SHRP-H-351

Road Weather Information Systems
Volume 2: Implementation Guide

S. Edward Boselly III
Principal Investigator
G. Stanley Doore
The Matrix Management Group
811 1st Ave., Suite 466
Seattle, Washington 98104

Donald D. Ernst, P.E.
The Washington Transportation Center (TRAC)
University of Washington
Seattle, Washington 98195

shrp

Strategic Highway Research Program
National Research Council
Washington, DC 1993

SHRP-H-351
ISBN: 0-309-05274-2
Contract H-207
Product No.: 3023

Program Manager: *Don M. Harriott*
Project Manager: *L. David Minsk*
Program Area Secretary: *Francine Burgess*
Copy Editor: *Katharyn Bine Brosseau*
Production Editor: *Cara J. Tate*

September 1993

key words:
highways
ice detection
maintenance
meteorology
pavement ice detectors
road weather information systems
snow and ice control
weather forecasting

Strategic Highway Research Program
National Academy of Sciences
2101 Constitution Avenue N.W.
Washington, DC 20418

(202) 334-3774

1.5M/NAP/993

Acknowledgments

The research described herein was supported by the Strategic Highway Research Program (SHRP). SHRP is a unit of the National Research Council that was authorized by section 128 of the Surface Transportation and Uniform Relocation Assistance Act of 1987.

We wish to thank the state highway maintenance personnel who took the time to complete the detailed questionnaire, and the following states and province of Canada that consented to in-person interviews of snow and ice control staff:

Massachusetts	Pennsylvania
New Jersey	Michigan
Minnesota	Missouri
Colorado	Wyoming
Washington	Alaska
British Columbia	Wisconsin

We wish to give additional thanks to the states that participated in our field test program during the 1990-1991 winter:

Massachusetts	New Jersey
Michigan	Minnesota
Colorado	Missouri
Washington	

We relied on the vendors of road weather information system (RWIS) equipment for assistance in data gathering and formatting for our analysis. Special thanks go to Surface Systems Inc. (SSI), Climatronics, and Vaisala for providing data support. SSI also assisted with a detailed investigation of the use of a hand-held radiometer for pavement temperature comparison measurements.

And special thanks must go to Mr. Ingmar Olofsson of SweRoad, a Swedish consulting firm, who served as an invaluable source of information through the EUCO-COST 309 international research project investigating road weather information systems.

Finally, we thank the meteorological equipment vendors and the private and governmental meteorological services providers who took their valuable time to complete questionnaires and to assist the project team.

Contents

List of Figures

List of Tables

Abstract

The Strategic Highway Research Program sponsored research into the use of road weather information systems (RWIS) for highway snow and ice control. The research indicated that the use of RWIS technologies can improve the efficiency and effectiveness as well as reduce the costs of highway winter maintenance practices. This Volume 2 implementation guide supplements Volume 1, the research report, which documents the research. Volume 2 describes RWIS technologies available, sources of weather information, communication requirements, guidance on siting RWIS, including sample Requests for Proposals for obtaining the necessary equipment and services.

Executive Summary

This implementation guide describes road weather information system (RWIS) components and their use so that highway maintenance managers can make decisions for implementing portions or all of these technologies. It also provides a process for agencies to use in acquiring and implementing an RWIS. Components of an RWIS include:

- *Meteorological sensors* that measure atmospheric temperature, relative humidity and/or dew point, wind speed and direction, and precipitation. The atmospheric data are used in assisting meteorologists to make detailed, site-specific forecasts. They are also used by managers to understand the nature of the weather conditions in the road environment in order to determine the potential for or occurrence of ice or snow accumulation.

- *Pavement sensors* that measure pavement temperature, subgrade temperature, pavement condition (wet, dry, or frozen), the amount of deicing chemical on the pavement, and/or the freezing point of a wet surface. Pavement temperature is the primary piece of information necessary for determining if frost or ice will form, or snow will accumulate on the pavement.

- *Site-specific forecasts* of weather and pavement conditions tailored to an agency's needs. Making decisions based on forecasts is the most effective means for reducing the costs of snow and ice control. Making decisions with knowledge of likely future conditions is considerably more efficient than reacting to existing conditions.

- Other *weather information* for use by meteorologists and snow and ice control managers, such as radar and satellite images and National Weather Service forecasts. Decision makers should use all available information. National Weather Service forecasts, although usually not detailed enough for effective decision making, certainly allow for planning; National Weather Service radar data help managers monitor the onset and duration of precipitation.

- *Communications* and data processing and display capabilities for data dissemination and presentation. Without effective communications, information cannot be used in a timely fashion. Effective communications includes human interaction between meteorologists and highway managers.

- *Temperature profiles* of roadways obtained from thermal mapping measurements. Profiles can be used to assist in selecting RWIS sensor locations, to provide information about road surface temperatures between sensor locations, and, in some cases, to plan for more efficient use of resources.

- *Weather advice* that allows for close meteorologist-decision maker coordination and consultation. A weather advisor can bridge the gap between the meteorology community and the highway agency, assist in acquiring RWIS technologies, and provide training for snow and ice control decision makers.

- A *plan* for the highway agency to acquire and use the RWIS data, including creating and maintaining a preventive maintenance program for winter weather problems.

Sensors, thermography, and other meteorological information help meteorologists prepare site-specific, tailored forecasts. Tailored weather forecasts allow decision makers to commit the appropriate mix of labor, equipment, and materials before, during, and after a winter storm. Such forecasts should contain information about both road and weather conditions.

Pavement temperature forecasts are usually accurate enough to reduce the likelihood that resources will be needlessly deployed when bad weather occurs. As a result, winter maintenance activities can become truly preventive in nature. Without an RWIS, only reactive procedures are available. Also, some expensive and inefficient operations, such as road patrolling during off-shift hours, can be curtailed or eliminated. With more than $2 billion spent annually in North America for snow and ice control, the ability to optimize the use of resources holds a potential for significant cost savings.

Volume 1 of this report provides details on the conduct of the investigation, describes RWIS cost analysis, documents the conclusions from the investigation, and lists recommendations for states to consider when implementing RWIS technologies. This guide (Volume 2) provides a process for agencies to use in acquiring and implementing an RWIS. It provides alternatives for RWIS communications, as well as for siting meteorological and pavement sensors.

The guidance provided herein will help users implement a complete RWIS. RWIS technologies are interdependent. Incorporating all of the components will maximize benefits of the system.

1

Introduction to Road Weather Information Systems

Highway use has increased as the growing population seeks greater mobility and more companies adopt a "just in time" approach to supply. In response to these trends, highway agencies have sought to ensure safe driving conditions on major highways during nearly all weather conditions, which has led to an increase in the cost of snow and ice control.

Use of deicing chemicals also has contributed to the cost of snow and ice control. Salt, the most commonly used chemical because of its availability, effectiveness, and low first cost, can damage vehicles, road structures, and the environment. Since the melting effectiveness of salt declines rapidly below 20°F (-6°C), use of RWIS pavement temperature sensors can indicate when alternative salt-reducing techniques should be employed.

Some European countries have implemented national weather information systems so that decision makers can use such resources more efficiently. Investigation of the use of road weather information technologies to reduce the amount of salt used, to decrease the cost of snow and ice control, and to improve the service to the traveling public has shown that proper use of these technologies can reduce costs and improve service.

There are two types of weather information: *observations* and *forecasts*.

Weather Observation

The organization and operation of weather services varies from country to country. The World Meteorological Organization (WMO), under the auspices of the United Nations, issues standards and procedures to ensure compatibility among worldwide operations. These standards and procedures allow the Global Telecommunications System (GTS) to distribute observations and products throughout the world.

The major meteorological processing centers of the world are linked by the main trunk of the WMO-GTS, as shown in Figure 1-1. The European Center for Medium-range Weather Forecasting (ECMWF) connects more than 160 nations to subnetworks of the WMO-GTS.

Each of the centers shown uses supercomputers to produce numerical weather observations, which are the basis for virtually all weather forecasts.

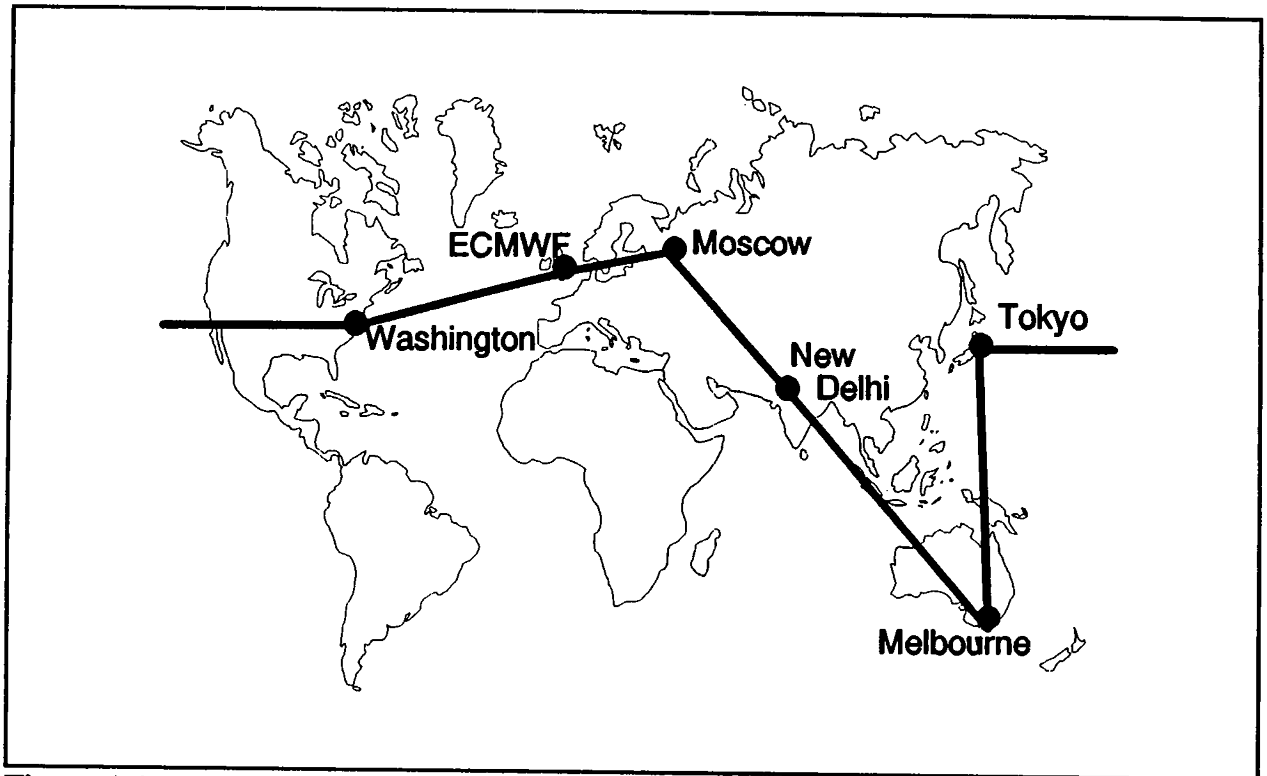


Figure 1-1. Major meteorological processing centers on the World Meteorological Organization's Global Telecommunication System

The federal government is investing large sums of money to improve the weather observation systems of the United States. Wind profilers, which measure wind direction and speed up to high levels in the atmosphere every six minutes, have been installed in certain parts of the country. A lightning detection system, consisting of federal agency networks and those of the Electric Power Research Institute (EPRI), monitors the 48 contiguous states. Satellites provide a view of the hemisphere. These major observation systems are the basis for weather forecasts and for local weather information systems and activities. Specialized observation systems for hydrology, forestry, agriculture, recreation, and environmental hazards are also being expanded to meet the needs of those specialized activities.

Today, National Weather Service (NWS) offices are located in nearly every state. This structure has worked well for the past two decades. However, new observational and automation technologies coming on-line during the 1990s will allow the NWS to reorganize its field structure into 115 Weather Forecast Offices (WFO). This will more than double the current number of offices and reduce the size of each office's service areas. Figure 1-2 shows the future locations of the WFOs. These locations essentially coincide with the locations of the Next Generation Weather Radar (NEXRAD). NEXRAD is a new network of weather radars that will provide coverage of nearly the entire United States. These radars will have computers that generate information to meet a variety of national needs. Figure 1-3 shows the locations and coverage of the planned radars.

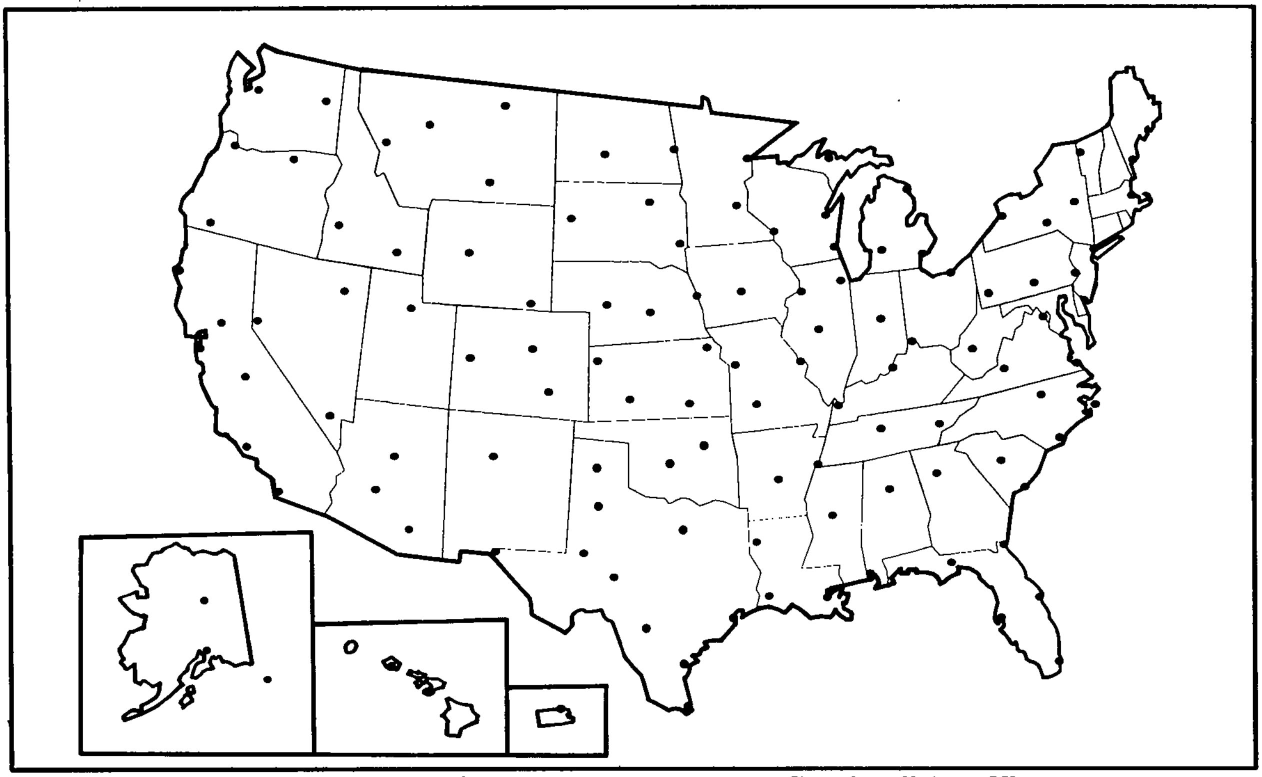


Figure 1-2. Future locations of the National Weather Service field offices

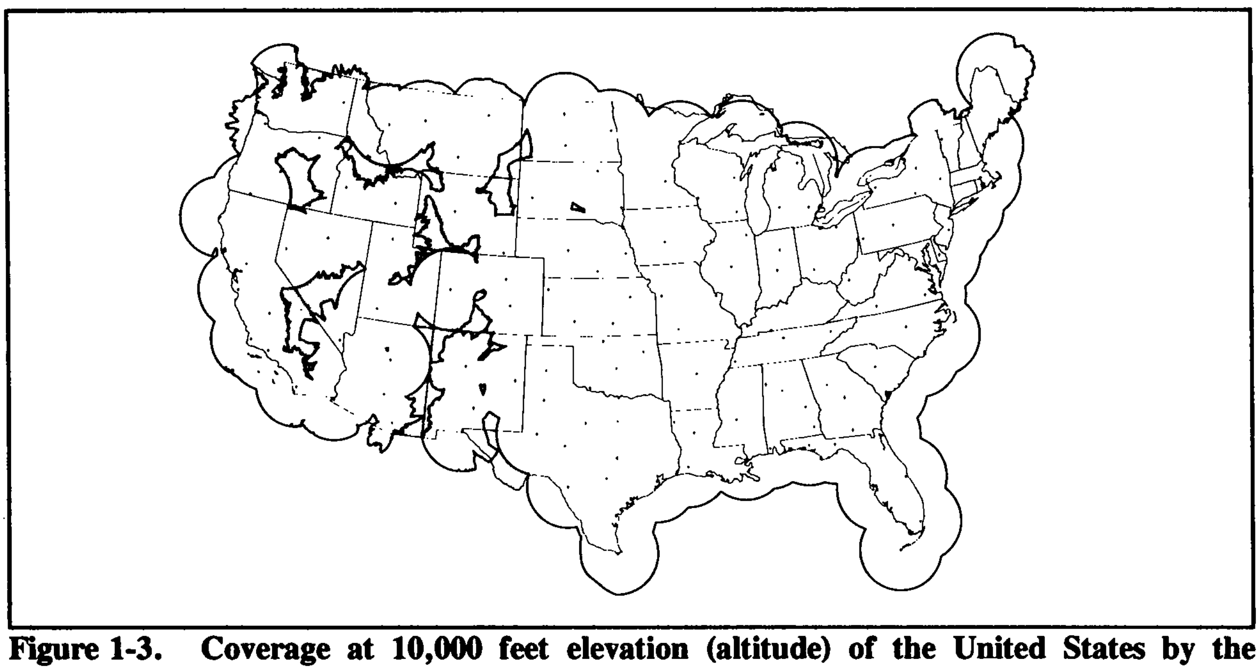


Figure 1-3. Coverage at 10,000 feet elevation (altitude) of the United States by the completed NEXRAD Doppler weather radar network

Figure 1-4 is a photograph of a NEXRAD product. It depicts the accumulation of precipitation over an area during the previous hour (upper left), the projected accumulation during the current hour (upper right), and the difference between the two (lower left). These pictures can be expanded to fill the entire computer display screen to provide greater detail. The expanded versions display rivers, county boundaries, and points. It is also possible to overlay streets, highways, and other features needed by highway agencies. NEXRAD promises to be a useful tool for snow and ice control decision makers. Although NEXRAD observations will be adequate for some local operations, additional surface weather observations will be needed for precise forecasts to enable road maintenance personnel to better manage available resources.

