Standardized Testing Methodologies for Pavement Sensors

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DRAFT FINAL REPORT

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EXECUTIVE SUMMARY

This project, funded by the Aurora Program, researched procedures for calibrating and testing RWIS pavement sensors. The project investigated existing procedures through a review of documented research and interviews with RWIS practitioners. Additionally, the study analyzed the perceived need for standardized testing methodologies for pavement sensors.

This project consisted of two tasks. The first task involved performing a literature review of existing documentation. Information was gathered from academic databases, the Internet, and manufacturer's manuals. Few specific procedures were found as a result of the literature. As well, the project team uncovered various specifications used by the United Kingdom and the Minnesota Department of Transportation for pavement temperature.

The results of the literature search assisted in formulating a survey administered to public and private agencies that actively participate in RWIS activities. This was the focus of Task 2. The survey consisted of questions relating to:

- the general history of RWIS activities within the agency;
- procedures for calibrating and re-calibrating pavement sensors;
- specifications for calibrating sensors; and
- the perceived need for standardized testing methodologies.

The experts interviewed for this task were obtained from the literature search findings, Aurora members, and referrals from other experts interviewed. These interviews were performed to further add value to the research findings. Also from experience, agencies may perform activities that are unavailable through literature searches or not widely known. The interviews also helped to determine the perceived need for these testing methods. This insight could only be adequately obtained by talking with the leaders in the RWIS community.

The study revealed little practical agency-experience for testing and calibrating sensors. The Ministère de l'Equipment des Transports et du Logement (METL) of France is an example of an agency that is successfully performing their own calibration and testing of sensors. Their efforts have evolved to a level where climate chambers were developed for testing sensors. Within the United States, the Kansas Department of Transportation (Kansas DOT) leads this effort. Due to their frustration with vendors, they took the initiative to test and calibrate sensors.

The support for developing standard testing procedures is mixed among transportation professionals. While some view standards as a necessary development, others are happy to place the burden on vendors. As RWIS technologies continue to play a greater role in transportation maintenance activities, the accuracy of the data obtained will need to be repeatedly scrutinized. It is hoped that these finding will provide a foundation for further advancements in developing procedures for calibrating and testing procedures for RWIS pavement sensors.

1. INTRODUCTION

RWIS data is integral to assisting transportation agencies in making critical maintenance decisions. To ensure quality and accurate data, RWIS technologies such as pavement sensors must consistently function properly. The techniques for testing and calibrating sensors have traditionally been the responsibility of vendors contracted for RWIS maintenance. While this relationship with vendors for performing maintenance services on RWIS technologies is adequate for some transportation agencies, others are looking at methods that can be utilized and applied within their organization.

The Aurora Consortium is a group of international transportation agencies specializing in RWIS research and advancing new technologies. The group has recognized the need to study the existence of standardized testing methodologies for pavement sensors in practice. The main objective of the Standardized Testing Methodologies project is to establish and evaluate the performance of standard procedures for testing pavement sensors. The purpose is to provide a baseline of information that will assist Aurora in developing comprehensive and flexible guidelines that can be used by Aurora and other transportation agencies. Ultimately, these procedures may be used as a method for recognizing pavement sensors that meet acceptable criteria and performance measures. It is hoped that these procedures will further assist transportation agencies in ensuring higher quality data and greater performance from pavement sensors.

1.1 Project Overview

The Standardized Testing Methodology project consists of two tasks. Task 1 consisted of reviewing previous research regarding evaluation and testing procedures of RWIS pavement sensors. This process involved searching academic databases and the Internet for sources of information in addition to a number of product manufacturer's pavement sensor manuals.

The goal of Task 2 was to interview RWIS experts to gain insight on their knowledge of standards or protocols for testing RWIS pavement sensors either in practice or documented. . Experts were chosen based on recommendations from the Aurora Consortium as well as from other interviewed experts and the literature search findings. A survey was developed to guide the discussion with experts. Questions were formulated to gain an understanding of:

- the general history of RWIS activities within the agency;
- procedures for calibrating and re-calibrating pavement sensors;
- specifications for calibrating sensors; and
- perceived need for standardized testing methodologies.

A copy of the specific survey questions can be found in Appendix A. Experts interviewed included those from state departments of transportation (DOTs), international transportation agencies, academia, and manufacturers of RWIS technologies.

2. REVIEW OF PREVIOUSLY DOCUMENTED RESEARCH

From the research gathered, some reports documented that many transportation agencies do not consider testing pavement sensors before installing them in the field (2,7). These agencies have assumed that these sensors have already been tested and calibrated in a manufacturer's laboratory setting and therefore feel further testing in the field is not a necessity. For example, pavement temperature is a parameter that has been "very well developed" and has provided accurate results (2). Other documents researched provided guidelines for agencies desiring field testing of pavement sensors.

Pavement sensors are primarily designed to detect temperature, chemical concentration, snowy or icy conditions, and moisture on the road surface. Procedures to test pavement sensors take into account certain performance criteria used to measure these parameters. These include: sampling rate, range and accuracy, calibration, reliability and robustness, and power requirements. Whenever available, some performance requirements can be compared to existing specifications.

2.1 Performance Requirements

Pavement sensors should ultimately satisfy key performance requirements before installation in the field. The following sections will further define the performance criteria and provide the procedures for testing (whenever information was available). It should be noted that some key requirements provide only guidelines "for consideration." For example, sensors should be able to function on low power consumption to allow for alternative power sources such as batteries or solar power when needed. While this is a description of the performance requirement, there were no documented data that suggests methods for testing power consumption.

