireless network topologies.

Because these technologies are commonly privately owned and operated by a transportation agency, they have little or no recurring fees associated specifically with data communications from remote field units to a point of presence on the agency local or wide area network. This is in contrast to cellular services requiring monthly or yearly service contracts. Installation and maintenance consists of setting up the link, antenna installation, load testing, and troubleshooting any link communications drop-out or malfunctions. Again, these technologies predominantly serve as the first-hop or data link layer linkage to a wide-area communications backbone.

In-house technical expertise is commonly called upon to maintain or install such systems, when available. Vendors also may offer support packages, which vary in cost and available services. Such services may be required when proprietary wireless hardware and protocols are deployed.

A CLOSER LOOK – EXAMINING THE RWIS NETWORKS OF SEVERAL AGENCIES

This section presents reviews of several organizational RWIS deployments, each with an emphasis on the communications technologies found to be in use, along with any notable "lessons-learned" type information encountered during our research interaction with the particular jurisdiction.

Jurisdictions were asked to respond to the following questionnaire:

1. What is the history of RWIS in your jurisdiction?
2. What is the current number of RWIS sensors deployed in your jurisdiction?
3. What is the mix of communications in use, and how has the mix changed over the history of RWIS deployment within your jurisdiction?
4. What RWIS technologies work and do not work in your jurisdiction?
5. What lessons learned would you like to pass along to other jurisdictions?

We received responses from the following jurisdictions:

- Alaska
- Illinois
- Indiana
- Iowa
- Massachusetts
- Minnesota
- Nebraska
- New Jersey
- New York
- Nova Scotia
- Ohio
- Ontario
- Wisconsin

ALASKA

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Deployment History: Began implementation in 2001.

Number of Sites: 49 sites.

Communications: Dial-Up, 900 mHz, Satellite, CDMA for Highway and Interstate.

Deployment Notes:

Implemented in 3 Phases.

8 initial sites in Anchorage area for testing.

WTI prepared a 10 year RWIS implementation plan.

Some power modules are needed.

Issues with poor telephone lines producing low quality images.

CDMA occasionally denies service when they are over used.

Lessons Learned:

Tie together your mission and goals to help justify of your budgets.

Communicate with maintenance staff and listen to their suggestion.

Work closely with your communications service provider.

ILLINOIS

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Deployment History:	Began implementation in early 1980's.
Number of Sites:	59 (Including 40 on Tollways).
Communications:	Mainly Dial-Up, with several using CDMA/Ethernet.
Deployment Notes:	3 new cameras are planned in the northern portion of the state, including 2 to 3 in the Peoria area. Hope to include cameras at all sites in the near future.
Lessons Learned:	Physically check sites for potential problems before upgrading or installing new sites. Check if the site can use CDMA/Ethernet or another form of communications (such as satellite) is available. Check if vegetation will interfere with camera visibility, communications, or atmospheric sensors. Illinois had atmospheric sensors that were placed in the woods which required the cutting of a lot of foliage due to the effect on humidity readings. Be aware of nearby resources for power and communications when choosing site placement.

INDIANA

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Deployment History: Began implementation in mid 1990's.

Number of Sites: 39 (Including 7 on Tollways and 3 from City of Indianapolis).

Communications: Mainly Dial-Up, with several using fiber-optic LAN or wireless.

Lessons Learned: Do not allow RWIS installations to fall out of your control or jurisdiction as a result of a lease agreement.

Make sure there is no way insects or rodents can gain access to the RPU cabinet and that all conduit is sealed and terminates inside the RPU cabinet.

Have all wiring and cables inside of conduit. The majority of the problems we have had have been a result of the initial installation.

Have a Maintenance Contract in force and a field technician designated solely or at least primarily to your RWIS network.

Establishing a good working relationship between your agency, RWIS vendor, and RWIS field technicians is imperative.

Try to locate your RWIS installations near an agency facility in order to use existing communication networks.

IOWA

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Deployment History: Began implementation in 1989.

Number of Sites: 62 sites.

Communications: 39 dial-up, 11 radio, 6 cellular, 6 DSL.

Deployment Notes: Not had good performance from any salinity-type sensors.

Temperature readings are ok.

Precip sensors are hit-and-miss. Some sensors are always giving false readings or really high accumulations and some are okay.

We have troubles with the atmospheric sensors only rarely.

Lessons Learned: Monitor the quality of your observations and communications.

You could be unaware of any problems unless you start a monitoring program.

MASSACHUSETTS

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Deployment History: Began with 11 stations in Boston.

Number of Sites: 29 sites (Including 15 with Cameras).

Communications: Mainly wireless.

Deployment Notes: Used Vaisala stations in pilot program, however these sites were not well maintained.

Now using SSI (Now Owned by Vaisala)

Lessons Learned: It is critical to set up appropriate maintenance contracts covering system hardware and software.

MINNESOTA

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Deployment History: Began implementation in early 1980's.

Number of Sites: 93 sites

Communications: Mixture of dial-Up, wireless, DSL, satellite, and leased.

Deployment Notes: MnDOT operates a network of 93 RWIS sensor sites located throughout the state's 87,000 square miles and 141,000 miles (290,000 lane miles) of roadways.

Communications upgrade decisions are based on current operating costs versus cost of upgrade and time to cost recovery.