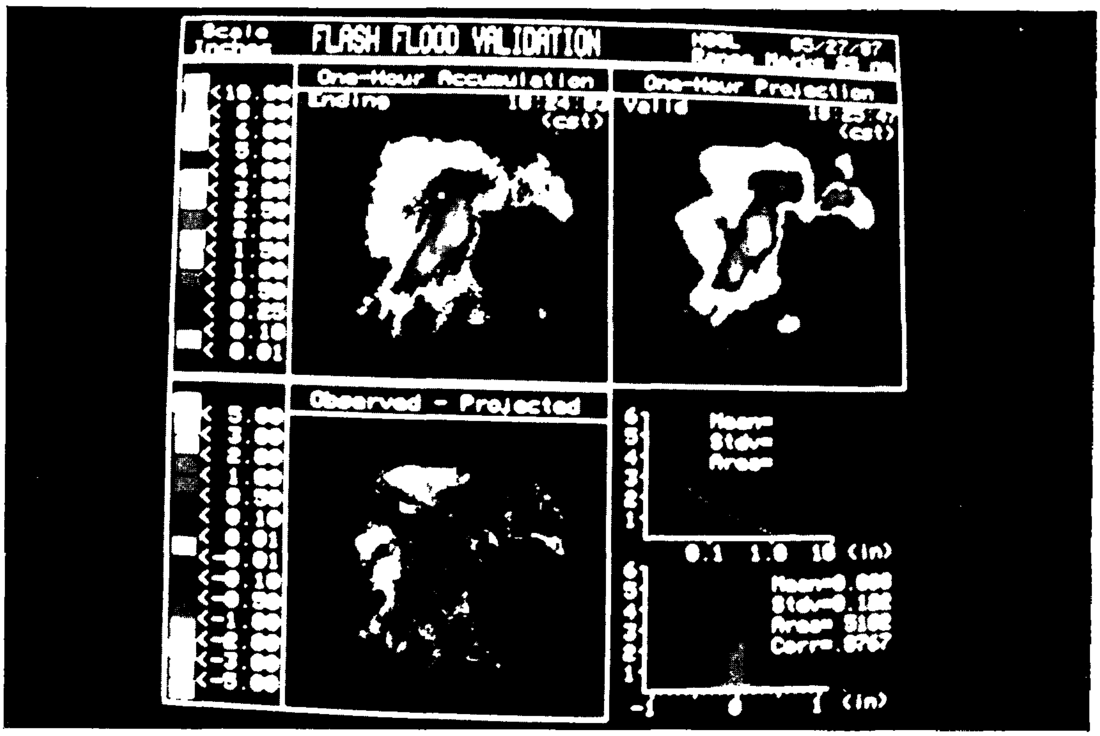


Figure 1-4. Example of a potential NEXRAD product for hydrology

Weather Forecasting

Weather forecasting involves the gathering of meteorological information, analyzing the information in order to understand the physics of what is occurring in the atmosphere, extrapolating the data to a future time, and assessing the weather that will result at particular locations or over an area at the future time. The extrapolation of data into the future is frequently assisted by the use of computers. The following sections provide a brief overview of weather forecasting.

Models

Weather modeling involves the manipulation of data through theoretical and empirical equations to simulate the behavior of the atmosphere. Meteorologists use models to analyze climate data, sensor data, and information from the NWS to make the weather predictions that form one of the components of an RWIS. Good weather predictions require good data, past and present. For instance, past data are used to build and improve forecast models, operational forecasting, and alerting procedures. Local knowledge of weather patterns, gathered by experienced operators and supervisors, also assists modelers.

The current system of weather prediction models consists of global, regional, fine-mesh, and point models. Each model varies depending upon its stage of development, its primary purpose, and the location on the earth's surface.

Global weather prediction models encompass the entire globe and are normally executed every twelve hours. These models provide the input for most other forecast models. Global models currently have a grid or mesh length of about 125 mi (200 km). Plans are under way to reduce this mesh length to less than 60 mi (100 km). The finer scale will improve the accuracy of forecasts. Forecasts from these models are made for up to ten days and outlooks to thirty days.

The regional model used for the United States covers North America and adjacent oceans and gulfs. It is linked to the global model and is used to make forecasts out to five days. It has a mesh length of about 50 mi (80 km). The NWS plans to reduce the length to about 20 mi (30 km). This will better represent surface characteristics such as mountains and coastal waters. This model may be executed every six hours. Forecasts produced by the regional model are used to derive local forecasts and can be used as input to point forecast models needed to manage highway snow and ice control.

Moveable fine-mesh models are special-purpose models used to cover snowstorms, hurricanes, and other critical weather situations. The NWS National Meteorological Center plans to investigate the use of a modeling technique that would have a mesh length of about 12 mi (20 km). This will provide better definition of terrain, lakes, and coastal waters, which cause major variations in local weather conditions. Finer resolutions will be useful in areas where there is complex terrain.

The finest-mesh models are currently used mainly to predict wind and precipitation amounts, snow, and rainfall. They could evolve into a system of fixed models tailored specifically for climate and topography of specific areas and to weather elements of importance to local users. These models may be adapted and tied to updated weather radar, wind profiler, and new surface observation systems. As computational power becomes less expensive, the mesh length should be further reduced.

The Strategic Highway Research Program has sponsored research into the development of a microcomputer-based forecasting system called the Portable Interactive Weather Processing

System (PIWPS). This expert system model will provide the capability to predict atmospheric and road conditions on a scale of one or two kilometers.*

At the smallest scale, meteorologists frequently use point models to specify what will take place at a location over time. An example of such a model frequently used in RWIS is a pavement temperature forecast. Each forecast issued is site-specific, valid for only one point. The input data for the models are predictions of weather and observations for only the forecast location.

Forecasts

The NWS produces a large number of different types of forecasts. These cover different combinations of region, altitude, and time of interest to specific users. They range from statewide area or zone forecasts in a state to site-specific forecasts for airports or special locations. They also issue some detailed forecasts for en-route aviation purposes.

Point forecasts in the form of model output statistics (MOS) have been used for years to forecast specific weather elements for aviation and for the public in general. MOS models produce forecasts accurate for up to 48 hours. More recently, a model has been developed to make weather predictions for every ten-minute interval for the next two hours.

Many other operations affected by weather obtain tailored forecasts that focus on the particular meteorological thresholds that have operational significance. Weather forecasters dedicated to such products integrate their knowledge of climatology, output of weather prediction models, forecasts by the NWS and others, sensor data, and objective forecast studies for the areas of interest to provide input regarding the operational decision-making process.

Value-Added Meteorological Services

Value-added meteorological services (VAMS) use meteorological information available from the NWS and other sources to construct specialized services. Sometimes called "private weather services," "private meteorological services," or "value-added weather services," they offer detailed forecasting services to individuals, businesses, or governmental agencies. However, not all VAMS are private or commercial ventures. VAMS may be part of a public agency, such as avalanche forecast centers.

VAMS range from large organizations with dozens of forecasters and weather centers with large computer capabilities to one person with a microcomputer. They provide their services in many ways. Some VAMS primarily provide weather data to subscribers. They purchase NWS products and tailor them for use by others. Some VAMS provide forecasts

---

* National Research Council. Strategic Highway Research Program. *Intelligent and Localized Weather Prediction*. Report by E.R. Reiter, D.K. Doyle, and L. Teixeira. Washington, 1992. SHRP-H-333

year-around, seasonally, or on an as-needed basis. Still other VAMS provide consulting services related to the environment, climate, meteorological instrumentation, or forensic issues.

Weather Advisor

A weather advisor serves as a consultant to a highway agency. The weather advisor understands the needs of the agency and the capabilities of a VAMS providing weather support to the agency. The weather advisor ensures that the weather information provided to the agency is tailored to satisfy the agency's needs. A weather advisor can be a VAMS, a consultant hired to perform the function, a member of the agency staff, or a shared resource among agencies. The weather advisor duties can represent a full-time or part-time workload depending on the needs of an agency.

Weather Information Sources

The discussion of weather information systems to this point has focused on general aspects of data collection, data processing, and distribution of products to users. A final link is necessary to disseminate advisories and weather information. Many avenues are now available for this, and others will become available as new technologies come online. Table 1-1 lists weather outlets available to the public and/or to agency personnel.

The print media provide great detail on weather events in a local area, state, nation, or the world. However, most of this information is usually presented in retrospect. There is a significant lag time between the writing or recording of the information and its availability to the public. Newspapers provide forecasts that may be up to twelve hours old by the time they are distributed. These forecasts describe expected general conditions in an area. Because of this lack of timeliness and detail, newspaper forecasts are a poor source of weather information for making anticipatory snow and ice control decisions.

Commercial radio and television stations are perhaps used most frequently by the public to get weather information, since weather is included as part of virtually every station's programming. Federal Communications Commission (FCC) regulations obligate commercial stations to broadcast weather advisories to promote public safety, security, and well-being.

Another source of information is the National Oceanic and Atmospheric Administration (NOAA) Weather Radio network, which consists of more than 380 continuous weather broadcast stations. Since they operate on special frequencies (around 162.55 MHz), special radios are necessary to receive these broadcasts. This limits their use. However, the system is extremely valuable for alerting those with special receivers. The alerting system has been particularly effective for schools, hospitals, and others agencies that need to know when severe weather is forthcoming. Some highway agencies have installed NOAA Weather Radio

Table 1-1. Sources of weather information for road operations

RADIO	UPDATE FREQUENCY
Commercial broadcasts	Periodic
NOAA Weather Radio broadcasts (VHF-FM)	Continuous (Local)
Company thru base station operator	On-call
Amateur radio operators	Ad Hoc and networks
Highway Advisory Radio	Continuous (Local)
BROADCAST TELEVISION	
Commercial broadcasts	Periodic
Public television ("AM Weather")	15 min. between 6-8 a.m. Mon.-Fri.
CABLE TELEVISION	
"The Weather Channel"	Continuous
NOAA Weather Radar/NOAA Weather Radio	Continuous (Local)
TELEPHONE VOICE ANNOUNCEMENT SYSTEMS	
Telephone Company	Continuous (Local)
National Weather Service	Categorized (Selectable)
DATA SERVICES	
Dial-in value-added services	Continuous
Agency-owned RWIS	Continuous
NOAA - Receive only via satellite	Continuous
NOAA - Receive only via land-line	Continuous
FAA - Terminals at selected locations	Continuous

crystals in all maintenance vehicle radios. The NOAA Weather Radio system blankets the U.S. with the exception of a few blind areas that lie in the shadows of mountains. The information is repeated, usually every five minutes or less.

Most commercial television stations present their weather reports during news programs. Public Broadcasting Service (PBS) stations carry a fifteen-minute weather program mostly in the early morning hours. Many television stations employ meteorologists who develop and issue their own forecasts. Because of their need to inform the public of impending problems, television broadcast forecasts tend to be overly pessimistic. For example, as pointed out by Mr. Ken Siemek, a television meteorologist, during a presentation at the 1990 American Public Works Association Snow Conference in Omaha, Nebraska, a forecast for two to four inches of snow would likely be broadcast as a forecast for four inches of snow.

There are two sources of weather information provided through cable television. First, many cable systems offer The Weather Channel, which emanates from Atlanta, Georgia. This twenty-four-hour-a-day commercial operation uses a mix of NWS products and its own. It provides both national and regional coverage with brief segments of local weather, shows radar and satellite images, and includes nearly continuous banners of current weather observations. Second, many cable companies allocate a channel to display the NWS local weather radar continuously, and some companies provide an audio overlay of the NOAA Weather Radio on the same channel. NEXRAD installation holds great potential to display radar products, such as those shown previously in Figure 1-4. These products, which can be modified for public viewing instead of showing a view of the radar scope, will be much more meaningful to users.

Telephone answering systems, which provide recordings of local weather observations and forecasts, have been used for decades. These systems traditionally use information provided by the NWS. Recently, these systems are becoming more commercialized, and non-NWS information is also being used. The NWS has a number of telephone answering systems that provide a variety of weather information, including forecasts for travelers and recreationists. In the past, each type of forecast was assigned a specific telephone number. However, with the advent of computerized voice mail and digital recordings, the same information is available through a single telephone number that can handle many calls simultaneously. After dialing the number, the caller keys a one- to four-digit number to retrieve the particular type of information desired.

More-sophisticated users of weather data and information have a variety of services available. These services include satellite broadcasts of both data and weather facsimile, private meteorological data services, use of the Federal Aviation Administration's (FAA) terminals located at facilities around the nation, or links directly to a terrestrial weather data network. For the most part, the cost of each of these services depends on the level of service used.

During the past several years, communication companies have been installing more sophisticated automated exchanges that are being interconnected with fiber-optic cable to provide faster, clearer, and more accurate information transmission. These systems can transmit voice, data, graphics, imagery, and television in digital form on the same cable. Cellular telephone systems are on the verge of being converted to digital voice. Satellite technology has also advanced to the point where digital transmissions can be received directly in mobile units, and positioning systems can locate vehicles within a few yards. These advances provide more efficient use of the airwaves, greater security, increased flexibility, and improved operational control.

Conclusion

Weather prediction systems use an integrated worldwide observation and communication system to get the data they need, and convert these data to weather forecasts of varying degrees of resolution. Each user determines what level of detail is needed. The feedback of

data input and product output among users can be synergistic. New technologies like those described above must be utilized and integrated if RWIS data are to be used effectively. If detailed road and weather data from an RWIS could be used in prediction models, the output from these models could provide a basis for VAMS to issue better point warnings and predictions of severe weather needed by state highway agencies.

There are many sources of weather information. However, the level of detail needed for highway snow and ice control decision making is, for the most part, not currently available. The next section describes the information needed for effective decision making.

Road Weather Information

This section describes the components that comprise state road weather information systems. Since local conditions, budgetary priorities, and other constraints vary from state to state, the design and implementation of RWIS technologies also vary to meet each state's specific needs.

User Requirements for Road and Weather Information

User requirements for road and weather information usually are based on time periods of a day or less and distances of less than 500 miles (800 km). Decisions to deploy snow and ice control resources usually are based on weather predicted for the next few hours, as are decisions to extend shifts or call out additional resources. The distance (grid or mesh length) requirements for monitoring and detecting weather vary from agency to agency, but from a prediction standpoint, weather conditions up to 500 miles away in the afternoon can affect an area of responsibility the next morning.

For the purposes of this guide, two time periods are described. These relate to the types of time-related decisions made by snow and ice control managers.

0 - 4 hours — Road maintenance supervisors need accurate, near-term forecasts to minimize the time interval between when they call in personnel and when the personnel need to be on the road to control snow and ice. This time period also applies to highway users and many nonhighway activities in the private sector.

4 - 24 hours — This time period is important for management planning where snow and ice control activities can be adjusted to accommodate weather conditions. These activities may include placing people on standby, planning night or early-morning activities, scheduling overtime, preparing equipment and materials, and advising highway users.

It is important that highway agencies work closely with the meteorology community when identifying the critical decisions affected by weather. One method for ensuring coordination

is to use a weather advisor as an interface between the decision makers and the forecasters. This weather advisor function can be an outside consultant, a VAMS, or an employee of the agency. A weather advisor can assist in many facets of RWIS implementation.

Road Weather Observations

States are beginning to install weather observation and pavement sensor systems at critical points along roads for snow and ice control management. Information provided by these systems can be used by roadway managers to reduce or avoid costs, minimize adverse environmental effects, and improve safety. However, observations and forecasts from these systems can be used for many other activities, such as road maintenance and construction, throughout the year. Table 1-2 outlines the observation needs of highway agencies as well as those of meteorological organizations and the traveling public.

Federal Weather Observations

Other than pavement and road weather observations, Doppler weather radar will be the most useful observation system for operational snow and ice control activities. An example of processed output expected from the NEXRAD system was shown earlier in Figure 1-4. Other products need to be developed. Examples of NEXRAD products applicable to highway operations include precipitation detection, projections, rates, and flash flood assessments.

As output from the NEXRAD system becomes available for improved automatic weather prediction models, it will be possible to project with reasonable accuracy storm movement and accumulations over several hours. Although the NEXRAD system will cycle every six minutes, products may not be available for dissemination more frequently than every fifteen minutes. These data will be provided by commercial data disseminators connected to the NEXRAD Information Dissemination System.

Other Agency Observations

Many city, county, state, federal, and other organizations gather weather and precipitation data and use or make forecasts to serve their own needs. Their data formats are not always compatible with the data base of an agency or RWIS communications system. Regardless of communications compatibility problems, it is advisable for weather advisors to become aware of these other organizations, develop cordial relationships with them, and seek areas of mutual interest to promote future cooperation, greater compatibility among systems, and improved information quality.