2.1.1 Sampling rates

A sampling rate is associated with three factors: the rate at which environmental parameters (e.g., temperature or precipitation) change, "response time and degree of integration incorporated in the sensor," and rate desired for recording measurements. For example, if the parameter changes relatively quickly, a fast sampling rate should be used. For slowly changing parameters a slower rate is adequate. Other considerations include the time increments at which measurements are recorded, such as real-time measurements or periodic measurements. (1) Although the sampling rate is a key requirement in evaluating the performance of the pavement sensor, no documented procedures were discussed in any of the research findings.

2.1.2 Calibration

Calibration of pavement sensors is required to achieve accurate sensor operation. Sensor calibration falls into three categories: initial calibration, onsite calibration and periodic re-calibration. The initial calibration occurs in a laboratory setting and is commonly performed by the pavement sensor manufacturers. Onsite calibration, if performed, occurs at the field installation site. Periodic re-calibration is conducted when sensor readings are inadequate or as determined or needed by an agency.

The temperature sensor calibration process consists of a zero calibration; calibrating the device to freezing, and a span calibration; calibrating the device at two or more temperatures to determine the calibration coefficient. This process is the same for all calibration categories. The procedure used in lab testing of pavement sensors is as follows:

Pavement temperature. A documented lab procedure for calibration of the pavement temperature sensor is to submerge the device into two baths of water at different known temperatures. From the sensor readings and the known values, calibration coefficients are created and used for that specific sensor. (4)

To test the accuracy of the temperature sensor in the laboratory, a mercury thermometer, a solid state pavement sensor and a thermocouple may all be placed in a bucket of water. The water temperature is decreased to 32 degrees Fahrenheit and then increased to two higher temperatures. The results of the three readings from all devices are then compared with one another. (5)

The United Kingdom has used thermal mapping by means of vehicle-mounted infra-red thermometers to measure roadway surface temperatures. The research indicates that the United Kingdom uses road climate / thermal mapping for several purposes among which is to calibrate sensors. (3,6)

Another source used a calibrated radiometer (RayTek PM-4) to verify pavement temperatures. From the literature search, it was suggested that the proper use of this device may allow for accurate surface temperature calibration in the instances documented. For example, the reading is dependent on the vertical placement of the device above the roadway surface. It was determined that the calibration readings producing the most accurate results occurred when the radiometer was held approximately two inches above the roadway surface. To obtain this height, an accepted rule of thumb has been to situate the radiometer on top of the shoe of the person obtaining a reading. (7) To eliminate variability in the vertical distance between the pavement and the radiometer placement, a mechanism whereby the device can be consistently placed two inches above the roadway would prove beneficial.

Freezing point / chemical concentration sensors. The documented laboratory calibration of freezing point sensors consisted of introducing five different solutions with known salinities / freezing points, and comparing the sensor readings to these known values. (4)

2.1.3 Reliability and robustness

RWIS pavement sensors are expected to function continuously and accurately in adverse weather, road, and traffic conditions over extended periods of time without maintenance. Typical performance criteria associated with the reliability and robustness of pavement sensors include:

- resistance to expansion and contraction;
- reliable and accurate operation through severe weather, road and traffic conditions;
- low maintenance; and
- long life expectancy.

While no formal evaluation procedures existed in the documented research, a probe of manufacturer's literature and warranties may prove fruitful. Furthermore, vendors should be questioned about the reliability and robustness of their sensors. (1)

2.1.4 Power requirements

Power requirements were another consideration. Power requirements comprise the sensor's ability to function continuously in the event of power surges, power failures, and not necessitating continual maintenance to change the power supply. It was recommended in several documents that battery back ups should be available in case of power failure (1). Battery power should not be relied on as the main source of energy since it would not provide sufficient, reliable and continuous sources of power. Again, no formal documented procedures were available to test power requirements. (1)

2.1.5 Range and accuracy

Another requirement is the ability for pavement sensors to accurately report parameter readings under all circumstances. As a guideline, typical situations under which sensors are expected to perform accurately include temperature extremes and varying levels of moisture. Furthermore, these sensors should be able to detect all forms of snow and ice cover and sense all types of chemical concentrations that are likely to occur on the roadway. The United Kingdom Department of Transport has developed specifications for the range and accuracy of temperature sensors. Aanderaa Instruments, a vendor of pavement sensors, has also developed its own requirements for the range and accuracy for temperature, ice / snow accumulation, and chemical concentration / freezing point. Since the accuracy of pavement sensors is closely related to the calibration, the procedures detailed in 2.1.2 for calibration of pavement sensors also apply to the testing of accuracy. The table below shows the range and accuracy used by the United Kingdom Department of Transport , Aanderaa Instruments, and the Minnesota Department of Transportation (Mn/DOT) in testing pavement sensors. (1)

	UK Department of Transport	**Aanderaa Instruments**	**Mn/DOT**
Temperature	**Range** **Accuracy** -25 C to -15 C ±1 C -15 C to 15 C ±0.5 C 15 C to 25 C ±1 C	**Range** **Accuracy** -43 C to +48 C ±0.2 C	**Range** **Accuracy** -30 C to 66 C ±0.28 C
Moisture	N/A	N/A	N/A
Ice or snow accumulation	N/A	detection level < 5 mm Range of operation -45 C to +50 C	N/A
Chemical concentration / freezing pt.	N/A	**Range** **Accuracy** -26 C to 0 C ±10%	N/A

:

Table 2.1 - Range and Accuracy Specifications

2.2 Existing Specifications

The literature search revealed few references to existing specifications. The only public agency that has developed specifications for pavement sensors was the United Kingdom Department of Transport. Other than that, it was determined from the research that each manufacturer has developed range and accuracy specifications for their own instruments. The values set by each vendor varies slightly from one another. Also, the sources and the means by which these values were obtained were not further discussed in the literature.