Communications upgrades are prioritized based on biggest cost savings over existing operating costs.

Site Breakdown:

Frame Relay	21
Wireless - External	16
Dial-up	11
DSL	20
Wireless - Internal	9
Satellite	10
Cellular	6
Total Sites:	93

NEBRASKA

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Deployment History: Began implementation in 1985.

Number of Sites: 60 sites.

Communications: Most sites have recently been converted to wireless modems.

Deployment Notes: Initially started with landlines and a few radio linked sites.

Nebraska does not currently have a site to share their information with the public, but they are working to develop one.

Lessons Learned: Get a good maintenance contract in place from a reputable vendor.

NEW JERSEY

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Deployment History: Began implementation in early 1990's.

Number of Sites: 38 sites (also 158 bridge sensors and 41 Sub-Surface Sensors).

Communications: CDMA.

Deployment Notes:

100% of sites are now CDMA.

Dial-up was historically used, but costs were too high.

Emergency 800 MHz state police radio backbone replaced Dial-up, but communication failures occurred due to police priority during snow events.

Lessons Learned:

Saw cuts for roadway sensors should not be in more than one or two lanes. Too many lanes makes replacement extremely difficult.

The safety measures required to reinstall the sensor leads is not cost effective.

Location for new RWIS sites must now take camera field of view into consideration.

NEW YORK

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Deployment History: Began testing in late 1970's.

Number of Sites: 35 sites.

Communications: All cellular.

Deployment Notes: NYDOT performs life cycle and performance analysis on RWIS equipment.

Most meteorological sensors have proven accurate, but pavement sensors have had mixed results.

Surface & subsurface temps are reliable, but percentage of ice/salinity/water film depth/freeze point etc. measurements have raised concerns.

Camera & IR imaging have shown good results.

Lessons Learned: New York recommends the following vendor questionnaire for all system components:

1) Manufacturer, make & model.
2) Mean Time Before Failure.
3) Complete manufacturer's maintenance & calibration procedures.
4) Controlled environment performance specifications.
5) Complete test procedures used to determine controlled environment performance specifications (& certified copies of test results).
6) Real world performance specifications.
7) Complete test procedures used to determine real world performance specifications (& certified copies of test results).

NOVA SCOTIA

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Deployment History: Began implementation in early 1994.

Number of Sites: 41 sites.

Communications: Cellular modem, mix of wireless and hardwired, also one satellite site.

Deployment Notes: Aim for 2 new installs per year.

The data from the sites provides our frontline staff with the information they need to better manage their winter maintenance activities.

In 2007 we conducted a pilot project whereby a portion of our roadway was thermally mapped (tied into specific RWIS sites).

Night Icing Potential (NIP) forecasts were produced indicating the time minimum pavement temperatures would be reached along roadways.

Nova Scotia pays one installation invoice, and one monthly fee which includes maintenance and forecasting.

Lessons Learned: Stick with the same vendor for equipment and to have turnkey operation.

OHIO

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Deployment History: Began implementation in 1992. Additional in 1992, 1195, 2003.

Number of Sites: 170 sites.

Communications: Spread Spectrum and Cellular Modems and one DSL. Phone line costs hampered ability to fully utilize system at first.

Deployment Notes: What Works:

- Solar/Wind Powered RPU's.
- Wireless Removable Pavement Sensors.
- Cellular and Spread Spectrum Modems.

What Does Not Work:

- Salinity measuring sensors (FHWA Report Number: FHWA/OH-2003/008B)
- Active Freeze Point sensors.

Lessons Learned: Training – Regular and consistent RWIS and Weather training helps users understand how RWIS works.

Ownership – Someone needs to take ownership to ensure data quality and repairs are done when necessary.

Maintenance – Planning for maintenance is vital to keeping RWIS working at a high level.

IT Support – A good working relationship between RWIS personnel and IT Staff has benefitted Ohio DOT.

ONTARIO

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Deployment History: Began implementation in 1999.

Number of Sites: 114 sites.

Communications: All dial-up.

Deployment Notes: Each site has:

-Air Temp/Relative Humidity
-Wind Speed/Gusts/ Wind Direction
-Pressure
-Precipitation (yes/no)
-Passive Pavement Surface Sensors
-Sub-Surface Sensor (depth 40cm, 1.5m)

Lessons Learned:

Ensure that yearly maintenance is performed.

Design RWIS system to be robust (lightning protection, surge protection, etc).

Design RWIS underground to facilitate ease of repair.

Have ability to assess real time operational status.

Remotely control components (e.g. RPU restarts).

Combine Transportation Department technologies where possible (e.g traffic data, traffic monitoring, and RWIS).

Reduce power/communications costs.

WISCONSIN

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Deployment History: Began implementation in mid 80's. Went from 21 to 51 sites in 1995.

Number of Sites: 57 sites.

Communications: All dial-up.

Deployment Notes: Biggest drawback of landline dial-up is high cost and the sensors only support hourly polling due to this high communications cost.

Using distributed polling CPUs has reduced some costs.

Lessons Learned: Plan from the start for what the RWIS System is designed to do, and how the deployment will be structured.

Avoid stove-piping.

Working with ITS managers is helpful as similar communications problems exist within the ITS domain.