Table 1-2. Observation requirements for users of road weather information systems

Types of observation	Road agency Snow	Road agency Other	Meteorology Snow	Meteorology General	Travelers Alert	Travelers General
Pavement						
Temperature						
Surface	Y	Y	Y	N	N	N
Subsurface	Y	Y	Y	N	N	N
Surface condition	Y	Y	Y	N	Y	Y
Chemical concentration	Y	N	N	N	N	N
Weather						
Wind						
Speed	Y	Y	Y	Y	Y	Y
Direction	Y	Y	Y	Y	N	N
Temperature						
Air	Y	Y	Y	Y	N	Y
Dew point/humidity	Y	Y	Y	Y	N	N
Solar radiation	Y	Y	Y	N	N	N
Pressure	N	N	N	Y	N	N
Visibility	Y	Y	Y	Y	Y	N
Present weather	Y	Y	N	Y	N	Y
Precipitation						
Amount	Y	Y	Y	Y	N	N
Rate	Y	Y	Y	Y	Y	N
Begin/end times	Y	Y	Y	Y	Y	N
Type	Y	Y	Y	Y	Y	Y

Legend

Snow = Snow and ice control activities
Other = Road maintenance activities other than snow and ice control
General = Weather and/or road condition information used for other than snow and ice control or severe conditions alert

Local Surface Observations

Accurate forecasts for road maintenance operations, including snow and ice control, require data from weather and pavement sensors. Each sensor site should provide real-time data, such as wind speed and direction, air temperature, pavement surface and subsurface temperature, the occurrence of precipitation, the presence or absence of moisture on the pavement, a pavement chemical factor, and dew point. These data are digital in nature and are provided by sensors strategically placed to obtain the most representative and reliable

information about roadway and weather conditions in the field. Criteria for siting RWIS sensors are provided later in this guide to ensure that each set of data is representative, useful, understandable, and consistent with sensor data from other locations.

Data from these sensors must be communicated to a data base, prediction systems, and meteorologists so that detailed forecasts can be made and used for managing snow and ice control activities. Within the RWIS internal communications scheme, the combination of sensors, microprocessor, power supply, and modem is normally called a remote processing unit (RPU) station. A collocated RPU processes raw data from each of the sensors at each site and transmits the data, either automatically or on request. RPUs transmit data via radio or telephone line to a central processing unit (CPU), which is a micro- or minicomputer located at an agency's administrative offices. The CPU transmits data to the agency field offices and VAMS for archiving and display.

The sensor data are available to weather advisors and agency personnel through the CPU. CPUs are accessed by microcomputers with appropriate acquisition and display software. RPUs are normally directly accessible on a real-time basis, both to check that all systems are functioning and to obtain direct readout of sensor data.

The agency field office supervisors need the information for monitoring and decision making. For instance, this information is used to decide whether to use chemicals by checking the current chemical factor of moisture on the pavement. Real-time data will also help to monitor the progress of storms or maintenance activities or detect unexpected road conditions such as an icy bridge deck. Portable computers also may be used to obtain the latest weather or pavement condition forecasts.

VAMS use the data to prepare forecasts and any necessary updates. Ideally, the VAMS can access the sensors to get real-time data. At a minimum, a VAMS should be able to use the data to assess the degree to which a prediction is reasonable. The raw data would also be used by the weather advisor or the VAMS to interpret or adjust models or forecasts.

Agency operational supervisors would also use the RPU access capabilities to make sure the RPUs and sensors are operating and providing satisfactory data in relation to each other. These supervisors also provide data about weather and roadway conditions, personnel, equipment, and materials problems to the next higher level of administration. The supervisors may directly use some NWS data, such as direct monitoring of weather radar as storms approach. Although NWS forecasts are usually too general for real-time, operational decisions, they can be helpful.

Additional real-time observations may be available from maintenance forces, police, the traveling public, and the media on a voluntary or request basis. This information is normally verbal and will describe local weather or roadway conditions.

Road Weather Information Sensors

Atmospheric and roadway sensors can provide important information to highway managers and meteorologists. In some cases, sensors in the road environment provide information to motorists, either directly or indirectly, through some communications medium. Some sensors are required in all road weather information systems. This *basic suite* includes instruments for wind direction, wind speed, air temperature, and dew point.

Wind instruments, for example, are used on bridges and in canyons and are necessary for snow and ice control management and automatic weather and road conditions prediction. However, temperatures and dew point are also needed for snow and ice control. The cost of building these capabilities into an RWIS is small compared to the overall cost of a system.

Table 1-3 outlines suites of sensors for road weather information systems. These suites were suggested by the research team as a result of analyzing road weather needs in conjunction with meteorological prediction needs. Cost and technical capabilities were considered in determining the composition of these sensor suites.

Table 1-3. Sensor suites for road weather information systems

Basic Suite	
Wind Direction	Wd
Wind Speed	Ws
Air Temperature	Ta
Dew Point/Humidity	Td
Additional Sensors for Snow and Ice Operations	
Solar Radiation	S
Precipitation Amount	Pa
Precipitation Rate	Pr
Precipitation Type	Pt
Precipitation Begin/End Times	Pbe
Visibility	V
Pavement Condition (wet, dry, icy)	Cp
Chemical Concentration	Cc
Pavement Surface Temperature	Tp
Subsurface Temperature	Ts
Earth/Soil Moisture	Em
Additional Sensors for Local Analysis and Forecasting	
Atmospheric Pressure	P
Present Weather	Wx

Sensors for Snow and Ice Operations

Sensors for snow and ice operations are recommended in addition to the basic set. Local conditions and management preferences will govern the selection of these sensors to augment the basic suite.

Solar radiation sensors can be used to determine how much energy is received by the road surface so that frost, freezing, and thawing conditions can be predicted with reasonable accuracy. Precipitation rates, amounts, types, and beginning and end times are used by road supervisors to monitor roads in their areas without having to travel the roads. Additionally, these data are inputs to the weather forecasting system. Finally, visibility data are useful for safety reasons and for resource management, since low

visibility can slow the deployment of resources as well as impede the traveling public. Visibility data can also assist in forecasting and monitoring freezing fog conditions.

The remaining sensors in this suite provide data on road surface and subsurface conditions. The pavement sensors tell whether the road is wet, dry, or icy, and they reveal the chemical concentration on the road surface. Subsurface temperature and moisture sensors are used to determine amounts of subsurface energy that will contribute to the change of road surface conditions. Data from these sensors are used at maintenance offices and by VAMS.

Sensors for Local Analysis and Forecasting

This suite of sensors is recommended in addition to the previous two suites to support automatic forecasts of weather on the fine-mesh scale previously outlined. Present-weather sensors are used in areas where fog and clouds may reduce visibility, such as in mountain passes and in lake and coastal areas. Present-weather sensors have direct applicability to road maintenance activities when knowledge of rain, snow, mist, and other variations of precipitation can be helpful in making decisions regarding snow and ice control.

Road Weather Forecasting

The NWS provides forecasts in various formats to government agencies and the media. Forecasts provided to the media are for large regions with slightly more information and detail targeted to areas such as large cities. These forecasts are for the general public and not to those in charge of snow and ice control. Nonetheless, these forecasts should be available in an RWIS to supplement smaller-scale weather information.

Road weather forecasts may be provided by any combination of the weather advisor, agency staff, and VAMS. These forecasts should consist of site-specific predictions of various weather and roadway conditions for the coming twenty-four hours. Updates should be made at regular cycles or as conditions or the forecast change. Conditions to be included are rain, snow, ice, frost, fog, freezing fog, cloud cover or clear sky, pavement and ambient temperature, dew point, or no significant weather. Also to be included are expected onset, duration, ending, quantity, and geographic distribution of the weather.

The actual thresholds of concern should be coordinated between an agency and its VAMS. These forecasts, tailored to the users' needs, are critical to the users' ability to select and deploy the proper resources at the proper time.

There is a hierarchy of benefits that is related to the type of weather forecasting service.

- Public forecasts from the NWS are frequently too general in nature and require further interpretation by decision makers.

- Some VAMS provide general area forecasts that are more accurate or more detailed than NWS forecasts. Decision makers must still interpret what these forecasts mean in terms of snow and ice on the roads. The agency weather advisor can assist in this interpretation.

- The most useful forecasts are provided by VAMS that issue detailed, tailored forecasts based on weather and road conditions meeting or exceeding critical thresholds. These thresholds are established interactively by an agency with assistance from its weather advisor, and they are understood by the VAMS.

- The best weather support is attained when the tailored forecasts are provided in a consultant-client relationship where the consultant (the VAMS) and the client (the agency, perhaps represented by its weather advisor) communicate through whatever medium is established for providing the forecasts and with verbal communication to ensure mutual understanding of VAMS limitations and capabilities, agency needs, the significance of the forecast, and the confidence the VAMS has in the forecast. Media options include teletype, facsimile, or a computer link.

The VAMS is the best source for tailored forecasts. The weather advisor and VAMS, if different, work together closely to make sure that mutual needs, strengths, limitations, and requirements are understood. The VAMS develops forecast models for each of the zones within the user's area of interest. NWS data and forecasts and RPU data are applied to these models to provide tailored forecasts over the coming twenty-four hours with scheduled updates and/or updates whenever the conditions or the forecast change. Supervisors and their crews may provide input both to model development and individual forecasts with accurate knowledge of their areas and real-time input about weather and roadway conditions.

The VAMS communicates the forecasts through the RWIS to the roadway supervisors who make the day-to-day and hour-to-hour decisions about the commitment of labor, equipment, and materials. Clear lines of communication must exist in each direction between the VAMS and these supervisors. They need to know each other's needs, language, and abilities on an individual and group basis. They also need to provide feedback or questions about a forecast or debrief an inaccurate forecast. The weather advisor can help bridge the gap between maintenance personnel and the VAMS.

Road Thermal Analysis

Road thermal analysis assists in the forecast of road surface temperatures at locations where there are no pavement sensors by interpolating temperatures between sensors. Thermal analysis also helps determine locations for placing RWIS RPUs.

Road thermal analysis usually involves driving an instrumented vehicle over a road network to measure pavement temperatures. An infrared thermometer measures the temperatures, and these are correlated to location along the road. These measurements are used to construct pavement temperature profiles. An example of a temperature profile produced by thermal

analysis is shown in Figure 1-5. Typically notations are made of important features that affect the pavement temperatures, such as sky-view blocked by trees, buildings, cuts and fills, and bridges and overpasses.

In theory, road temperatures tend to have similar patterns under similar conditions. Road thermal analysis is conducted under clear sky and cloud cover conditions when roadways are dry and wet. Road temperatures are measured in the early morning hours when the pavements tend to be coldest. These data only apply to dark hours.

When skies are clear and winds are light, radiational cooling reaches a maximum. Cold air pools in valleys or low spots. The coldest pavement temperatures tend to be in the low spots while the warmest may be at the higher elevations. Under these conditions, temperature variations will be the greatest.

Clouds absorb the outgoing radiation and then radiate thermal energy back to earth. Because there is not the radiational cooling that occurs under clear skies, road temperatures tend to mirror the standard atmospheric temperature profiles, with the warmest temperatures at the lower and the coldest at higher elevations. The temperature variations also are not as great under cloudy conditions. During precipitation, temperature profiles show even less variation.

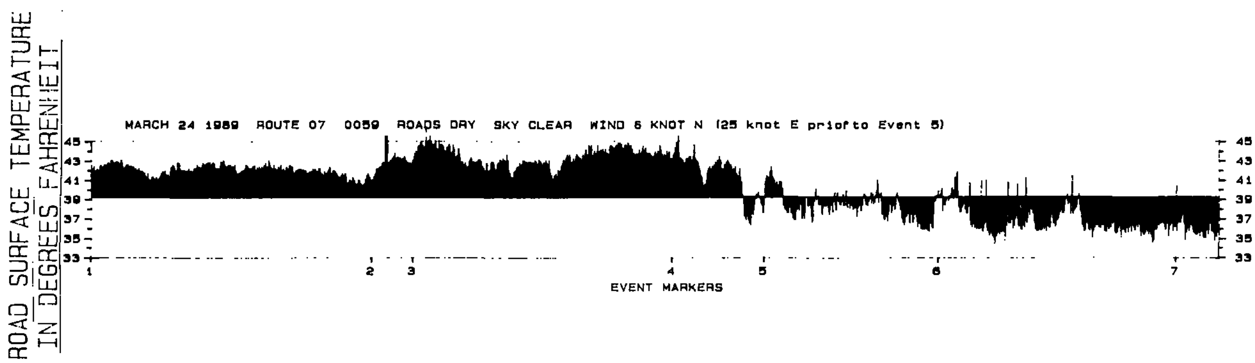


Figure 1-5. Sample temperature profile (reproduced with the permission of Vaisala, Inc.)

Alternatives exist to contracting for road thermal analysis. The Road Weather Information Systems Volume 1: Research Report (SHRP-H-350) describes thermal profiles constructed using a hand-held infrared radiometer. This process may be used by highway agencies to create thermal profiles of selected road segments at substantially less cost, but without the detail of commercial thermal analysis. A radiometer and a portable computer, to store and process the data, can be purchased for less than $4,000. The remaining cost is the investment of time and equipment. In addition, it is also possible to lease thermal measuring equipment to mount on an agency-owned vehicle so that the agency can perform the measurements for a consultant to analyze later.

Data Archiving

A significant part of an RWIS is an archival data base. The data base should consist of records of RPU data over several years. Data should be archived for each RPU. In addition, selected NWS data and edited verbal data from various sources may be included. A third part of the archive should be copies of forecasts issued to agency personnel. Lastly, the archive should indicate whether the RWIS and its components down to sensor level were operational at particular times.

Data are needed to develop weather prediction models and to determine how well a road weather information system works. Archived data are also essential for performing the objective forecast studies by which weather advisors and VAMS can improve forecasting skills for particular locations of concern.

Archived data may provide a good record of agency snow and ice control activities. These data, and activity logs, will provide the basis upon which operational decisions were made. Also, see Volume 1 of this report for a discussion of liability issues.

States are now involved in data collection and management, usually through the auspices of state climatologists. Many of these activities are confined to specific disciplines such as hydrology, agriculture, aviation, and forestry. Although some data sharing exists, much is largely uncoordinated. RWIS data should be considered for addition to state meteorological data archives.

Conclusion

States are beginning to plan, and some are implementing, weather information systems to meet a variety of needs. RWIS equipment can monitor weather and pavement conditions for snow and ice control management. Wind measuring equipment installed on bridges, along exposed highways, and in canyons can help determine when action should be taken to close roads to certain types of traffic. Wind socks advise the public of high winds on exposed areas or bridges. Snow-depth measuring equipment can help determine when to take action concerning avalanches. In short, states, counties, and municipalities can use observing equipment to obtain detailed information to help fulfill their responsibilities to the public and to reduce the costs of providing road maintenance services.

Current Snow and Ice Control Practices

There is a wide variety of snow and ice control practices and implementing decisions. These practices include patrolling, deicing, plowing, removal, and applying chemicals and abrasives. In some areas, anti-icing, or pretreatment, is being tested or implemented.

In most organizations, snow and ice control decisions result from a reaction to current conditions, or at best, a supposition based on a media forecast of wintry weather or other

indications. Forces are mobilized, perhaps first by instituting patrolling to check road conditions or by changing shift schedules. Often a supervisor will get word that roads have become icy or snow has begun to accumulate. The supervisor sends out crews to respond to problems as they occur, and these crews remain in the field until the problems have subsided. This type of response can be costly in time and materials, especially since plowing or deicing may take longer if the forces are late in getting started.

Labor, equipment, and materials all are needed to perform snow and ice control. Personnel rules and regulations and/or union contracts provide the framework, limitations, and penalties affecting labor decisions. Callouts typically incur costs, such as a guaranteed two or four hours of overtime pay per person. An unwarranted callout can be very costly. Efficient use of labor resources is critical to maintaining reasonable costs.

A typical agency equipment fleet is sized to meet perceived needs for snow and ice control based on a reactive decision process. During the winter, some agencies keep the truck fleet ready for snow and ice with plows permanently mounted and deicing materials (salt, abrasives, or other chemicals) loaded. This practice places unnecessarily heavy wear and tear on these vehicles. Some states have quick-disconnect plow hitches, which allow removal or mounting in a few minutes. Others have automatic belt loading systems for chemicals or abrasives so trucks are loaded only when needed. These latter procedures can be used more effectively if tailored weather forecasts are available.

Working in a reactive mode precludes timely, customized material applications for known or forecast road conditions. It also poses problems for efforts to reduce mis- or over-applications of chemicals. Tailored weather information allows roadway agencies to work in an anticipatory mode. This can make it possible to reduce the use of deicing chemicals, resulting in cost savings and less environmental impact. For instance, reduction in the use of abrasives is sought in some air quality nonattainment areas to reduce the amount of airborne dust during dry weather.

Strategies for Using RWIS Information

Opportunities exist for using weather and road condition information to change certain snow and ice control practices. Reduction in costs of labor, equipment, and materials is possible for nearly all practices and weather scenarios.

Patrolling

The use of winter patrols is a relatively common practice for monitoring or detecting road conditions. Patrols are normally used on a daily basis which may be supplemented by nighttime patrols. Patrols are also used in some areas to monitor other effects of winter storms, such as blown-down trees, flooding, plugged drainage facilities, or drifting snow from earlier storms. RWIS information can make regular patrolling an unnecessary function

of snow and ice control. Similarly, RWIS tailored forecasts will alert supervisors to high wind and/or heavy rain conditions that can cause other hazardous roadway conditions.

Tailored forecasts of weather and road conditions, combined with data from RWIS sensors, provide the information decision makers need for implementing snow and ice control. The sensors become the eyes and ears of the supervisors. The forecasts and sensors, used in conjunction with road temperature profiles, tell supervisors when and where maintenance will be required. With good weather information, the only weather-related reason for a patrol would be to check for downed trees or power lines or other damage assessment activities.

Plowing

Typical snow plowing decisions include where to plow and what to mobilize (plows, motor graders, snow blowers). If plows are not mounted permanently for the winter season, there is the additional decision of when to mount or dismount plows. For agencies that use contractors to help with plowing or snow removal, the decision of when to mobilize the contract force is also important. Calling out contractors too soon can significantly increase expenses.