2.3 World Meteorological Organization (WMO)

From correspondence with the Ministère de l'Equipment des Transports et du Logement (METL) of France, it was suggested that the project team review a study commissioned by the World Meteorological Organization. The study was undertaken as a result of the Commission of Instruments and Methods of Observations (CIMO) recognizing the potential of road weather information contributing to traffic safety and long-term cost savings. The purpose of the study was to determine previous work undertaken to standardize RWIS instruments and methods of observations. It also consisted of performing a literature review, administering a general survey to all Permanent Representatives of WMO and a detailed questionnaire to nominated points of contact, and speaking directly with practitioners. It should be noted that the practitioners contacted within the WMO study were drawn from the meteorological community. Nevertheless, the study very much parallels the Standardized Testing Methodologies project. The report concludes that there has been little emphasis, throughout the world, on ensuring that meteorological data derived for road applications are consistent or of "known quality." (8)

The study recognized the "general agreement" among agencies about the types of meteorological measurements and instruments used for RWIS purposes. However, the study noted that observing practices (e.g., location and exposure of sensors) among agencies differ greatly and may affect the quality of the data. In other words, the "quality of the data is likely to be uncertain." The report stated that agencies need to be cautious of using the data obtained from RWIS instruments for purposes other than for the original intended applications. As a final note, agencies simply rely on the specifications provided by vendors as a result of the lack of standardized and accepted guidelines. (8)

3. SURVEY RESULTS

The following sections summarize the information gathered from the interviews performed with (DOTs), international transportation agencies, academia, and manufacturers of RWIS technologies. Please note that due to language barriers with France, the information was derived from materials provided by the agency. Translation of the documents was required and due to limiting factors within this project the full translation of all documents was not possible. Rather a summary of the findings is provided.

3.1 Public Agency and Private Sector Road Weather Information Systems (RWIS) Activities

All of the agencies interviewed recognized the value of calibrating, testing, and re-calibrating RWIS pavement sensors. These procedures were deemed important in ensuring that high quality data could be obtained from the sensors. This section details the RWIS-related activities performed by the public agencies and private vendors interviewed. The history of RWIS within these agencies helps to better understand the extent of their involvement and knowledge of existing procedures or protocols.

3.1.1 Illinois Department of Transportation (Illinois DOT)

As an example, the Illinois Department of Transportation (Illinois DOT) has installed 28 pavement sensors in their District 6. The Illinois DOT has a contract with a vendor for complete maintenance of their RWIS technologies. The contract covers repair and replacement of all equipment except for phone/communications lines. The responsibility of the RWIS stations is divided by district. Also, Illinois, Iowa and Missouri have partnered to share the information provided by all the sites within their boundaries. This has been performed for advanced warning for severe conditions.

3.1.2 Iowa Department of Transportation (Iowa DOT)

Currently, the Iowa Department of Transportation (Iowa DOT) has 50 RWIS stations installed across the state. The stations were installed by Surface Systems, Incorporated (SSI). In addition, the Iowa Department of Transportation has contracted SSI to maintain all of their stations. The stations monitor pavement temperature, moisture content, chemical concentration, and accumulating precipitation. Maintenance personnel obtain data through a local network called “SCANWeb”. However, the Iowa Department of Transportation is in the midst of changing to a file transfer protocol (FTP) server to allow for data to be distributed over the Internet and to the public.

3.1.3 Kansas Department of Transportation (Kansas DOT)

The Kansas Department of Transportation’s (Kansas DOT) current RWIS network consists of 41 sites, mainly containing SSI FP2000 and E sensors. The collected information is disseminated through an Intranet allowing Kansas DOT personnel to access data through login and password mechanisms. The Kansas DOT has hired a technician within the agency to specifically maintain their RWIS stations. The RWIS technician was trained by SSI to perform maintenance activities on all of the Kansas DOT RWIS stations. In addition, this technician performs annual preventive maintenance.

3.1.4 Montana Department of Transportation (MDT)

The Montana Department of Transportation (MDT) has implemented 59 RWIS sites across the state. Typically, an RWIS station will house two to three pavement sensors. The RWIS network is running on 12 servers with data disseminated via SCANWeb. The MDT does not actively calibrate or perform maintenance activities on their RWIS stations. As a result, they currently contract with the original manufacturer to provide annual preventive maintenance. It was noted that during the solicitation process, they did not foresee obligating the contractor to meeting a certain set of standards for RWIS maintenance. Rather, they consulted with other states on their previous experiences with RWIS vendors. As such, it was determined that the vendor-provided specifications for calibration and preventive maintenance would be sufficient.

3.1.5 New York Department of Transportation (NY DOT)

The New York Department of Transportation (NY DOT) is in the process of selecting a contractor for their next set of RWIS stations. They have developed checks and balances to monitor the contracted services. Furthermore, they have developed methods for verifying the calibration of their pavement sensors.