RWIS information helps to make these decisions more effectively. Many weather scenarios can occur. They include, but are not limited to, moderate snow falling with pavement temperatures above freezing, and snow falling with pavement temperatures below freezing or expected to drop below freezing. In the first case, it may not be necessary to plow because the snow will not stick; in the second case, plowing may be necessary depending on the amount of snow expected to accumulate. The combination of the forecast for the amount of snow expected to accumulate and expected pavement temperature are important factors in a decision whether and when to initiate snow and ice control activities.

Deicing

Chemical deicing for snow and ice control is a practice which has grown significantly over the last few decades. Deicing is used to ensure reasonably safe passage for the traveling public on roads during inclement winter weather. The amount of deicing chemicals used in some states exceeds 500,000 tons annually. A typical application rate is 300 lbs (140 kg) per lane-mile. Salt is the predominant chemical used, due to its effective action in melting ice and snow and its relatively low cost. However, salt becomes less effective as the temperature drops below about 25°F (-4°C). Below these temperatures, salt can be mixed with other dry chemicals such as calcium chloride, or wetted with liquid calcium chloride or magnesium chloride. Some agencies also mix salt with abrasives (50-50 mixes are common, while some use a 5:1 mixture to keep sand piles from freezing). Others use alternative deicing chemicals, such as calcium magnesium acetate (CMA), urea, or a chloride with a corrosion inhibitor.

All of the chemicals, or mixes of chemicals, have temperature thresholds for limits of effectiveness. If pavement temperatures are too cold, the chemicals may not prevent the snow bonding to the pavement. For example, if salt is used, the pavement temperatures may be too cold for the salt to prevent icing.

Supervisors who select application rates or chemicals without pavement and weather condition information base their decisions on perceived existing conditions. Pavement temperature sensors enable more informed deicing decisions; pavement temperature forecasts enable even more effective decisions, since needed actions are based on what the temperature is going to be. For example, if the pavement temperature is forecasted to rise above freezing, little or no action may be warranted.

In addition to the pavement temperature, pavement sensors provide information on the amount of deicing chemical already on the road surface. Typically, a parameter called chemical factor is used to indicate the presence of a deicing chemical. If the chemical factor, which has a range of 0-100, is high (greater than 50), no further treatment may be needed. On the other hand, a low chemical factor (less than 50) may indicate the need for action. It should be noted that the chemical factor is a relative value, which needs to be calibrated by each user for the chemical in use. The chemical factor is based on the conductance of the surface. Ionic compounds, such as chlorides, will produce relatively higher chemical factor readings than substances such as CMA or urea.

Anti-Icing

Anti-icing is the practice of applying chemicals to pavement before freezing precipitation accumulates to prevent ice-pavement bond formation. Preventing the bonding of ice to pavement requires less chemical than is required to break that bond. Effective anti-icing allows snowplows to remove accumulations with less effort, to cover greater areas, and to clear pavements more effectively.

Anti-icing is used routinely in the United Kingdom. Its effectiveness there is enhanced because their road salt is very hygroscopic, i.e., attracts moisture, and is essentially pre-wetted salt in storage. In effect, a brine is applied to pavements, and some chemical remains on road surfaces regardless of traffic. The United Kingdom is also blanketed with RWIS sensors, and most road authorities there use weather and road forecasts provided by the National Ice Prediction System from the British Meteorological Office. Good weather information is essential for effective anti-icing. SHRP is investigating anti-icing in a companion research project, H208. A guide for implementing anti-icing is scheduled for completion in 1993.

2

Communication

Communication is an important component of a road weather information system and is required for disseminating and acquiring RWIS information. Communication includes:

- the transmission of data from sensors to RPUs, RPUs to CPUs, and CPUs to users;
- the dissemination of road condition information to police, road users, and the traveling public;
- the acquisition of weather information by VAMS, which includes NWS-disseminated data, RWIS data, and data from other remote monitoring sources; and
- the communication of RWIS forecasts and information between forecasters (VAMS) and users.

Weather forecasting is not an exact science. General forecasts tend to overpredict the occurrence of bad weather. This caution stems from the criticism that erupts when a bad weather condition occurs that was not forecasted. Additional criticism occurs when resources are deployed to respond to a weather condition that does not exist. The result is an unnecessary expenditure of funds.

However, accuracies of over 80 percent for detailed, tailored forecasts have been documented by the Washington State Department of Transportation. The key to developing tailored snow and ice control forecasts is access to meteorological and pavement data. Weather forecasters tend to use all pertinent available data. Unfortunately, their ability to access RWIS data is limited. The same holds true for highway maintenance personnel.

Historically, weather information systems were installed mostly at airports in the United States. Their information was used to assist airport authorities in their conduct of snow and ice control. RPUs with associated atmospheric and pavement sensors were installed on airfields, usually near the ends of runways, on runway intersections, and on parking ramps.

These RPUs sent data to a CPU in an airfield operations office where supervisors made decisions related to chemical applications for deicing and snow plowing.

The snow and ice control problems highway authorities face only differ in magnitude and methods of treatment. Weather information systems were sold to highway agencies. RPUs for atmospheric and pavement sensors were installed along highways, and CPUs were installed in highway maintenance facilities. These RWISs generally were installed on a research or test basis.

Meteorological data historically have been exchanged freely within the international meteorological community. RWIS data, however, usually have had limited distribution because of concerns over data ownership and liability issues.

Availability of RWIS data at highway maintenance centers is an important consideration. Weather information from other agencies may be available. An agency weather advisor can assist highway agencies to determine the availability and utility of other weather information for an RWIS.

Dissemination of Weather Information

Road condition and weather data are produced in various formats for use by agencies, but these data must be relayed to those who need them. It also is necessary for data users to provide feedback to data providers to ensure good communication and understanding in order to obtain the best possible public service.

Maintenance Managers

Highway maintenance managers and supervisors without an RWIS get weather information about potential snow and ice conditions from the same sources available to the public. Maintenance organizations that have a weather advisor or pay for a VAMS receive forecasts via telephone, teletype, or through computer-to-computer connections. Managers with access to portable computers can access VAMS weather information twenty-four hours a day regardless of their location.

While on the road, maintenance supervisors use two-way (VHF or UHF) radios to communicate with their bases of operations. These supervisors usually access telephone lines with operator assistance if they need to call the VAMS or other weather information sources. In many areas, managers can use cellular telephones when radio channels are either congested or are of insufficient quality to meet their needs. They can use these telephones with portable computers to access RWIS information. This gives decision makers continuous access to weather forecasting services to make more timely and efficient decisions.

Most raw meteorological data provided through subscription services are of limited value to decision makers. Agency decision makers do not have the training or the time to interpret

weather maps depicting surface and upper-air weather patterns, or other meteorological data. Real-time weather radar, and in some cases, meteorological satellite images can provide decision assistance. Areas prone to shower activity, such as lake-effect snow showers around the Great Lakes, use National Weather Service radar data to monitor the progress of storms and deploy snow and ice control resources. Most weather radars, though, do not provide good information on light precipitation events and snow. NEXRAD will correct this deficiency. Once data are available from NEXRAD, computer-generated products, rather than raw data, will also provide useful tools for agency decision makers.

Pavement temperature forecasts are particularly useful in helping decision makers select appropriate chemical mixes for deicing. Heretofore, most managers have been using ambient air temperature readings or air temperature forecasts for deicing chemical decisions. With the advent of pavement sensors, better information has been available for these decisions. But the best decisions are made based on what the pavement temperature is going to be when the chemicals are applied or after they are applied. Pavement temperature forecasts also have the potential to help make anti-icing a viable, acceptable practice, and they should be routinely available to snow and ice control decision makers. To provide good pavement temperature forecasts to agencies, VAMS need access to RWIS data.

Commercial and Private Traffic

Road users need real-time information about existing or potential road problem areas before and during their travel. Information about detours, potential delays, and travel restrictions caused by accidents, snow and ice, bridge closures, or flash floods must be communicated quickly to vehicle operators to help reduce traffic problems.

The key requirement is to provide road information in near real-time. Currently, Highway Advisory Radio can do this, but areas where this is available are limited. Changeable message signs are limited in message content. In Europe, matrix signs are used with specially devised symbols to communicate road hazards and conditions over a relatively limited area (within a 30-mile (50-km) radius of any point except for major highways, where the area extends up to 500 miles (800 km) and the lead time up to ten hours). Emergency notification of road closures should be immediate.

Management and Administration

Highway agencies are improving their communication and information systems using available and emerging technologies. As RWIS technologies evolve, there is a need to bring improvements in communication and information systems to maintenance offices and highway crews in vehicles. This is particularly necessary to help mitigate problems during potential and actual adverse weather and road conditions.

Many people in an agency maintenance organization make decisions regarding snow and ice control activities and costs. The equipment operator decides whether a particular section of

roadway conforms to the hills, curves, and intersections policy for deicing and whether to turn on the spreader. The supervisor decides whether to extend a shift on overtime if a forecast indicates that a snowstorm is going to last until 6:00 p.m. The maintenance engineer allocates the available funds, people, and equipment among the districts or reallocates resources in the middle of winter when one district is over budget and others are under budget.

Each of these decisions must be transmitted within each organization. An RWIS creates a new, different, and, in some cases, more sensitive set of decisions and data to be communicated among the weather advisor or VAMS, agency administration, operational supervision, operations personnel, and the public. Decisions need to be made about who could benefit from the various products of an RWIS, what data will be routinely transmitted, and what data will be available by computer or on a call-up basis. In some cases, it is possible that some data will be restricted to certain groups or levels.

Agency administrations need climatology data for overall planning, and resource expenditure data for monitoring against budgets. Supervisors and operators need current forecast data for short-term planning and individual decisions, such as when to mobilize or send the crew home and whether and when to use what quantities of what chemicals or abrasives. Instantaneous communication is required between trucks operating in tandem during plowing operations. Improved methods for calling in crews and for communicating with them once in the field are required to increase productivity and to better deploy resources.

The number of decisions, information needs, and methods of communication are large and will vary from agency to agency. It is appropriate to set up a communications system related to an RWIS that is flexible enough to allow for changes as experience is gained.

Communications Alternatives for RWISs

The communication system architecture alternatives for RWISs described here are based on the research results published in Volume 1 of this report. Agencies may wish to review these alternatives with regard to their individual goals and objectives and begin to refine their requirements where opportunities exist. Agencies may also wish to take action on some of these alternatives, since many do not require additional research to demonstrate their effectiveness.

When acquiring an RWIS, users must decide whether to use a proprietary (closed) or nonproprietary (open) system. A proprietary RWIS is developed and sold by a single manufacturer and contains vendor-developed software, data formats, and communication protocols for data exchange. A nonproprietary RWIS uses existing formats and standard communication protocols for the dissemination of information. If an agency's existing protocols are different from proprietary RWIS specifications, the cost of developing the capability for using the agency's protocols may be significant.

Currently, most of the RWISs sold in this country are proprietary. Each system is designed to meet a particular need, though all include RPUs, sensors installed at RPU stations, a CPU, and communications software and protocols provided by the vendor. The advantages and disadvantages of both proprietary and nonproprietary systems are discussed below.

Proprietary (Closed) Systems

Proprietary systems have certain advantages over nonproprietary communications systems. These advantages include:

- Proprietary systems are relatively easy to procure. Acquiring such a system involves establishing the number of RPU stations, number and types of sensors, mode of communications, and methods of data access for decision makers. The systems are basically off-the-shelf, although the component complement is tailored to the user's needs.

- The systems are quickly expandable to serve both inter- and intra-agency needs. Adding an RPU station, additional sensors, or access capability can be easily accomplished.

- Proprietary systems are proven technology. A new system will be similar to one installed elsewhere, and its users can be contacted to determine the utility of the system.

- System maintenance may be easier with the same components throughout a system than with components from different vendors.

Proprietary systems also have certain drawbacks:

- RWISs from different vendors have difficulty communicating with one another. This lack of interoperability results from proprietary communications protocols and data formats.

- A single proprietary system may not meet all of a user's needs. Each vendor's system may have some desirable feature, but without interoperability, a user is forced to purchase what a vendor has to offer, or else attempt to merge two or more systems that have overlapping capabilities.

- It is not possible to exchange data with other sources. A closed system may not allow access to other weather information systems or be able to disseminate, process, or display data from them.

- If an agency wants to install RPU stations or sensors from different vendors, even where existing sensors from a different vendor are in place, the agency must have multiple CPUs to access and process the data.

- Proprietary systems may require a dedicated, single-user radio frequency for data transmission. This means that even if multiband communications already exist, an additional radio link will have to be installed for RWIS data collection.

- There is generally no provision for continuing, long-term software support if the vendor goes out of business. (When agencies acquire an RWIS, system software ought to be placed in escrow.)

Nonproprietary (Open) Systems

Nonproprietary system architecture requires communications standards. Since no standard RWIS protocols or data formats exist, each agency needs to specify standards in any request for proposals (RFP). Protocols need to be specified for RPU-CPU and CPU-CPU options, as well as for using state-owned communication systems for distributing RWIS information.

Advantages of nonproprietary systems include:

- Open systems enhance opportunities for interoperability and connectivity among RWISs from different vendors, e.g., across state lines and among different agencies.

- There is a potential to foster RWIS technology development due to competition, which could broaden purchasing options.

- Open systems provide more flexibility in acquiring RWIS technologies. If an agency wants to mix types of pavement sensors, or replace obsolete sensors with new technology, the opportunity to do so is made possible with open systems.

- Data exchange with various sources can be accomplished with open communications, using a standard data format. Meteorological data from another system may have great utility for highway maintenance decisions. Without an open system, these data might not be accessible or useable.

- Open systems can be designed to operate with existing, multiple-frequency radio transmission capabilities, eliminating the need for additional special-use radio equipment and frequencies.

- If an open system is specified in an RFP, control of system software can also be specified, providing the opportunity for long-term software support and maintenance.

Certain disadvantages are also likely with nonproprietary systems:

- If an open system is specified, a significant development effort may be required. A proprietary system may need to be redesigned to meet the specifications, or a new system may be required. Either case will likely increase the cost and the time required to acquire the system.

- Vendors of proprietary RWISs might not respond to an RFP. Some private enterprises may not want to deal with certain requirements, such as RPU-CPU communication standards and requirements for delivery of proprietary software.

- There may be concern regarding product liability when dealing with open systems, such as who is responsible for another vendor's sensors. If an agency is unwilling to indemnify an open-system vendor, that vendor may choose not to respond to an RFP.

- Issues surrounding open communications systems necessitate increased knowledge of RWIS technologies within user organizations. Establishing standard communication protocols and standard data formats requires knowledge of the options, an understanding of the implications of each option, and the ability to work with the selected vendor to ensure successful implementation.

- True open systems, with components from more than one vendor, may complicate system maintenance. For instance, acquiring ten items from different vendors rather than ten items from the same vendor can significantly increase maintenance requirements. A system vendor may not want to maintain, even under contract, components from a different vendor.

Standards for Communication. Examples of standards for communications protocols, data formats, and hardware applicable to an RWIS include:

- X.25 communication protocol with three virtual circuits,
- X.400 message handling,
- V.32bis for variable modulation,
- V.42bis for data compression,
- FM 94 BUFR coding schema for road and weather data,
- FM 92 GRIB formatting schema for gridded data,
- ASOS surface observation precision, accuracies, and timing refined for RWIS and formatted to BUFR standards,
- SI metric units of measurement for elements internal to RWIS (SI units may be converted to customary units for external presentation and display where needed),
- Group 3 and Group 4 facsimile,
- UNIX and MS-DOS operating systems for computers,
- GOSIP open system interconnection,
- POSIX portable operating interface,
- MOTIF graphical user interface,
- 386/486-class microprocessors,
- Super-VGA color monitors,
- small computer system interface (SCSI),
- EISA bus interface where SCSI is not appropriate, and
- 3.5", 1.4-megabyte floppy diskettes.

Base Station and Communication System Interface

This section discusses various considerations concerning the base station segment of a road weather information system, the segment where snow and ice control activities originate. The maintenance center is the hub of data collection, communication control, and snow and ice control management. The center is where decisions are made to adjust operations to meet conditions. Each agency will have its own procedures for information dissemination and snow and ice control implementation. Some of the suggestions herein may enhance both existing and future systems.

System Needs

Pertinent data in the hands of supervisors at maintenance centers and in vehicles can significantly improve decisions concerning deployment of personnel and material. An RWIS must link supervisors with crews in the field, decision makers, and weather information suppliers in both the public and private sectors. Such a system should include data and voice communication.

Interviews with highway maintenance supervisors revealed that considerable time is spent calling in equipment operators during prestorm preparations. Automated calling and response could reduce callout leadtime and give supervisors additional time to make preparations. Reducing callout leadtime also would reduce expenditures and allow supervisors to get better information before committing to a decision.

There is a need to improve communication between equipment operators in the field and maintenance offices. In some areas, congestion on a limited number of radio frequencies is a problem. Digitized messages to terminals in vehicles, digitized voice to provide up-to-date road information, and voice mail to distribute information are technologies that could improve service.

Finally, there is a need for automated data collection, processing, and distribution. This includes polling observation stations, fixed and mobile, for data and message collection, information distribution, processing and displaying data in a coherent manner, executing forecast algorithms, and presenting results to users and the public.

System Operation

The primary purpose of a road weather communication system is to provide the basis for a meteorological watch program for roads. The watch concept includes constantly monitoring weather conditions and forecasts, and alerting those who have a need to know of changes that will affect their activities. The aviation industry for years has had a weather watch program, and the United Kingdom has established its equivalent for roads.

A good observation, communications, and information system is essential for a weather watch program to succeed. Computers would be placed in maintenance offices to collect observations from various sources, assimilate them, and alert road supervisors to possible problems. These systems also would be able to control variable-message boards along highways to alert the traveling public to possible hazards. Similarly, the systems would be able to generate text and graphic presentations. Human monitoring of these products would be necessary to prevent erroneous information from being disseminated.

A weather watch can assist road supervisors to determine when to call in crews to control snow and ice, when and where to apply abrasives, and when no action is needed. The following scenario may help to illustrate how such an approach might work.

Road supervisors keep cognizant of general weather forecasts from the NWS, while private weather services monitor weather and road conditions in detail. From the general forecasts, road supervisors get an indication of when severe weather events may be expected. However, supervisors also need to know if, when, and how much snow or freezing precipitation may fall or whether water on roads will freeze. Details would come from the VAMS, the algorithms in the maintenance center's computer, or from NEXRAD and NOAA's hydrologic precipitation projection system. The constant flow of observations from pavement and weather sensors along roads into computers in maintenance centers updates the data base. Forecasts are produced for supervisors to use in making decisions.

These forecasts, weather observations, and road surface conditions are displayed on electronic maps contained in the base station computer. These displays are accessed by the supervisors in the maintenance center, at home, or in their vehicles with portable computers. If a decision is made to call out crews, the supervisors initiate an automated calling system in the computer either immediately or by selecting a time for the computer to begin automatic calling. This calling system would automatically dial each crew member, and the member would respond by keying the action he is taking — will come in, cannot work, or some other response established by a supervisor. This automatic calling system frees the supervisor to make other preparations. These could include driving to the maintenance center.

The information system suggested here may be used throughout the year to help manage highway maintenance operations. However, it is designed to meet peak demands for snow and ice control operations; therefore, it will probably exceed operational needs during nonwinter seasons, except perhaps during unusual circumstances such as tornados, flooding, hurricanes, and other storm conditions. Technologies needed for this system are readily available and in use, although application of the technologies may need to be adapted to meet the specific needs of highway agencies.

Technical Considerations

Initially, CPUs provided by RWIS vendors will provide the central hub for collection and dissemination of RWIS information. Microcomputers in maintenance centers and/or portable computers would be used to access sensor data, forecasts, and meteorological or road

condition display products. Options exist for expanding system hardware and communication capabilities to meet agency needs. It is even possible to interconnect CPUs through state communications systems. However, standard communication protocols may be required. A standard data format also would be needed to facilitate data exchange.

For data sharing, users should consider exchange arrangements among states, counties, municipalities, and the private sector. Arrangements for data exchange may provide more information to all agencies.

Users might also consider arrangements for data and product exchange with the National Weather Service and NWS Office of Hydrology offices located in each state. Future capabilities of the NWS will include the ability to provide NWS data to state emergency operations centers. The potential for sharing data in two directions may exist, however, the NWS may require RWIS data to be available in a format the NWS can use.

Applications Software

There are two types of applications software needed for an RWIS: *generic* and *special.* Word processing programs, spreadsheets, data bases, presentation graphics, and miscellaneous utilities, such as a calendar, calculator, notebook, voice mail, and electronic mail, are examples of *generic* software. Many of these could be used in base stations, where major activity and control occurs.

Special software is that which is designed for meteorological, pavement condition, and other applications associated with weather and highway maintenance. For snow and ice control, this software includes but is not limited to programs to:

- track, display, and save road surface and weather conditions;
- analyze observations and use automated prediction techniques to project road and weather conditions tailored for specific highway segments and points;
- produce automated decision guidance;
- teach road personnel about snow and ice control, equipment operation, and the use of information to make operational decisions;
- produce statistics and reports;
- control variable-message boards; and
- provide logistics management, an audit trail, and a data archive.

Data Storage

Many types of data storage are possible in a base station weather information system. The small 1.4-MB, 3.5" diskettes have stronger casings and have higher densities than 1.2-MB, 5.25" diskettes. A variety of fixed hard disks is available with larger capacities. A large-capacity hard drive should be considered to provide sufficient startup capacity, since audio and facsimile applications consume large amounts of storage. In addition, compact-disk

read-only-memory (CD-ROM) optical disks have been adapted for digital data recording. Multimedia disks could also be used for equipment maintenance manuals, roadway and bridge specifications, detailed maps for displaying hazardous conditions, vehicle tracking, and other applications. Multimedia disks would be used for audio, television, pictures, maps, diagrams, and data. This technology should be considered if large amounts of digital data are to be recorded or archived.

Data Output

The primary purpose for an output device should be considered when acquiring a base station weather information system. Many types of output devices are available. Laser printers produce crisp, hard-copy output. These printers are capable of producing high-quality graphics, halftone images, and text at reasonable speeds; however, they are relatively expensive. Color printers produce usable reproductions of color weather graphics, but they are very expensive and a costly option if they will be the sole output device. Other printer terminals, such as dot-matrix printers, may be used as output devices. Multiple output devices may be needed.

Staff

Maintenance offices usually do not have the staff to plan and develop the weather information system described. Therefore, another section within the agency may be needed to plan, provide guidance, develop training materials and manuals, and coordinate implementation of the system among maintenance centers. It is suggested later in this guide that an RWIS implementation committee be established. A person in each maintenance center should be assigned responsibility for the automated system and trained accordingly. These persons should be given the flexibility to freely exchange ideas with other centers and the agency weather advisor.

Agencies should consider how many computer workstations are needed in each maintenance center. Two or more people may be on duty in a center at one time. Secretarial staff, supervisors, and maintenance managers would be able to work as a team using the integrated data base, graphics, and audio capabilities of the system. Logistics and administrative work, as well as RWIS information processing, can be handled by an automated system. An automated system using multimedia disks, for instance, could be used during noncritical times to train employees in maintenance, operations, and other facets of roadway management.

3

RWIS Sensor Siting

Nationwide networks of RWIS sensors have been installed in some European countries. In others, RWIS sites have been established along entire lengths of highways. This has been possible in part because European countries are relatively small, and in some cases, a government's meteorological service and RWIS hardware manufacturers have formed a consortium.

Systematic installations of RWIS sensors have recently begun in the United States. Since 1988, agencies have begun to expand RWISs or create new networks. Some of these networks are being established along highway routes, and others cover geographic areas. Wisconsin has a statewide network of RWIS installations.

RWIS sensors are installed to provide current pavement and atmospheric conditions information that can be used to make cost-effective snow and ice control decisions. For example, this information can be used to make decisions on whether to deploy snow and ice control personnel and equipment. Sensors, combined with road thermography and other meteorological information, help meteorologists to prepare pavement temperature forecasts, as well as site-specific, tailored weather and road condition forecasts.

Atmospheric sensors provide data for forecasting for relatively small areas and inputs to pavement temperature forecasts. Roadway surface sensors provide a check on the progress of pavement temperature forecasts and help to predict what effect, if any, atmospheric weather will have on the roadway surface. Chemical detectors indicate in relative terms the presence of deicing chemicals, which lower the freezing point of any moisture present.

Subsurface temperature sensors are also utilized. A roadbed is a very large heat sink. Like the atmosphere, a roadbed influences surface pavement temperatures. Roadway surface temperatures are affected by heat flowing to or from the subgrade.

Sensors are used for three purposes: *forecasting*, *detecting*, and *monitoring*.

- Sensors are sited to provide local information to supplement NWS or other weather observations. This information will be used to develop site-specific *forecasts* of weather and road conditions. Since the benefit of using weather information is to make timely decisions through the use of forecasts, acquiring specific local information should be considered the primary reason for siting sensors. Sites selected should be meteorologically representative of an area.

- Sensors are sited to *detect* existing or changing weather or roadway surface conditions on a real-time basis. Typical sites would include known trouble spots, fog and frost hollows, bridge decks, elevated roadways, as well as sufficient sites to provide a suitable grid for the reliable reporting of snow accumulation or other precipitation events.

- Sensors are also sited to provide a *monitoring* function to check the onset or existence of predicted conditions. Monitoring sites should be selected to provide information "upstream" of an area. For example, if weather usually comes from the west, place sensors to the west.

It is possible to cover some or all of these siting considerations at one location. One possibility may be to put a few pavement sensors on a bridge for detecting and monitoring surface conditions. Instead of locating an RPU station at the bridge, cables will be run from these sensors to an RPU that is in a much better location for forecasting purposes. Also, the ability to obtain precise forecasts for the condition of the bridge should reduce the importance of monitoring real-time data.

There are a number of criteria and considerations involved in locating RPU stations and deciding where various sensors will be placed within a chosen site. They are discussed below.

Locating Remote Processing Units

A remote processing unit (RPU) is the basic stand-alone component of an RWIS. To support prediction needs, a suite of sensors with an RPU should contain:

- atmospheric sensors for wind speed and direction, air temperature, relative humidity or dew point, and information about the occurrence of precipitation;

- pavement sensors to monitor pavement surface temperature; pavement condition (wet, dry, ice, or snow); chemical factor; and perhaps surface freezing temperature; and

- a subsurface temperature sensor.

An RPU is usually mounted on an instrument tower with the atmospheric sensors. The tower may be located at the side of a road or at a distance from a road if such would provide more typical data. The tower also will have an antenna for radio communication if that

medium is used. Otherwise, a modem is needed in the RPU for telephone communication. Pavement sensors are embedded in the pavement near the RPU and connected to it by buried cable. A subsurface sensor is placed under the pavement near the RPU and close to a pavement surface sensor. Figure 3-1 illustrates a typical RPU station configuration.

For roadside installation, the location of the RPU should be based on the following:

Figure 3-1. RWIS remote processing unit station installed along a highway (reproduced with the permission of Climatronics)

- Meteorological considerations need to be addressed in siting the atmospheric sensors. The better the meteorological information, the better the forecasts will be. These considerations are discussed in the next section.

- Equipment limitations should be considered. Manufacturers of atmospheric sensors specify a distance limit between each sensor and the RPU.

- An RPU should be installed as close to the road as possible without being influenced by passing vehicles. During winter road conditions, vehicles can splash slush and deicing chemicals onto the electronics enclosures, atmospheric sensors, and tower. The effect of snow plowing on the precipitation sensor is also an important consideration.

- A site should be as protected as possible to prevent vehicles from striking the assembly. On-ramp gores are usually low-impact areas. Along highways, the areas on rights-of-way outside of roadway prisms and the clear zone are also preferred locations if the elevation of such an area is within a few feet of the roadway and the area is relatively open and not lined with trees. Trees and cuts or fills preclude gathering representative data.

- Availability of power should not be a primary consideration. It is better to install an RPU 500 ft (150 m) away from power and pay for cabling than it is to install the RPU in an area not representative of local conditions. Also, solar power, which

approximates the cost of more than 150 m of trenching, can be used at an RPU if no other type of power is available.

- Proximity to communications also should not be a primary consideration. If telephone communication will be used, telephone cable can be buried to a suitable location; repeater stations can be used if line-of-sight radio communication is not possible.

If roadside RPU installations are difficult because of lack of room or other problems, atmospheric sensors can be mounted on top of utility poles or sign bridges. It should be noted, though, that for other than wind and precipitation, atmospheric data obtained at sign-bridge height are not representative of the road surface. Furthermore, wind data are potentially disrupted by the signs. The details related to sign bridge mounting of instruments are discussed in the section on siting meteorological sensors.

RWIS RPU siting can be assisted by the use of road thermal analysis data. If RPUs are to be located in an area, then thermal profiles of many road segments throughout the area should be analyzed. If RPUs are to be sited along a long stretch of road, then thermal profiles from its entire length should be used.

It is suggested that thermal profiles be used based on two considerations:

- sensors should be placed at locations where the pavement temperature is close to the mean; and

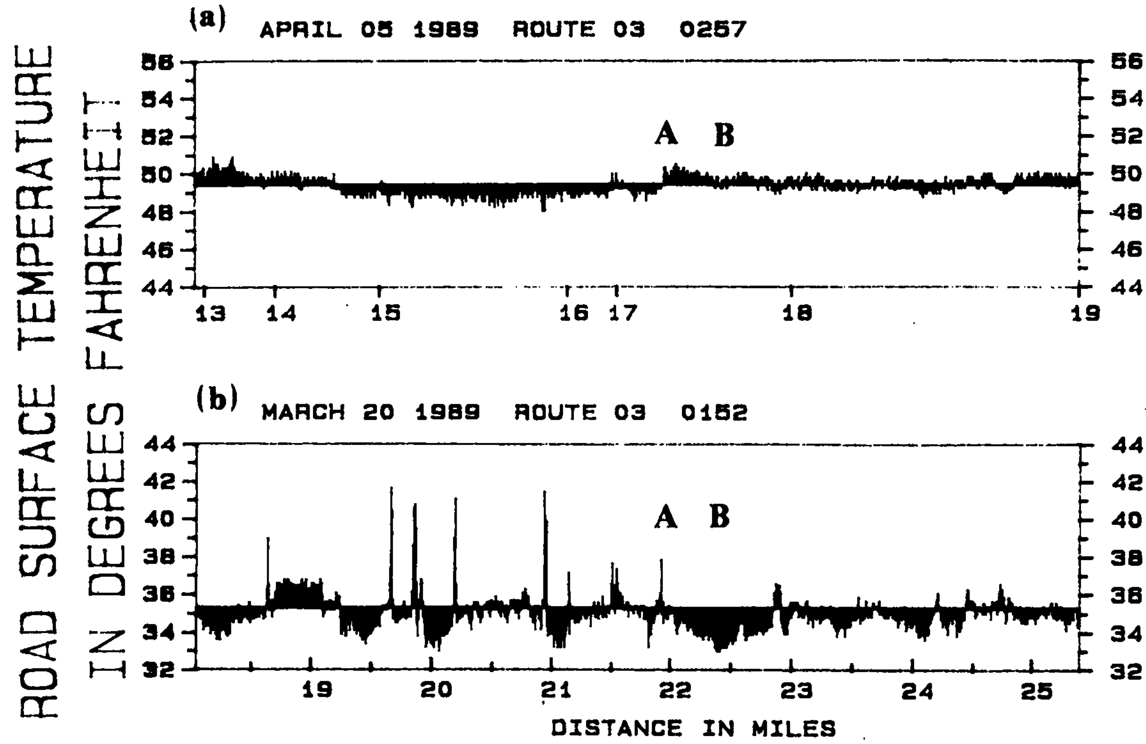
- sensors should provide information for the warmest and coldest locations.

Figure 3-2 shows two thermal profiles that were developed under different atmospheric conditions on the same stretch of pavement. Profile (a), dated April 5, 1989, was taken under very low clouds, with moderate winds, and with the road surface wet. Profile (b), dated March 20, 1989, was taken under clear sky and light wind conditions, with a dry road surface. Compare the temperature patterns of the two profiles. Profile (a) shows about a 3°F variation, while 9°F variation can be seen in profile (b).

The overall temperature patterns also show a temperature reversal. Profile (a) shows relatively cool and uniform temperatures between miles zero and nine, and then a gradual cooling after mile nine. In profile (b), the temperatures start warm, then cool to mile seven; they reach a low between miles six and seven, then warm again between miles seven and nine. The region from miles five to seven is low-lying. Minimum temperatures can be expected here under clear skies. In profile (b), the lower elevations are cooler, and the higher warmer: in profile (a), the reverse is true.

These profiles provide examples of how to use road thermal analysis to assist in selecting RPU sites. Just after mile nine, indicated by the *A*, is a location that shows near-mean temperature on each profile. This location, if it meets other criteria for siting, such as openness and representativeness for meteorological observations, could be an ideal mean-temperature location. In addition to mean temperature, it is located less than half a mile

from location *B*, which is a bridge that shows up as cold. It should be noted that this figure shows only a small segment of a highway that was thermally mapped. Additional mean-temperature locations would be needed.



A = near-mean temperature location
B = cold temperature location

Figure 3-2. Examples of road thermography conducted under varying atmospheric conditions (used with the permission of Vaisala, Inc.)

A cold location is found near mile ten. A second is found between miles six and seven. A warm site would best be situated near mile one. This site is clearly warm under clear skies, and exhibits a tendency toward thermal reversal under cloud cover. This area also shows the relationship between temperature and elevation: inversely related under cloud cover, and directly related under clear skies.

Locating Meteorological Sensors

The purpose of using meteorological sensors in an RWIS is to gather meteorological information related to the road environment in order to assist with the forecasting, detecting, or monitoring of weather and road conditions. In order for meteorological information to be representative, standard meteorological instrument siting criteria should be followed to the extent practicable. Different meteorological parameters have different instrument siting criteria. These criteria are discussed below.

Wind Speed and Direction

The flow of air is affected by any object in the air. Just as water is diverted around objects, and swirls are formed downstream from objects, air is deflected, and the air flow in the atmosphere can be deformed. If wind instruments (anemometers) are exposed to disturbed flow, the wind speed and direction they indicate may be significantly in error. Figure 3-3 shows an anemometer.

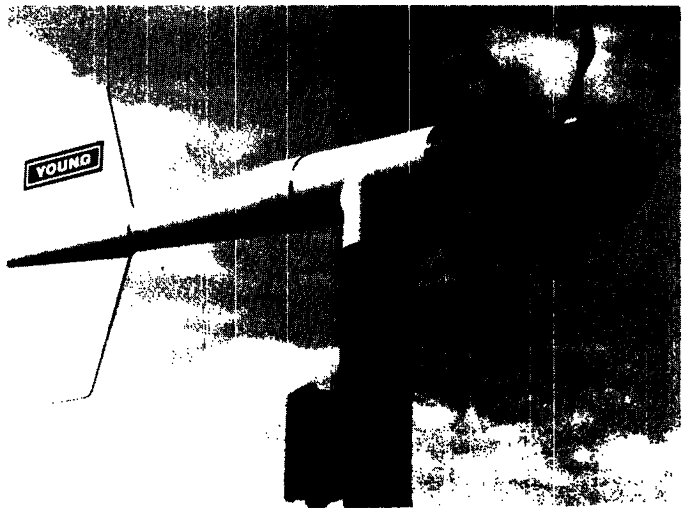


Figure 3-3. Anemometer for wind speed and direction (Used with the permission of R. M. Young Company)

Air has to flow over and around objects. In general, the larger the object, the larger the disturbed area downwind from the object. One general rule is that anemometers should be sited at least twice as far downwind from an object as the height of the object. If a row of 100 ft (30 m) tall trees lines a highway, then the anemometer should be at least 200 ft (60 m) downwind. A second general rule applies to very broad, disturbing objects, such as a large area of trees or a large building. In these cases, the anemometer should be installed at least four times as far downwind as the height of the object.