3.1.6 South Dakota Department of Transportation (SD DOT)

In 1991, the South Dakota Department of Transportation (SD DOT) installed their first RWIS station. Today, the SD DOT owns 31 stations across the state. Of these, five stations are owned by a city or a county. All of the sites are connected to four central processing units (CPUs) that collect, analyze and distribute the data. They are under contract with the original manufacturer for maintenance of these sites. A SD DOT technician performs routine checks on all sites on an annual basis with the aid of a manual provided by the manufacturer. The manual is used as reference for re-calibrating sensors when they are replaced. Calibration and replacement are performed by SSI.

3.1.7 Washington Department of Transportation (WS DOT)

The Washington Department of Transportation (WS DOT) has been involved with RWIS applications since the late 1980's. Their involvement included installing a few RWIS stations and the use of thermal mapping. They currently have 45 RWIS sites statewide including all major mountain passes and "trouble spots." The data collected is inputted into a statewide weather forecasting model that was developed by Washington State University.

3.1.8 Wisconsin Department of Transportation (WisDOT)

The Wisconsin Department of Transportation (WisDOT) installed their first RWIS stations in the mid-1980's. As of 1994, WisDOT contracted with SSI to install 29 more RWIS stations. Twenty six additional RWIS stations were installed from 1995 to 1996. By the summer of 1999, WisDOT will have a total of 53 RWIS stations maintained by SSI. Two types of stations are currently in place within the system. The early 22 stations have the capability of monitoring pavement temperature, pavement moisture conditions, and chemical concentrations. The installations occurring after 1995 are additionally capable of monitoring snow and ice accumulation.

3.1.9 Federal Highway Administration (FHWA)

The Federal Highway Administration does not own or maintain any RWIS stations. However, they encourage states to implement RWIS technologies. It is hoped that RWIS data will be streamlined into National Weather Service (NWS) data in the future to provide more complete reporting of weather and road conditions. Therefore, the agency feels it is imperative to elevate the quality of data received from RWIS stations by implementing standards.

3.1.10 Ministère de l'Equipment des Transports et du Logement (METL) of France

The Ministère de l'Equipment des Transports et du Logement (METL) of France has an extensive network of 221 RWIS stations as of 1993. The agency is very much involved with standardized testing procedures for pavement sensors. As an example, they have proceeded with testing of sensors in climate chambers. Additionally, a working group was initiated to further progress on standardization. Other working groups have been formed in France to unite vendors, users and material suppliers of RWIS stations. METL has also developed a plan for homologation of RWIS sites.

3.1.11 Ontario Ministry of Transportation (MTO)

The RWIS system in Ontario is expanding rapidly. Since installing their first RWIS station in 1991, the Ontario Ministry of Transportation (MTO) has expanded their network to 32 stations. In 1997, legislation was passed to privatize the maintenance of RWIS stations. Currently, MTO is soliciting installation and maintenance of an additional 50-60 RWIS sites within the next year.

3.1.12 Swedish National Road Administration (SNRA)

The Swedish National Road Administration has been involved with RWIS activities since the late 1970's. The major increase in the system occurred in the late 1980's with some additions in the 1990's. The SNRA currently has 660 RWIS sites. Their distribution of RWIS stations correlates to the density of roadways. As a result, a majority of their stations have been sited in the southern part of the country.

The main component of SNRA's RWIS system is their central ice collection system. During the winter months starting in October, data is transferred from the remote sites to the central system every half an hour. The system stores the data, calculates the forecasts, and displays the information on their Intranet. Also, SNRA purchases radar and satellite images for precipitation and weather front information from the Sweden Meteorology and Hydrology Institute. This information is also displayed on the Intranet.

3.1.13 United Kingdom Highways Agency

The United Kingdom Highways Agency owns a network of roadside weather stations. However, the number of stations was not indicated in the interview. These stations are licensed to the maintaining agents for their use. A contract with the vendor covers five years of maintenance, calibration (to manufacturer's specifications), updating equipment and a 24-hour bureau service.

3.1.14 Regional Weather Information Center (RWIC)

RWIC works with several DOTs as an independent evaluator for placement of RWIS sites. They provide knowledge and guidance in RWIS to states that plan on installing RWIS sites.

3.1.15 Coastal Environmental Systems

Coastal Environmental Systems is a manufacturer of RWIS technologies. They currently supply RWIS technologies for several situations. They have developed and documented in-house procedures for calibrating sensors. Typically, calibrations are performed at installation. Once sensors have been installed, they do not re-calibrate sensors.

3.1.16 Surface Systems, Incorporated (SSI)

Surface Systems, Incorporated is another vendor of RWIS products. Many of DOTs are currently using SSI equipment and are under contract with them for maintenance. It is understood that they have developed and documented internal standard procedures for calibrating and testing pavement sensors. However, after several attempts at contact, no information was provided by SSI at the time of compiling this report.

3.1.17 Vaisala

Vaisala is a manufacturer of RWIS equipment with a complete line of products. Their equipment is capable of root optimization, thermal mapping, and reporting several pavement conditions. Calibration of their sensors is performed at the factory prior to shipment. They also re-calibrate the sensors during installation. They have developed a set of specifications that meet expectations set forth by their customers. Vaisala's specifications are proprietary and cannot be shared.

3.2 Types and Brands of Sensors

Several different brands of sensors are currently in use across the United States, Canada and Europe. Within the United States, the majority of states use SSI equipment. These states include Wisconsin, Iowa, Kansas, Illinois, South Dakota, Washington, and Montana. The most common type of SSI sensors used are the E Sensor and the FP2000 models. These sensors measure pavement temperature and the percent of moisture on the surface. Additionally, the sensors monitor characteristics of solutions applied to roadway surfaces. Parameters measured include: percent of chemical concentration, freezing point temperature of the solution, and depth of liquid solution. MTO's RWIS stations also primarily consist of SSI's FP2000 sensors. However, they have also experimented with Vaisala and Luftt sensors.