It may not be possible to locate an anemometer sufficiently far from an object within the highway right-of-way. However, the siting should first be determined based on the prevailing wind direction and/or the direction from which most winter storms flow. Anemometer siting guidelines are provided below.

- Install anemometers in as open an area as possible.

- Do not install an anemometer downwind from a highway obstruction in the prevailing flow. For example, if the prevailing winds are from the west, do not install an anemometer just east of a bridge.

- In general, take power to a site; do not locate sites because of power availability. The extra cost for burying a few hundred yards of cable or implementing solar power will generally be cost-justified by obtaining more accurate data.

- The advice of the weather advisor or other meteorologist should always be sought for all RWIS site selections.

The ground also influences wind flow. At the surface, the wind speed is zero. Frictional effects diminish with height. The closer anemometers are to the ground, the greater the influence of the ground. Standard meteorological wind instrument height has been established at 33 ft (10 m) by the WMO and the NWS. Standard meteorological towers are available for placing anemometers at this height.

- The standard 10-m anemometer height should be used whenever possible. At lower heights, the ground and even vehicles may affect anemometer readings. Wind observations representative of the conditions in the area are desired.

- The tower should be sited using the guidance offered for RPU siting, above. The RPU will normally be mounted on the tower.

- If a standard tower cannot be used because of insufficient area in the right-of-way outside the roadway prism and the clear zone, anemometers can be installed on light standards or utility poles. Anemometers should be placed on top of poles to negate the flow-disturbing effects of the poles. Extension arms to the side of poles are unsatisfactory due to the possibility of air flows being disturbed by the poles.

- If no pole or tower is available, anemometers, like RPUs, can be installed on sign bridges. Care must be taken, however, to ensure that anemometers are installed to minimize disturbances from the signs and sign bridges themselves.

Temperature and Relative Humidity (Dew Point)

Standard temperature measurements used to be obtained from thermometers mounted in wooden shelters painted white. The shelters were louvered to allow the flow of air over the instruments, and were installed in grassy areas to preclude the influence of heat from pavement below. The instruments were mounted at about 6 ft (1.8 m). Electronic temperature measuring devices (sensors) have now replaced many of the sheltered-thermometer sites. Along with temperature, sensors are also used to measure the relative humidity or dew point. The dew point is the temperature at which the atmosphere would be saturated (100% relative humidity) if it were cooled. The relative humidity is the amount of water vapor in the atmosphere at a particular temperature compared to the amount the atmosphere can hold. Hygrometers are the devices used to measure relative humidity. Hygrometers should be located with thermometers so that the relative humidity is measured concurrently with the temperature. Most electronic devices contain both types of sensors in one housing. Figure 3-4 shows a radiation shield for a temperature sensor and relative humidity or dew point sensor.

The dew point is a key parameter for the formation of frost or ice. If the pavement temperature is below the dew point, moisture will condense on the pavement. If the

pavement temperature then falls below 32°F (0°C), that moisture will become ice. If the pavement temperature is below the dew point *and* the dew point is less than 32°F, frost will form on the pavement.

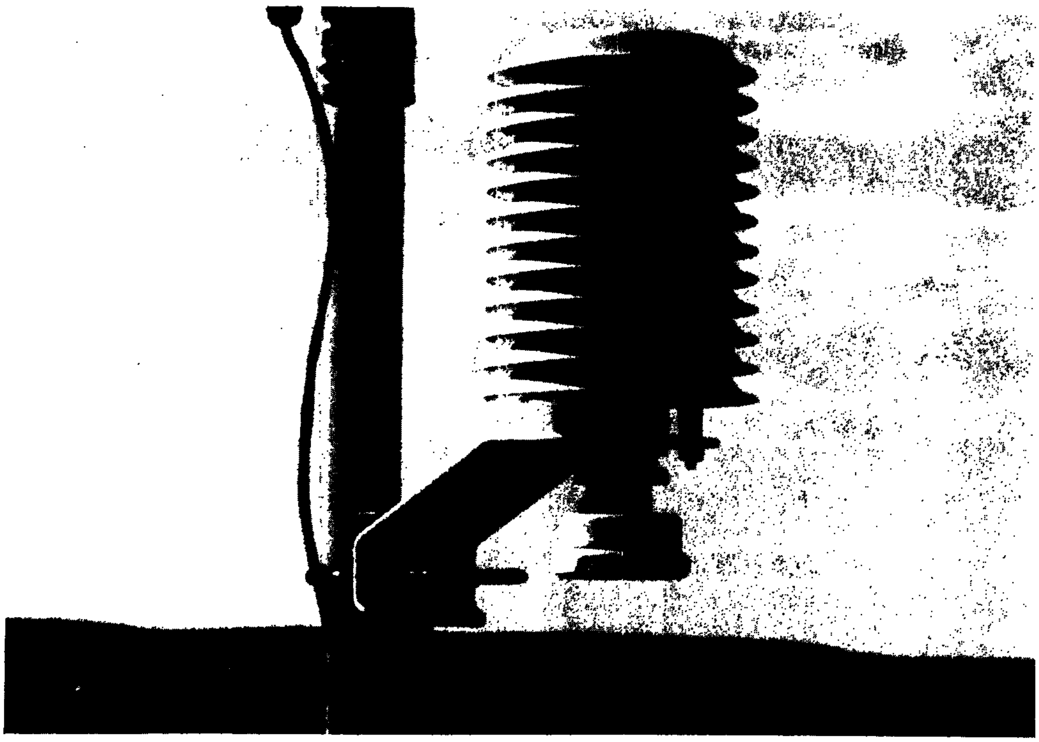


Figure 3-4. Radiation shield for a temperature sensor and a relative humidity or dew point sensor (Used with the permission of R. M. Young Company)

In the roadway environment, sensors for temperature and relative humidity should be located in accordance with the following standard instrument siting criteria:

- Instruments should be located as close as possible to 6 ft (1.8 m) above the surface, or 6 ft above the average maximum snow depth.

- Instruments should be placed over grassy areas, with a second choice of bare ground, rather than pavement.

- Temperature and relative humidity should *not* be measured from the top of light standards or sign bridges. The heights of these installations preclude determining representative meteorological values.

The combination of atmospheric moisture and surface temperatures pose complicated problems for understanding the formation of frost and ice. Even with air temperatures below freezing, ice will not form on or bond to pavement with surface temperatures above freezing. Conversely, with air temperatures above freezing, ice can form or bond to pavement with surface temperatures below freezing.

Precipitation

Different types of devices are used to measure precipitation. One type measures the occurrence of precipitation, which is the most important information for snow and ice control. A second type measures the amount of precipitation, and a third measures the rate of precipitation. Two or more functions are incorporated in new commercial designs (Figure 3-5).

The primary consideration for the siting of a precipitation measuring device is exposure. As is the case with wind, precipitation patterns are heavily influenced by obstructions. An instrument should be located in as open an area as possible. The anemometer siting criteria can be used to determine suitable locations. However, the tower itself can influence the flow through a detector and, hence, the determination of the occurrence of precipitation. Therefore, the detector should be installed as high as possible on the tower without obstructing the anemometer, and it should be located on the upwind side.

Figure 3-5. Example of a precipitation visibility detector (Used with the permission of Scientific Technology, Inc.)

Placing Roadway Surface Sensors

The other component of RWIS sensor suites is the pavement sensor. Figures 3-6 and 3-7 provide examples of pavement sensors. As is the case with meteorological sensors, correct pavement sensor siting is important for obtaining useful information. Maintenance engineers frequently disagree on precisely where pavement sensors should be placed in the roadway.

Several options exist which depend on the type of road surface, traffic volume, and the purpose of the sensor information.

The placement of sensors in the roadway should relate to the intended use of the data. As is the case with meteorological data, pavement sensor data are used for predicting, detecting, and monitoring pavement temperature. Also, pavement sensors provide pavement condition (e.g., wet, dry, icy) and chemical-factor data that may affect their placement.

Successful anticipatory strategies for snow and ice control require accurate forecasting of pavement temperature. The primary pavement sensor siting consideration should be the need to obtain accurate pavement temperatures to use in forecasting models and to monitor forecasts of pavement temperature. Pavement temperatures are important for near- and long-term pavement condition predictions.

Pavement sensors should be implanted in the pavement flush with the surface. This will help to ensure that liquid does not pond on the sensors. It will also prevent the sensor from being scrubbed off at a rate greater than the surrounding pavement. Care must be exercised when installing sensors in grooved pavement. The sensor should be flush with the top of the grooves, not the bottom. Care should also be taken to ensure that the slope of a road at any location is such that there is no drainage onto sensors from the shoulder or the median. Sensors should not be placed in the roadway on curves.

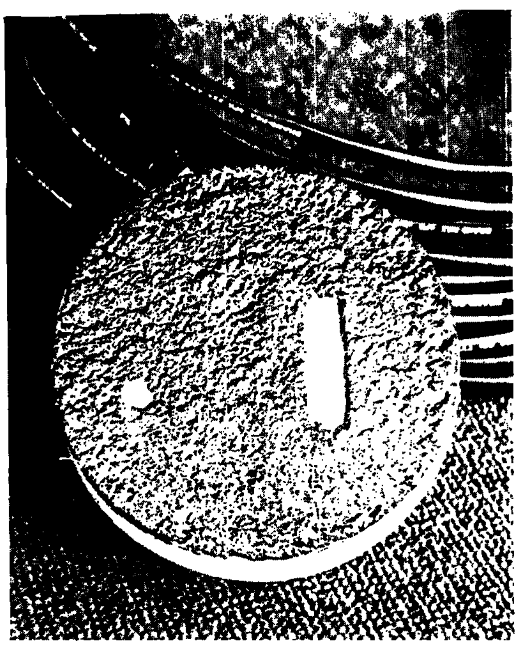


Figure 3-6. Pavement sensor (Used with the permission of Surface Systems, Inc.)

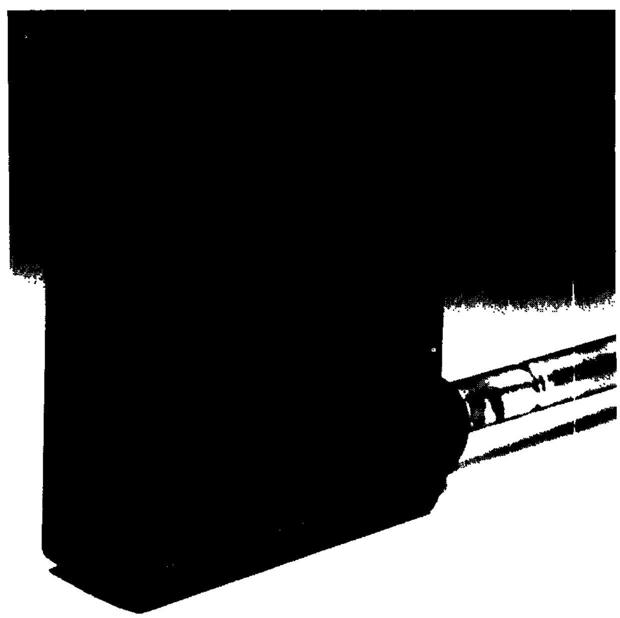


Figure 3-7. Pavement sensor (Used with the permission of Vaisala)

To assess where sensors should be placed in the roadway, hourly data from the Minnesota Department of Transportation's road research facility (Mn/ROAD) were used. The Mn/ROAD consists of approximately three miles (five kilometers) of Interstate Highway 94 west of Minneapolis near Monticello. There are four lanes of rural commuter highway, with an average daily traffic (ADT) of 25,000. The eastbound asphalt lanes carry inbound (toward Minneapolis-St. Paul) commuter traffic; the westbound portland cement concrete lanes carry outbound commuter traffic.

Two surface sensors are located in each lane, one in the center of the lane, the other in the outermost wheel track. Sensor locations in the roadway are shown in Figure 3-8. The sensor located in the westbound inside lane wheel track (#6 in Figure 3-8) was selected to be the reference against which the other sensors were compared. This sensor was selected because it is located in what was anticipated to be the coldest location. Research in Sweden had indicated that vehicles can affect pavement temperature, and that the greatest influence is in the center of a lane.* In addition, traffic volumes tend to be larger in the outside lanes, especially during inclement weather, as indicated by highway volume statistics from the Washington State Transportation Center.

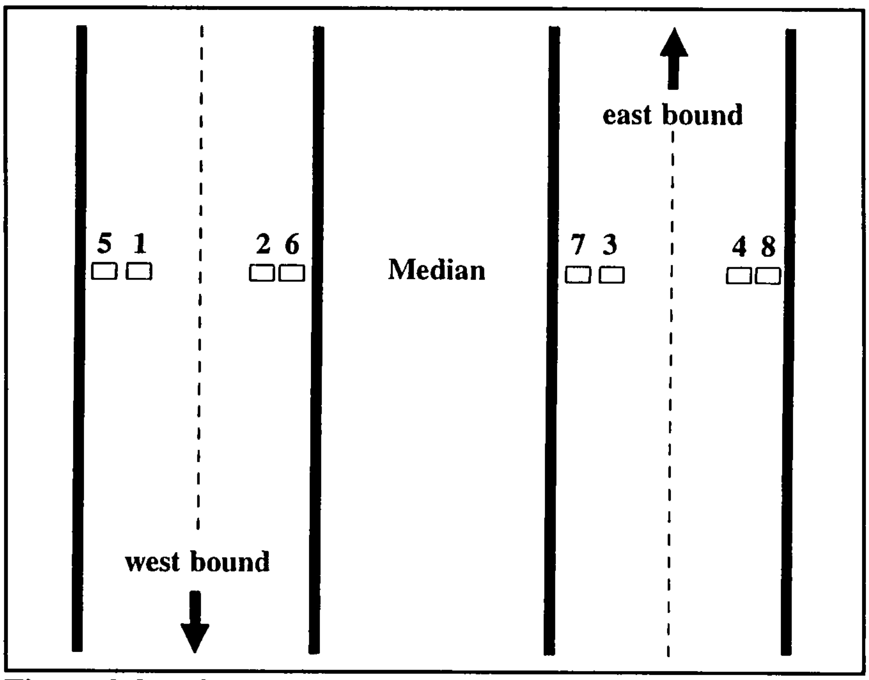


Figure 3-8. Sensor locations in the Mn/ROAD pavement

A large volume of data was obtained from the Minnesota Department of Transportation on computer diskettes. Three months of data were processed to analyze the temperature differences between the seven sensors and the reference. The statistics for January and February, 1991, are given in Table 3-1.

The statistics indicate that the temperature differences, when averaged over a long period of time, show little difference, except for sensor #8. Separate measurements with a radiometer and a contact probe at the site indicated that sensor #8 was consistently reporting temperatures too warm. However, there were other possibilities for temperature differences that would be masked when considering the long-

* Gustavsson, T. and J. Bogren. 1990. Infrared thermography in applied road climatological studies. Department of Physical Geography, Gothenburg. *GUNI Report 30*, 10-17.

term averages. Daily fluctuations in traffic and atmospheric phenomena, as well as changes due to pavement conditions (wet, dry, frozen) could also influence the sensor temperatures.

Table 3-1. Deviation of sensor pavement temperatures (°F) from reference sensor (#6), January-February 1991

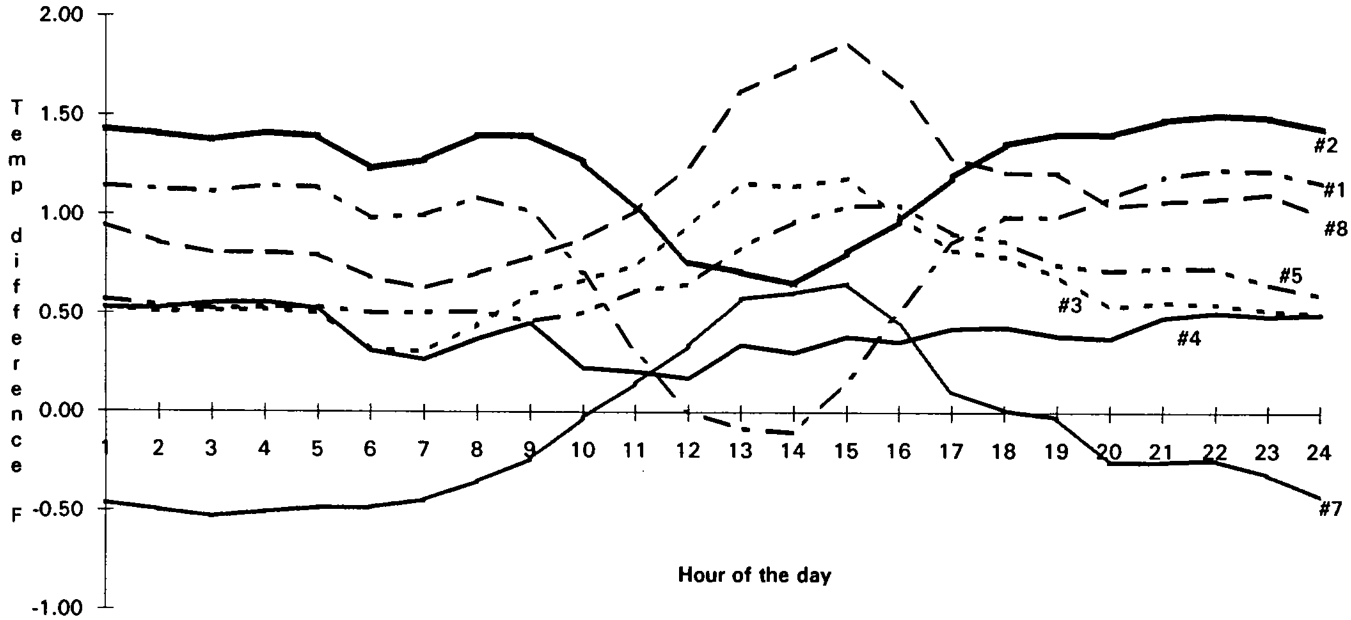
	Temperature (°F)						
Sensor # →	1	2	3	4	5	7	8
Mean difference	0.6	1.1	0.7	0.4	0.6	-0.1	1.2
Standard deviation	1.1	0.9	0.7	0.8	0.4	0.7	0.8
Maximum	4.3	5.3	3.7	3.0	2.0	3.8	4.8
Minimum	-5.1	-3.7	-1.0	-3.6	-3.4	-2.5	-1.2
Variance	1.2	0.7	0.5	0.7	0.2	0.5	0.7

First, the temperatures were compared by time of day to determine the extent of diurnal influences. Because of the large volume of data, observations were processed for three-hour periods from 5:00 a.m. to 9:00 p.m. These times were selected because 5:00 a.m. covers the cold period before any influence from traffic, 8:00 a.m. covers the morning commute inbound to Minneapolis-St. Paul, 3:00 p.m. picks up any solar influence, and 6:00 p.m. covers the evening commute. Data for two time periods are shown in Figures 3-9 and 3-10.

The data indicate that temperatures in the center of the lanes are warmer than in the wheel tracks, and that traffic volume influences the temperatures. However, it is the experience of most snow and ice control people that wheel tracks clear first. This is due to tire grinding, pressure, and friction, which overcome the tendency for the wheel tracks to be cooler. It should also be pointed out that these temperatures are measured without snow or ice cover.

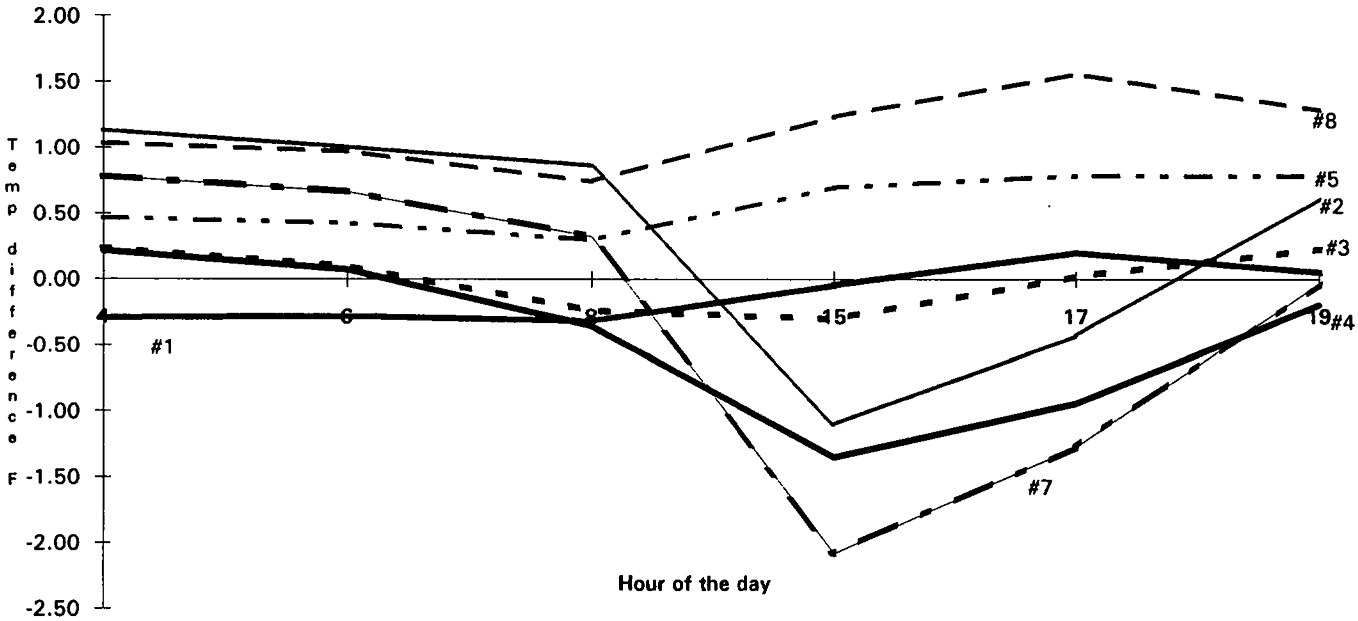
In order to relate temperature differences to traffic, volume data were requested from Mn/ROAD. Temperature differences resulting from traffic could not be obtained because only daily ADTs were available; no data were available by hour.

We also attempted to determine the influence of pavement surface conditions on the temperatures. Each sensor provided an output indicating whether it was wet or icy. Solar radiometer measurements were also available to indicate whether it was clear or cloudy. The pavement temperature observations were classified into wet, dry and cloudy, and dry and clear cases. However, it was found that in the middle of January, the sensor system stopped reporting the pavement condition properly. The vendor was contacted to see if the data could be corrected. No response was received by the end of the field test.



Based on average temperature differences between sensor #6 and other sensors during January 1991

Figure 3-9. Sensor temperature differences at Mn/ROAD facility, January 1991



Based on average temperature differences between sensor #6 and other sensors during the period 3/1/91-3/25/91

Figure 3-10. Sensor temperature differences at Mn/ROAD facility, March 1991

Placement within Lanes

Where sensors should be located within lanes is also a matter for discussion. Some engineers would prefer to place sensors in wheel tracks. However, wheel tracks tend to get cleaned out by tire friction, and may not be representative of the rest of a roadway. Heavy vehicles such as trucks can disturb the pavement surrounding a sensor.* Also, with wear on some road surfaces, water can pool and ice can form first in the wheel tracks. In other circumstances, particularly in large traffic volume areas, wheel tracks can dry out first.

The centers of lanes in urban environments can be affected by vehicle heat. Pavement temperatures can be as much as 1°C higher in lane centers. Since vehicle heat influences pavement temperature, placing sensors in the center of lanes is not recommended.

A third possible location for pavement sensors is between lanes. This area is probably the least disturbed, but it is also subject to increased concentrations of deicing chemicals and debris. In addition, sensors here could be accidentally covered with paint during striping operations.

Table 3-2 provides a matrix of options for sensor placement within lanes. Figure 3-11 depicts these locations graphically. Placing sensors for *prediction* of pavement temperature and for forecasts should be the primary criteria. When *detection* of current conditions is desired, installing an additional sensor at a location selected for prediction offers the opportunity to obtain both prediction and detection information.

Table 3-2. Suggested placements of pavement sensors in roadways

	Location of Pavement Sensors within Lanes			
	Urban (Commuter Route)		Rural (Non-commuter Route)	
Primary Use of Sensors	**Multilane Road**	**Two-lane Road**	**Multilane Road**	**Two-lane Road**
Prediction	Just outside of outside wheel track of outbound passing lane	Just outside of outside wheel track of outbound lane	Just outside of a wheel track of a passing lane	Just outside of a wheel track of either lane
Detection	Just inside of outside wheel track of inbound through lane	Just inside of outside wheel track of inbound lane	Just outside of a wheel track of a through lane	Just outside of a wheel track of either lane
Monitoring	Use prediction placement whenever possible			

* Personal communication from Bob Hart, Surface Systems, Inc. (SSI), 1991.

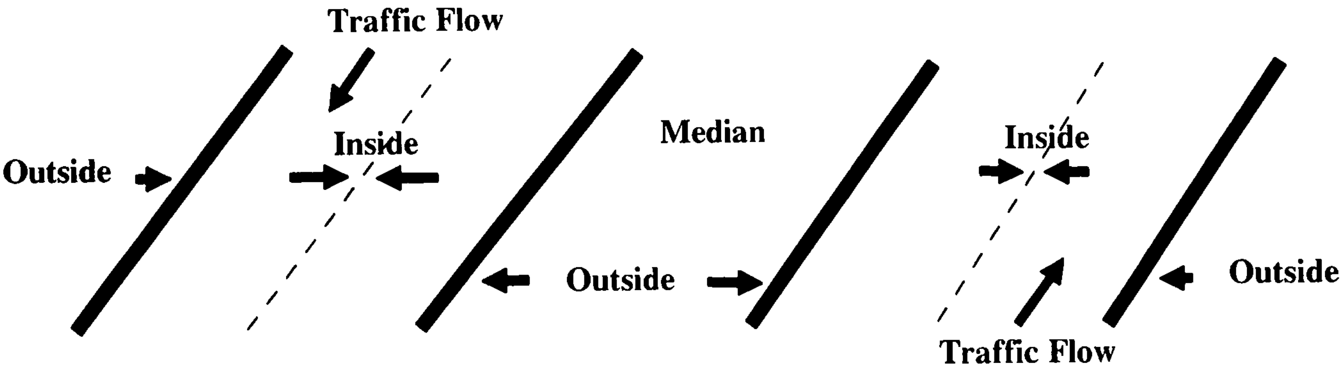


Figure 3-11. Lane orientation

Placement within Wheel Tracks

There is considerable discussion among highway engineers as to just where sensors should be placed in wheel tracks. Some prefer the center of tracks because that is where most of the vehicles run; others prefer just off-center to get out of the bottom of the track. In portland cement concrete surfaces, the precise location may not be as crucial as in asphalt because PCC pavements do not generally rut as deeply as asphalt surfaces. Whatever lane is chosen and for whatever purpose, it is suggested that pavement sensors be placed approximately 8-12 in (0.2-0.3 m) from a wheel track center. This will keep the sensor away from vehicle influences in the center of the lane, outside the possible pooling of materials in the wheel track bottom, yet close to where engineers want to know what is going on. Figure 3-12 provides a cross-sectional view of preferred sensor placement in a lane.

Care should also be taken to ensure proper placement in grooved pavement. The top of a sensor should be flush with the top of grooves so that groove runoff does not flow onto the sensor.

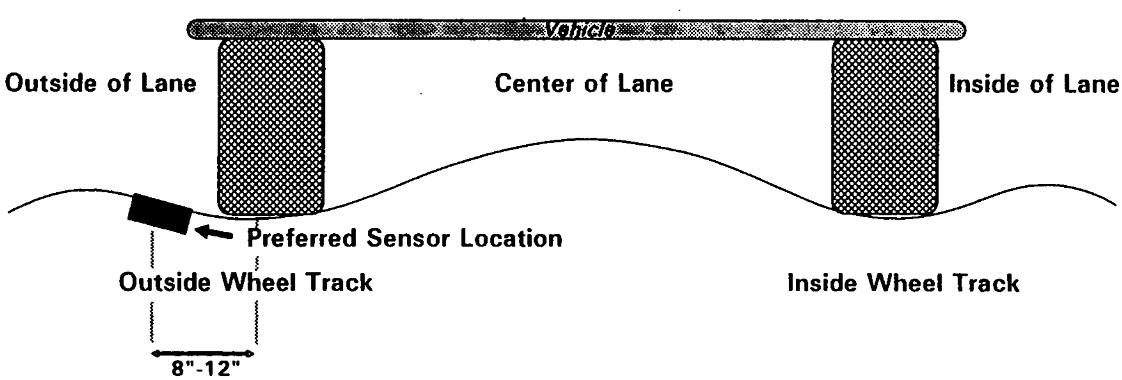


Figure 3-12. Sensor placement in a lane

Additional Siting Considerations

Numerous considerations for siting RPUs and sensors have been discussed above. Some additional siting considerations include terrain variation, weather patterns, crew knowledge, and statistical analysis. These and other considerations are discussed below.

Terrain variation. Local terrain variation provides the greatest challenge for snow and ice control. Higher terrain can increase precipitation, and the location of roads relative to terrain can determine whether they will be subject to rain or snow, ice or frost, blowing and drifting snow, cold air pockets, and sources of moisture. Depending on the road and the elevation change, a manager might wish to have RPUs and sensors at a high point, a low point, or somewhere in between.

Weather patterns. Analysis of the weather impacts in an area will usually reveal that most snow and ice control problems occur under certain weather patterns. RPU sites should include locations which assist in the identification and prediction of those patterns and the resulting road conditions. A sensor system should be installed on the west or southwest side of an urban area if that is the prevailing direction from which weather comes.

Crew knowledge of each of the above can significantly contribute to effective pavement sensor location.

Statistical analysis can be used to specify the mean pavement temperature. Statistical analysis indicates that a minimum of four sensor sites should be selected in an urban area or along a roadway at sites representative of the mean. Refer to Chapter 2 in Volume 1 of this report for a detailed discussion of statistical analysis.

Population density may suggest that more RPUs are needed in metropolitan areas because of the potential for greater impact on the highway users from weather. A similar argument would suggest, from a detection standpoint, that vehicle influences on pavement temperature could negate sensor usefulness for pavement temperature prediction in areas of high traffic density.

Road classification can be used in determining siting requirements. This can also be tied to the service level for snow and ice control.

Longitudinal spacing. Each of the siting considerations described above should be used to determine how close sensor sites are to be spaced along a highway. From a meteorological perspective, spacing of about 30 km fits projected computer forecasting model resolution. The 30 km spacing must be adjusted based on the locations of known trouble spots and the need to acquire information where gaps of data exist.

4

RWIS Implementation

This chapter describes a process that will lead to the successful implementation of an RWIS. Because agencies differ in their management structures and procedures, the process described is generic and flexible. Although the process is sequential, some of the tasks can be accomplished in parallel or nearly simultaneously.

Agencies implementing RWIS technologies should prepare a detailed plan for collecting and disseminating RWIS information. A weather advisor should be involved in the development of the plan. An RWIS master plan should, at a minimum:

- Identify locations where road weather observations should be taken;
- Establish priorities for installing observing systems;
- Include a detailed description of communication systems to be employed for data collection and dissemination, including raw data, forecasts, feedback, and communication with media, the public, and other agencies;
- Describe the pros and cons of RWIS communication system architectures, such as proprietary (closed) systems and nonproprietary (open) systems; and
- Identify potential future interfaces for RWIS data.

Analyze Variables

The first variable is the impact that weather has on current snow and ice control activities. This impact may be described in terms of areas within a state where snow and ice control problems exist, where there is a lack of familiarity with road or weather conditions, or locations that tend to be precursors of impending problems. The impact may be confined to locations where decision makers need more information: bridges with significant snow and ice problems, mountain passes or high elevation roads, or "trouble spots" where icing causes

problems. Most of these locations, either because of their weather or maintenance difficulties, can be described by the maintenance people who are out on the roads. Their knowledge is usually the best starting point.

A second variable is the type of maintenance activities conducted by an agency. For example, if deicing chemicals are used, pavement sensors may be more important than if only abrasives are used. Similarly, if anti-icing is practical, sensors and forecasts are key to determining when to make the applications.

Finally, the agency's policies must be considered. If bare pavement is the policy, weather and road sensor information and forecasts will help an agency reach its goals.

Describe Expectations

Management's expectations must be clear when acquiring RWIS technologies. Reducing costs of snow and ice control may be paramount. In many agencies, snow and ice control is the largest item in a highway maintenance budget. Reducing the cost of snow and ice control can free money for other maintenance activities.

Management may want to improve service. Using RWIS information for snow and ice control can improve the level of service to the traveling public. This improvement results from getting the right people and materials to the right place at the right time. Interviews with snow and ice control managers indicate that some administrators find service improvements more attractive than cost savings.

Management may also want to change its snow and ice control practices. They may want to reduce the amount of deicing chemicals, use different chemicals, or perhaps implement anti-icing. RWIS information will help with all of these objectives.

Undertake the Implementation Process

Based on the variables described above, and a clear understanding of management's expectations, an agency needs to define the actions required to implement an RWIS. A process for acquiring RWIS technologies is outlined in detail below. A checklist is presented in Appendix B.

I. Designate an office of primary responsibility (OPR). Someone should be in charge of the process: responsible for gathering information, planning, and implementing. Define the OPR's authority, define responsibilities, and define goals.

II. Design the system. Specify component locations, types, and quantities.

A. Consider using a weather advisor. A weather advisor can assist at the interface between meteorologists and highway managers.

B. Determine the needs and attitudes of other agencies in the same area. For instance, determine whether municipalities, counties, airport authorities, turnpike authorities, or state highway agencies will participate, cooperate, or help fund the project.

C. Survey users of existing RWISs or other systems that could help satisfy requirements that are in or near areas or roads of concern.

D. Analyze the agency's snow and ice control methods. Determine how RWIS data will assist with maintenance activities decisions.

E. Enumerate RWIS technologies to consider, e.g., sensors, tailored forecast support, and road thermal analysis.

F. Determine the structure for information flow from RWIS to decision makers. Determine whether the decision process will be centralized or decentralized, what kind of interaction will take place between levels of supervision, and what levels of supervision will directly use the information and advice.

G. Determine how the RWIS communications are to be established: using, e.g., statewide network, leased lines, microwave, radio links.

H. Conduct a preliminary siting analysis involving the weather advisor and snow and ice control supervisors.

I. Make decisions that will have implications in how an RFP is developed.

   1. Decide who will install equipment: agency staff or contractor. If the agency plans to perform the installation, determine whether there are workers on staff or in other agencies qualified to do this work. If only a few RWIS stations will be installed, it may be cost-effective to have the sensors and RPUs installed by a contractor. If more than a few will be installed, or additional systems will be acquired over a period of time, it may be more cost-effective to have a cadre of technicians trained to perform these installations.

   2. Decide who will maintain the system: agency personnel, other agency personnel, or contractor-provided maintenance. The rationale for installation also applies for maintenance. At a minimum, electronics technicians and signal technicians will be required.

3. Decide who will be trained and how. Training is critical for successful RWIS implementation. Determine whether installation and maintenance employees, decision makers, and/or information users will need to be trained, and to what level training will be required: shift supervisors, foremen, superintendents, maintenance engineers. Anyone involved in using RWIS information for decision purposes should probably be trained, although the level of training detail required will probably be greater for those who will be using computer terminals to acquire RWIS data.