SNRA's RWIS system primarily consists of PT100-sensors that measure pavement temperature. The PT100-sensor obtains pavement temperature by measuring the resistance over a platinum thread that is normally housed in a steel tube. The accuracy is believed to be +/- 0.2 C.

France's RWIS network includes sensors from numerous vendors. These include equipment manufactured by: Boschung, Vaisala, Sermo, Scan, Mourgeon, and Sur. As well, the agency uses these sensors to collect pavement temperature, percent of moisture on the surface, chemical concentration, freezing point temperature of the solution, depth of liquid solution, and status / state of the pavement surface.

The United Kingdom Highways Agency uses sensors manufactured by Vaisala TMI, SSI, and Findlay Irvine. These sensors are used to detect pavement temperature, pavement moisture content, chemical concentration, and ice / snow accumulation.

Both vendors interviewed stated that they manufacture pavement sensors to measure pavement temperature, pavement moisture content, chemical concentration, and ice/snow accumulation. Although full descriptions of the types of sensors that the vendors provide is available, it was not provided at the time of this report.

3.3 Existing Specifications

Most of the agencies interviewed for the project did not include specifications (such as range and accuracy for certain parameters) for pavement sensors as initial requirements. Generally, the specifications provided by the manufacturer for their products were accepted in "good faith." As a result of most agencies contracting maintenance and calibration of sensors to vendors, they did not perceive the need for setting specifications.

3.3.1 TNO (Netherlands) Road-Vehicles Research Institute

METL noted a study performed by the World Meteorological Organization (WMO) published in 1997. The study cited specifications developed by the TNO Road-Vehicles Research Institute under the Commission of European Communities R&D programme, Telematics System in the Area of Transport (DRIVE II) Project V2045 Road Safety Enhancement System (ROSES). The findings from the ROSES project included outlining parameters of importance relating to road meteorology as well as technical specifications for weather and road data. These specifications have been duplicated in a table in Appendix B.

3.3.2 Ministère de l'Equipment des Transports et du Logement (METL) of France

The materials received from METL indicate that they have developed experimental specifications by which they calibrate and test pavement sensors. The specifications are documented in detail in *Recueil des méthodes d'essai*(9). However, the information is documented in the French language and due to the length of the document, a thorough translation of the document was not performed.

3.3.3 Coastal Environmental Systems and Other Vendors

Coastal Environmental Systems provided the following specifications for their pavement sensors.:

Temperature measurement accuracy:	+0.2 C (+0.36 F) over -80 C to +80 C
	+0.1 C(+0.18 F) over 0 C to 70 C
Solution freeze point:	-5 F to 32
Percent of Ice:	0% to 100%
Chemical concentration	0% to 100%

Vaisala also has specifications for pavement sensors but did not provide specific details. However, they stated that their proprietary specifications meet both their North American and international clients' requirements.

3.4 Calibration Procedures

Typically within the United States and Canada, the general arrangement for calibrating sensors is performed by RWIS vendors. In practice, vendors supply transportation agencies with a technical manual that provides an overview of maintenance procedures. From the interviews, it was often noted that when problems with sensors arise, the contractor must respond or provide a solution within a predetermined amount of time. Oftentimes, rather than bothering with re-calibration, problematic sensors are replaced with new sensors. This was the popular opinion of the RWIS vendors.

Calibration of sensors by vendors usually involves initial laboratory and in situ testing of pavement sensors. Laboratory testing will ensure proper functionality. In situ testing is required as a result of variations in the environment surrounding the sensor as well as differences in equipment. In the laboratory setting, for example, the output of a sensor at the RPU may be measured with a 25-foot cable. When the sensor is installed, re-calibration is necessary as there may be more cable length which affect readings. Generally, calibration occurs on an annual (preventive maintenance) and as-needed basis. Another approach performed by RWIC is to measure biases from sensor readings to determine the need for re-calibration.

3.4.1 Ministère de l'Equipment des Transports et du Logement (METL) of France

The French Ministère de l'Equipment des Transports et du Logement (METL) has developed testing procedures for their RWIS stations and individual tests for each component. They have standard quality control and quality assurance (QC/QA) requirements for their sensors associated with the standards for measurement and display. There are three distinct requirements for each unit prior to shipment by the manufacturer, including:

- technical documentation for the end user detailing methodology for optimal use;
- indication of the behavior of the station under conventional roadside environments that includes
- the expected durability of the sensor under thermal stress (heat and cold applied to the unit), chemical stress (gasoline, salt, etc.) and physical stress (application of loads such as by simulating passing cars, etc.); and
- type and quality of the data provided by the sensor.

Discussions on the proper methodology and choice of components for testing were conducted through a working group composed of manufacturers, users and representatives from technical services of the French administration. After several years of use, it was concluded that the evaluation should place priority on the "meteorological" quality of the atmospheric and road surface instruments and ultimately on the quality of the decision support information. The type and quality of the information from a station is determined by testing a group of sensors as shown below. Four configurations, corresponding to those typically found in RWIS stations available on the market, form standard RWIS station configurations labeled here as configuration A, B, C and D, shown in Table 3.4A.

Sensor Configurations	A	B	C	D
Ambient air temperature	Ta	Ta	Ta	Ta
Relative Humidity	RH (Td)	RH (Td)	RH (Td)	RH (Td)
Surface temperature of the network	Ts	Ts	Ts	Ts
Network surface (dry / wet)	-	wet / dry	wet / dry	
Network surface (icy / frost) Freezing Temperature of surface water / chemical concentration	icy / frost Tc	icy / frost Tc	icy / frost	
Precipitation (yes / no)	Yes	Yes		
Network surface (humid / damp)	humid			
Network surface (wet)	wet			
Network surface (humid / damp and salted)	humid & salted			

Where: Ta = Ambient Temperature
RH = Relative Humidity
Td = Dew Point Temperature
Ts = Pavement Temperature
Tc = Freezing Temperature of Surface Liquid (function for chemical concentration given known usage of salt)

Table 3.4A Type and Quality of Information for Group Testing

It is these four configurations that were established as those to be used to test the entire RWIS station. In addition to the configuration label, a quality index is associated with each sensor configuration from a manufacturer, creating an RWIS station quality ID used to identify the overall type and quality of the RWIS station. Using the lettered sensor configuration label and the numbered quality index (e.g. A2, C1), each station is identified. These tests are conducted generally by pre-approved agencies or organizations similar to Underwriter's Laboratory for electrical equipment in the United States. Table 3.4B identifies how the quality index is determined.

Sensor Configurations	Number of tests	For QI = 1	For QI = 2	For QI = 3	Test Range
Ambient air temperature	n = 770	+/- 0.2 C A = 21	+/- 0.5 C A = 21	+/- 1.0 C A = 21	5 to - 15 C
Relative Humidity or dew point temperature in the shade	n = 770	+/- 5 % +/- 0.5 C A = 21	+/- 10 % +/- 1.0 C A = 21	+/- 20% +/- 1.5 C A = 21	60 to 95% + 5 C
Surface temperature of the network	n = 830	+/- 0.2 C A = 21	+/- 0.5 C A = 21	+/- 1.0 C A = 21	5 to - 15 C
Network surface (dry / wet)	n = 40		A = 2	A = 3	5 to - 15 C
Network surface (icy / frost)	n = 70	A = 1	A = 2	A = 3	- 5 C
Freezing Temperature of surface water / chemical concentration	Steady state n = 40	+/- 0.5 C A = 1	+/- 1.0 C A = 2	+/- 1.5 C A = 3	2 to - 10 C
Precipitation (yes / no)	n = 80	A = 4	A = 11	A = 15	10 C
Network surface (humid / damp)	n = 20	A = 1	A = 2	A = 3	5 to - 5 C
Network surface (wet)	n = 20	A = 1	A = 2	A = 3	5 to - 5 C
Network surface (humid / damp and salted)	n = 20	A = 1	A = 2	A = 3	2 to - 20 C

n = Number of test cases

A = Acceptable number of readings outside tolerance

Table 3.4B Quality Index for RWIS Group Testing

Standard testing is performed for sensors under both permanent condition testing and variable condition testing. Permanent condition testing tests the ability of the sensors to produce accurate results in laboratory conditions for the range of temperatures between $-15^{o}C$ and $+10^{o}C$ in successive stages. They are also tested to verify that readings can be provided at the upper ($+50^{o}C$) extreme ranges for the sensor. Variable condition testing is used to test the sensors under the standard ambient temperature range of winter conditions.

The agency has developed a climate chamber to test sensors in a laboratory setting. In situ calibration procedures are performed by the manufacturer as a part of vendor contracts. However, METL has developed "experimental" procedures for calibration and control.

A detailed and thorough review and translation of the French government testing and maintenance documentation would be needed to identify and produce potential standards for RWIS stations within the United States.

3.4.2 Other Agencies

The Kansas DOT has appointed an in-house technician to calibrate and maintain RWIS sensors. The technician was trained by the manufacturer of their implemented RWIS technologies. They have documented procedures for calibrating pavement temperature, pavement moisture content, chemical concentration, and snow / ice accumulation. At the time of reporting the results of this study, the documented procedures compiled by the Kansas DOT had not been received.

MTO has experimented with developing calibration and testing procedures for pavement sensors. The agency began a research group to further explore the possibilities. Unfortunately, the group was dismantled due to a lack of funding and the efforts of this group were not documented. Also, with privatization of all maintenance activities within their organization, the perceived need for defining calibration and evaluation procedures has diminished.

NY DOT has issued a request for proposal (RFP) to extend their current RWIS system. As a part of the RFP, they have included certain guidelines and expectations from RWIS vendors in terms of calibration and maintenance services. NY DOT is actively setting these guidelines to ensure that RWIS sensors will provide data with an adequate level of accuracy. Additionally, these guidelines were set with the intent to provide future flexibility and expansion of their RWIS network. While initially, one vendor may be contracted to install their sensors, provide maintenance and calibration activities, these guidelines provide provisions for seeking the services of other vendors. Furthermore, NY DOT has indicated that sensors should be tested by the temperature range, wet/dry, type of solution, and recovery to normal or a new percentage of solution. They also stated that there are temperature probes that will provide accurate readings that have been calibrated for testing with a digital read out that are available for under $1000.

SNRA performs all of the maintenance work on their RWIS stations. It was noted that re-calibration of the sensors is performed on a regular basis. At the present time, SNRA does not have documented standardized testing methodologies for pavement sensors. However, a project has been planned to begin during the year 2000. The goal will be to develop standardized methods for calibrating all of their sensors.

In the UK, the Transport Research Laboratory performs calibration of pavement sensors for research purposes. They are currently involved in a research project on the value for money of winter maintenance. Part of the work includes a review of RWIS equipment including a study into the accuracy and calibration of sensors.

3.4.3 Vendors

Both of the manufacturers contacted for interview maintained that their standards for calibrating sensors are proprietary. It was noted that most manufacturers are ISO 9002 certified. ISO 9002 is a quality assurance model made up of quality system requirements. This model applies to organizations that produce, install, and service products. The International Standards Organization (ISO) expects organizations to apply this model, and to meet these requirements by developing a quality system.

During correspondence with SSI, they indicated that they have developed standard in-house procedures to test and calibrate all sensors. At the time of this report, the documented procedures were not received.

4. DISCUSSION

In light of the apparent absence of standard testing procedures for pavement sensors, RWIS experts interviewed were asked about the perceived need for definitive testing and calibrating procedures. Many felt that testing procedures were necessary while others did not feel the need. Proponents of developing standardized procedures indicated many reasons for continuing the effort. These included:

- **Current practices rely on "good faith" of vendors.** Since no standardized procedures exist for calibrating and testing pavement sensors, agencies are depending on the "good faith" of the vendor RWIS technologies. Standard procedures will allow agencies to be better informed of the quality and accuracy of the data obtained from pavement sensors.

- **Standard procedures allow public agencies to compare "apples with apples".** Standard methods would assist agencies in comparing vendor responses to RFPs more easily. Standards would also ensure that vendors are meeting the data accuracy needs of agencies. Ultimately, agencies will have a stronger role in specifying RWIS systems that will satisfy their data requirements.

- **More comparable accuracy level of RWIS data.** Currently, many agencies that share common geographical borders have partnered up and share RWIS data. Standard testing procedures will ensure that the data obtained from various agencies meet an agreed level of expectations.

- **Reliability of data decreases without standard maintenance.** Some international agencies have found that the reliability of the sensor readings decreases over time as well as with climatological changes. This is especially true during winter months. It was noted that the winter effects on pavement sensors can greatly alter the reading. It is important to increase the level of maintenance during the winter months. As well, sensor reliability is more imperative to snow and ice control. The existence of standard methods would allow agencies to address problem sensors more proactively.

- **To coordinate efforts within an agency.** It was noted that RWIS data is used by multiple departments within an agency. Standard testing methods would ensure that calibration being performed by the various departments would be consistent.

- **To ensure high quality data for future expansion and applications.** One agency envisioned streamlining RWIS data into the pool of information already provided by the National Weather Service (NWS). The meteorological data collected by NWS has evolved over time and experience to a high level of quality. In order to integrate RWIS and NWS data, the quality levels of data should be on par.

- **Every scientific instrument needs calibration.** Standards organizations such as the American Society for Testing Materials (ASTM) and the International Standards Organization (ISO) recognize the need to calibrate and standardize scientific instrumentation. Pavement sensors are considered scientific instrumentation and should require calibration. While calibration procedures exist, they are proprietary. Transportation agencies should be able to access procedures or have a set of standardized methods for use at their disposal.

- **To provide checks on data obtained by vendors.** Standard procedures for testing and calibrating pavement sensors would assist public agencies in regaining some control over the quality of data obtained by vendors. Standard procedures would allow agencies to perform "in-house" random checks on the equipment and re-calibrate, if necessary.

Developing standardized procedures for testing and calibrating pavement sensors was generally perceived positively. However, there were cases recognizing that standard methods may not be necessary. These reasons included:

- **Testing requires a completely controlled setting.** One agency felt that a completely controlled setting (such as in a laboratory) is needed to test and calibrate sensors. The investment incurred for a controlled setting would not make testing and calibrating cost effective.

- **Lack of interest from DOTs.** One respondent perceived a lack of interest by DOTs for highly accurate data. Rather, this individual claimed that there is more support for lowering operational and maintenance costs.

- **Loyalty to vendor.** One agency did not foresee purchasing equipment from other vendors. They are satisfied with the current maintenance practices for their pavement sensors. Since these activities are contracted to the vendor, this agency did not feel a strong need for standard methods.

- **Impractical.** For another agency, since their privatization of all maintenance services, it would be impractical to focus on developing procedures. Also, there is not be enough technical support within the agency to test and calibrate sensors.

5. CONCLUSIONS AND RECOMMENDATIONS

This project provided great insight into the current existence of standard methods for testing and calibrating sensors, both documented and in practice. Several agencies, Kansas DOT and METL, have developed their own testing methods. Their experiences may greatly benefit and provide the needed background for standardizing these testing procedures. The SNRA is planning to probe the possibility of developing methods for use within Sweden. The CIMO performed a study similar to this project investigating the need and existence of standardized testing methods. As well, the Transport Research Laboratory in the UK has performed limited studies within the laboratory setting. Bearing in mind the current efforts that exist, the following recommendations have been made:

- The research performed on standardized testing methodologies for pavement sensors uncovered the activities of METL. This agency, alone, has extensively developed and recognized the value of developing standardized procedures and protocols. This agency provided a host of follow-up documents for consultation that provide comprehensive procedures for calibrating air temperature, relative humidity, surface temperature, wet / dry state of pavement surfaces and freezing point temperature. However, these documents are written in French and were not fully translated due to resource limitations. **It is recommended that since METL provided the most comprehensive, documented source of procedures, the next phase of the project should consider translation of these methodologies.**

- Kansas DOT has paved the way for standardizing testing procedures within the United States. As a result of their frustration with vendors to obtain an adequate level of accuracy from their sensors as well as acceptable levels of maintenance, the agency decided to perform these activities. At the time of writing this report, the documents promised by the Kansas DOT were in transmission to the authors. **It is recommended that the Kansas DOT testing procedures be reviewed to provide a baseline for developing Aurora standard testing and calibrating procedures for testing pavement sensors.**

- As a result of the WMO / CIMO report on road meteorological observations, the authors of that report provided a set recommendations which included "seeking to forge cooperative links to appropriate national or international highway organizations such as the Standing International Road Weather Conference (SIRWEC), so as to serve, primarily in an advisory capacity, with regard to the meteorological measurement requirements of the road traffic sector." **It is suggested that CIMO be contacted to determine the status of their interest in furthering the development of guideline and standards for pavement sensors.**

- SNRA is planning to develop their own standardized testing methodologies in the year 2000. With a network of 660 RWIS sites, their need to develop testing methods that are efficient and cost-effective may be a priority. Also, SNRA has been viewed as a leader in the RWIS movement. Their insight and experiences may prove valuable to Aurora. **It is recommended**

that the project lead (Lars Frimodig) be contacted for further information on the project.

- The Transport Research Laboratory in the UK is also working on a study into the accuracy and calibration of RWIS technologies. They currently test sensors in the laboratory setting. Their work and experience with testing sensors will provide more background for developing standard methods. **It is suggested that a summary of their work be obtained for review.**

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Appendix A

Aurora Program
Standardized Testing Methodology Project Survey

Name: ________________________________

Organization: ________________________________

Phone: ________________ Email: ________________________________

1. Could you please give a general description of RWIS activities in your agency.

2. What types and Brands of pavement sensors does your agency currently use?

Type	Pavement temperature	Pavement moisture content	Chemical concentration	Ice/Snow accumulation	Others
Brand					

3. Does your agency calibrate or test sensors prior to installation in the field?

3a. If yes, for which types of sensors

4. Does your agency have any standardized procedures for calibrating RWIS pavement sensors prior to installation?

4a. If yes, for which types of sensors and what are the corresponding procedures?

4b. What specifications, if any, are used when calibrating or testing these sensors?

4c. Are the procedures and/or specifications in written form and can we receive a copy?

5. Are you aware of any documented procedures for calibrating/testing pavement sensors within your agency at the time of installation?

6. Does your agency ever recalibrate pavement sensors once the are placed in the field to ensure accurate reporting of data?

6a. If yes, is there a common procedure for this and could you please describe the procedure?

6b. Are the procedures in written form and could we please receive a copy?

7. Do you feel that a standardized procedure for testing pavement sensors would be useful? (Yes___ no___) Why?

8. Is there anyone else you suggest we contact concerning the foregoing questions?

APPENDIX B

Technical specifications of road and weather data developed by TNO (Netherlands) Road-Vehicles Research Institute (8).

	Parameter	Resolution	Up. Rate (s)[1]	Accuracy	Range	Dimension	M[2]
1	Water layer thickness	0.1	12	0.1	<3	mm	*
2	Wet/dry/ice	1	60	1	1,3	--	
3	Type of ice	1	60	1	1,2	--	
4	Local gust speed	1.0	0.5	1.0	<50	m/s	
5	Local wind direction	5	0.5	5	0,360	o	
6	Visibility Distance	10%	12	20%	0,300	m	
7	Viscous aquaplaning	1	60	1	1,2	--	
8	Snow/ice-thickness	0.5	60	0.5	<5	cm (?)	
9	Temp. medium height	0.1	12	0.3	-10,+20	°C	*
		1.0	60	1.0	-30,+50	°C	
10	Temp. road surface	0.1	12	0.3	-10,+20	°C	*
		1.0	60	1.0	-30,+80	°C	
11	Temp. soil	0.1	12	0.3	-10,+20	°C	*
		1.0	60	1.0	-30,+80	°C	
12	Temp. 10m	0.1	12	0.3	-10,+20	°C	*
		1.0	60	1.0	-30,+50	°C	
13	Relative humidity	2.0	12	2.0	70,100	%	*
		2.0	30	5.0	0,110	%	
14	Air pressure	0.2	12	1.0	930,1060	hPa	*
15	Global radiation	5.0	12	5.0	0,500	W/m²	*
16	Longwave radiation	5.0	12	5.0	0,100	W/m²	*
17	Amount of precip.	1.0	300	1.0	0,15	mm	*
18	Rain intensity	1.0	300	10	0,150	mm/hr	
19	Global wind speed	.05	3	0.5	0,15	m/s	*
		1.0	3	1.0	15,50	m/s	*
20	Global wind direction	5.0	3	5.0	0,360	o	*
21	Ground wetness	y/n	600	95%	reliability	reliability	
22	Electric conductivity	0.5	60	0.5	0,1000	S	
23	Cloud cover	1.0	600	1.0	0,8	Oktas	*
24	Transv. Gradient	0.001	--	0.001	0.001	m/m	*

25	Afflux length	1.0	--	1	1,70	m	*
26	Texture depth	0.1	--	0.1	0,5	mm	*
27	Water source index	1	--	1	1,4	--	*
28	Topographic index	1	--	1	1,4	--	*
29	Site index	1	--	1	1,4	--	*
30	Environment index	1	--	1	1,4	--	*
31	Traffic flow	200	600	200	<2000	veh./hr	
32	Traffic speed	1	600	2	<50	m/s	
33	Standard dev. speed	1	600	1	<25	m/s	
34	Ratio heavy vehicles	0.1	600	0.1	0,1	--	

[1]Update rate (sec.)
[2]M, data importance for meteorology