4. Typical issues might concern personnel rules or labor agreements, their flexibility or need for change, changes in snow and ice control equipment, deicing chemical use changes, or changes in snow and ice control practices.

J. Define the management indicators to be used for deciding whether to expand or improve the system.

III. Begin the RWIS acquisition process.

A. Specify the lead procurement agency.

B. Determine the source(s) of funds.

C. Prepare an RFP. For a VAMS, it is desirable to get the best possible expert advice through an RFP for professional services. A request for bids usually forces low-cost bidder contracting. A consultant relationship is needed.

1. Determine whether the acquisition will be phased. It may begin with a small procurement, and expand as the budget allows.

2. Check the timing and lead-time requirements. For example, if a system is desired by the winter, do not wait until the fall to issue an RFP.

IV. Install the system based on the decision in II.I, above, for contract, vendor, or agency installation.

A. Take care of site preparation: details for concrete pads, power installation, and communications.

B. Make sure the timing and lead-time requirements for site preparation will be met.

V. Integrate the RWIS into snow and ice control operations.

A. With the weather advisor, develop and conduct training and prepare an orientation program for the VAMS that will provide the tailored forecast support.

B. Develop and implement a maintenance plan to ensure that the RWIS performs as required. Procedures must be developed and followed for routine maintenance, including hardware calibration. If maintenance or calibration are to be undertaken by a contractor or vendor, procedures for documenting this company's actions need to be agreed to contractually.

VI. Evaluate how well the system performs. Regular evaluations are needed in addition to continuous feedback on RWIS performance. Significant problems must be corrected immediately. The evaluation process should be agreed to within the agency and included in an RFP. The evaluation process should include deciding:

A. Who is going to perform evaluations: the user or an independent agency or consultant.

B. How frequently evaluation will be performed.

C. What components of the RWIS are to be evaluated (ideally, all components should receive some form of evaluation).

1. Whether the sensor system is performing as required by the RFP specifications.

2. Whether the communication system set up for the RWIS is functioning properly and information is being received accurately and on time by the right people.

3. Whether the workstation and computer systems are user-friendly and meeting the agency's needs.

4. Whether RWIS forecast and observation information has been useful.

a. Forecasts.

b. Sensor data, additional meteorological data, graphic displays, and data presentations.

5. Whether the road maintenance level of service and safety of the traveling public have increased or decreased.

D. How evaluations are to be conducted. This needs to be determined early so data gathering for evaluation can begin in time. Determine whether evaluations will be formal or informal. A combined formal and informal evaluation is recommended because of the need to quantify performance *and* deal with the institutional aspects of system implementation.

   1. A formal evaluation requires data gathering, logging, and comparison to known performance standards. Forecast evaluation requires computation of percentage of correct forecasts, skill scores, and Type I versus Type II errors, at a minimum. (A Type I error occurs when unforecasted weather occurs; a Type II error occurs when forecasted weather does not occur.

   2. Informal evaluation may involve interviews of users and managers to document perceptions of the utility of the system, such as how the system is or is not being used and deficiencies that exist.

E. What to use as evaluation criteria. A successful evaluation requires meaningful evaluation criteria. Thresholds of acceptable performance should be agreed to by the agency and the RWIS providers before the evaluation. This will establish a framework within which corrective action, if required, can take place. RWIS expansion or improvement decisions should also be based on evaluation of the system.

The process described above is not expected to be all-inclusive, but it should serve as a reminder that implementing an RWIS into the snow and ice control activities of an agency involves more than installing sensors, getting tailored weather forecasts, and setting up computers. The process is truly a management initiative that requires planning and training for the implementation to be effective. Where an RWIS is not already used, behavioral change will typically be required to optimize the results.

Contracting for Weather Services

There are two basic aspects to weather information: observations and forecasts. Once a manager decides to use RWIS technologies, hardware and forecasting services will most likely be needed. This section focuses on acquiring meteorological forecasting services by contract.

Contracting for Professional Services

Acquiring meteorological services is frequently treated like the purchase of goods by maintenance and purchasing agencies. This tends to lead to purchasing choices based solely on cost.

Value-added meteorological services (VAMS) should be treated and acquired as professional services, such as architectural and engineering services. The same general practices should be used when contracting for meteorological services, because the needed characteristics of accessible knowledge and experience, ability to understand the client situation and operational requirements, and willingness to serve all require subjective evaluation.

Technical Merit and Qualifications

The primary emphasis in acquiring the services of a VAMS should be on the ability of the VAMS to provide the required service. To evaluate VAMS, an agency should issue a request for proposals. The RFP should require each responding VAMS to state its understanding of the nature of advice needed, the qualifications of its staff, the numbers and types of customers who use its services, and references.

Low-Bid Problems

The tendency of agencies to contract for forecasting services on a low-bid basis sometimes causes problems for these agencies and their VAMS. Bidders may submit knowing that they will not be able to meet the requirements for services being sought. For instance, low-bid contracts sometimes result in a lack of tailoring of the forecasts and unavailability of the VAMS for synergistic evaluation of the situation.

Two actions can be taken to alleviate this problem. The first step is to develop clear and comprehensive technical specifications (i.e., scope of services to be provided). This will ensure that there is no misunderstanding by responders of the exact services that are to be provided. The second step is to acquire services on a professional services basis, which is selection based on technical merit rather than cost. This type of selection process entails: 1) evaluating responders on the basis of technical merit, 2) interviewing the responders receiving the highest scores, 3) selecting the top responder, and 4) negotiating a contract. These actions will help agencies to select qualified responders.

Consultant Relationship

The primary advantage of contracting for professional services is the ability to establish the requirement for a consultant relationship between an agency and a VAMS. The key to successful integration of weather information into the snow and ice control decision making process is good communication between the agency and VAMS. The meteorologist needs to

understand the terminology and needs of the agency. The snow and ice control manager needs to understand the VAMS' capabilities. A weather advisor, which can be the VAMS, is responsible for this function.

In establishing such a relationship, it is wise to think of the VAMS as an extension of the agency's staff. If a maintenance manager needs information, he or she uses information at hand or contacts someone on the maintenance staff. Similarly, the snow and ice control decision maker must decide how to address weather and road conditions occurring or predicted to occur. If more information or clarification is required, the decision maker should contact the VAMS. Also, the VAMS and the decision maker should meet frequently to debrief significant weather events, critique mistakes, and appraise successes to improve knowledge, capabilities, and products.

Even though communication does not need to be continuous, it always should be available. If actual weather conditions seem to be deviating from those forecast, either the VAMS needs to update the forecast, the agency needs to contact the VAMS to discuss the situation, or both. Important decisions related to initiating, extending, or curtailing snow and ice control activities require up-to-date information.

Considerations for Weather Service Contracting

Each agency should establish its own rules for obtaining forecasting services. Following are some topics which should be considered when developing an RFP. These topics are in addition to agency-developed criteria stating the numbers and types of forecasts required, areas to be covered, and normal or extraordinary operating considerations. Appendix D provides a sample RFP format for acquiring weather forecasting services.

Technical Qualifications

An agency needs to know that its VAMS has professional meteorologists on staff. A professional meteorologist is considered to have at least a bachelor degree in meteorology or atmospheric science. This does not mean that all of the forecasters must be degreed meteorologists. Many excellent forecasters come out of specialized training programs, such as that provided by military service. However, the professional staff should still contain a degreed meteorologist. The American Meteorological Society (AMS) recommends that at least one of the staff be a Certified Consulting Meteorologist (CCM). A CCM must meet certain requirements, and must pass an AMS test.

References

An RFP for professional forecasting services should request references from organizations using a VAMS' services. These references ideally will include highway agencies and the names and titles of specific individuals at those agencies who are familiar with the VAMS'

performance. An agency interested in acquiring VAMS services should contact several of these persons to corroborate the information received.

Experience

No training in meteorology can substitute for experience, whether the experience consists of forecasting for a specific area or specific types of customers. Experience should include analysis and forecasting for similar climates and operational thresholds as those of the organization issuing an RFP. A VAMS need not be in the same geographical area as the agency to provide high quality forecasting support. An agency acquiring VAMS services should ask references about the specific experience of the VAMS and its staff.

VAMS Staff Size

Forecasting services should be available twenty-four hours per day, seven days per week, during the contract period. If a forecaster is not on duty, the time to get one into work and the time required to establish an understanding of weather phenomena occurring can result in an agency reverting to reactive maintenance procedures. To maintain 24-hour-per-day services, and using 12-hour shifts as an example, three people would be required if the forecasters worked six days "on" and two days off. This does not allow for management and technical oversight. A VAMS should have at least four, preferably five, meteorologists on staff.

Method of Communicating Forecasts

As discussed above, the consultant relationship between a VAMS and an agency is critical to establishing anticipatory actions for snow and ice control. Decision makers need to have access to the forecaster and vice versa. Forecasts can be provided by a VAMS using computer or facsimile, but these forecasts should not be just a checkoff form, or a form where the decision maker is required to fill in blanks. Decision makers should not be left in the position of having to interpret forecasts. A tailored forecast should be provided to decision makers by the most efficient method, along with person-to-person communication to ensure mutual understanding between the decision makers and the VAMS. Too much can get lost in translation of forecasts, and information can be misinterpreted if it has to pass through other levels of management or supervision.

Appendix A

Acronyms and Abbreviations

ADT	Average Daily Traffic
ASOS	Automated Surface Observation System
BUFR	Binary Universal Format for Data Representation
CCM	Certified Consulting Meteorologist
CMA	Calcium Magnesium Acetate
CPU	Central Processing Unit
ECMWF	European Centre for Medium-Range Weather Forecasts
EISA	Extended Industry System Architecture
EPRI	Electric Power Research Institute
GOSIP	Government Open Systems Interconnect Profile
GRIB	Gridded Binary Data Format
GTS	Global Telecommunications System
MB	Megabyte
MHz	Megahertz
MOS	Model Output Statistics
MS-DOS	Microsoft-Disk Operating System

NEXRAD	Next Generation Weather Radar
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OPR	Office of Primary Responsibility
POSIX	Portable Operating System Interface for Computer Environments
RFP	Request for Proposals
RPU	Remote Processing Unit
RWIS	Road Weather Information System
SCSI	Small Computer System Interface
SI	System International (metric system of measurement)
VAMS	Value-added Meteorological Service
VGA	Video Graphics Array
WFO	Weather Forecast Offices
WMO	World Meteorological Organization

Appendix B

RWIS Implementation Checklist

The following checklist is designed to be a prompting device for use once a decision has been made to evaluate, acquire, and use RWIS technologies. This checklist is to be used by the person in charge of the RWIS development process.

1. **Obtain competent meteorological advice.** Appoint a qualified existing staff member, or if it is decided to hire a weather advisor:

   a. Prepare an RFP or job description for a meteorologist. ☐

   b. Advertise the position or RFP. ☐

   c. Rank proposals (Consultant Selection Committee). ☐

   d. Conduct interviews (Consultant Selection Committee). ☐

   e. Rank candidates. ☐

   f. Negotiate. ☐

   g. Hire. ☐

2. **Form an RWIS team.** Minimum membership should include:

   a. Weather Advisor ☐

   b. Maintenance Engineer ☐

   c. Maintenance Superintendent ☐

   d. Maintenance Foreman ☐

e. Communications Specialist ☐

f. Electronics Technician ☐

3. **Determine agency points of contact (not necessarily RWIS team members) for:**

a. Equipment and services evaluation. ☐

b. Site selection. ☐

c. Communications. ☐

d. Installation (and installer training, if appropriate). ☐

e. System operation and operator training. ☐

f. System maintenance and maintenance training, if appropriate. ☐

g. Weather/road condition forecasting. ☐

4. **Establish RWIS requirements.**

a. Specify geographical area(s) to cover. ☐

b. Review reasons for acquiring (prediction, detection, monitoring). ☐

c. Consider using road thermal analysis. ☐

d. Select and prioritize target RPU locations. ☐

5. **Design RWIS hardware and services based on requirements identified above.**

a. Determine the number of RPUs. ☐

b. Determine the types and number of sensors. ☐

c. Determine the number of CPUs. ☐

d. Determine the number of portable computers. ☐

6. **Design RWIS communications.**

a. Determine the feasibility of radio or telephone lines. ☐

b. Determine ownership of telephone lines (agency-owned or leased). ☐

c. Determine the location(s) for CPU(s). ☐

d. Identify the lowest decision level for direct data access (e.g., foreman with portable computer). ☐

e. Ascertain availability of microcomputers for data transfer. ☐

7. **Establish a budget for RWIS technologies.**

a. Estimate costs for the requirements identified above. ☐

b. Determine availability of funds. ☐

c. Divide the project into segments, if necessary, to match availability of funds over time. For example: ☐

1) Acquire forecasting services.

2) Conduct road thermography, if it was decided to do so.

3) Acquire sensor systems.

8. **Acquire Road Weather Information System.**

a. Set up and follow an acquisition schedule including specified dates by which to accomplish each of the following activities.

b. Prepare draft RFPs. Use Appendix C and/or D as a starting point. ☐

c. Gain RFP approval by contracting personnel. ☐

d. Release request(s) for proposals (hardware and services). ☐

e. Review proposals (RWIS team). ☐

f. Select vendors (Consultant Selection Committee). ☐

g. Negotiate contract(s), with weather advisor participation. ☐

9. **Hold RWIS team and vendor(s) meeting.**

a. Develop a plan with goals and objectives for implementation and installation. ☐

b. Establish time schedules for events. ☐

10. **Initiate training program(s).**

a. Manager training. ☐

b. Installer (e.g., signal technician) training. ☐

c. RWIS system and operator training. ☐

d. Equipment maintenance training (if appropriate). ☐

e. VAMS training in snow and ice control plan. ☐

f. System orientation/briefing for all snow/ice personnel and VAMS personnel. ☐

11. **Monitor implementation progress.**

a. Determine timeframe for progress reports (e.g., monthly). ☐

b. Determine recipients of program reports. ☐

c. Determine evaluation tools, criteria. ☐

d. Observe system implementation. ☐

12. **Commission a fully operational system.** ☐

13. **Monitor operations.**

a. Establish criteria for:

1) System performance. ☐

2) Forecast performance. ☐

3) Snow and ice control performance. ☐

4) Communications network performance. ☐

b. Devise data gathering process, procedures for above. ☐

c. Gather data for above. ☐

d. Conduct evaluations. ☐

e. Change operations to improve performance where needed. ☐

Appendix C

Sample Request for Proposals for Road Weather Information System Technologies

The following is a sample format for a Request for Proposals (RFP) for use by highway agencies desiring to install road weather information system hardware. The agency's consultant selection committee should review the proposals, interview the top two or three responders (based on technical merit), and negotiate a price with the top-ranked responder.

Some companies are listed below which are known to offer RWIS products and services.

Company	Products/Services
Climatronics 140 Wilbur Place, Bohemia, NY 11716 516/567-7300 516/567-7585 Fax	RWIS hardware, forecasting service, and road climatology/thermography (uses Bergab of Sweden)
Rust Environment & Infrastructure 1020 N. Broadway, Milwaukee, WI 53202 414/225-5100 414/225-5111 Fax	Road thermography
Surface Systems, Inc. (SSI) 10420 Baur Blvd, St. Louis, MO 63132-1905 1-800-325-7226 314/569-1002 314/569-3567 Fax	RWIS hardware and forecasting service
Vaisala, Inc. 100 Commerce Way, Woburn, MA 01801 617/933-4500 617/933-8029 Fax	RWIS hardware, forecasting service, and road thermography (bought Thermal Mapping International, Ltd.)

The sample RFP on the following pages is intended only as a guide since each agency will have its own rules and procedures. It is intended as a reminder of the important items which should be considered for inclusion in an RFP for RWIS components.

(Agency Name)

NOTICE TO VENDORS OF

ROAD WEATHER INFORMATION SYSTEM TECHNOLOGIES

SAMPLE REQUEST FOR PROPOSALS

ISSUED (*DATE*)

The (*Agency Name*) is soliciting proposals from vendors of road weather information systems (RWISs) and consultants with special expertise in providing RWIS technologies for use in support of (*Agency Name*) snow and ice control activities.

PROJECT DESCRIPTION

(Describe here the purpose of weather forecasts and road condition information for monitoring road and weather conditions, and as an input into forecasting for anticipatory decision making regarding when to deploy snow and ice control resources. A description of the types of snow and ice control practices employed by the Agency also should be included here. It should also be stated that research has indicated that RWIS technologies can provide accurate and tailored forecasts, which help to deploy snow and ice control resources in a more timely and efficient manner and, therefore, save money and improve the service level of roads and safety to the traveling public.)

(The area(s) requiring RWIS technologies should be described. For instance, if the Agency is divided into maintenance districts, the districts, subdistricts, or subareas to receive the technologies should be named. The anticipated number of sensor locations should be stated, but this number can be stated as negotiable depending on the outcome of consulting with the successful responder. If some RWIS technologies already exist, describe the Agency's intentions for interfacing any new and old technologies and how RWIS data are to be controlled or not controlled for distribution.)

TIME OF PERFORMANCE

Work under this agreement is anticipated to begin on *(a date suggested by contracting officials to ensure that installation of hardware will commence at least two months prior to the first occurrence of frost. Depending on the area, first frost could occur anywhere from October 1 to December 1)*. A one-month evaluation period will follow the winter season, with the provider(s) of the RWIS components participating in a detailed review of system performance.

BACKGROUND

Vendors submitting proposals for this project must thoroughly understand all components of road weather information systems, including sensors, processing units, road thermography (*if desired*), and communications. They must be able to demonstrate experience in the installation and successful operation of similar equipment.

REQUIREMENTS

___ copies of the Proposal are to be submitted to:

> *(Name)*
> *(Title)*
> *(Organization)*
> *(Address)*

Proposals will be received until *(date at least 30 days prior to the commencement of the services, or a date in advance as specified by contracting officers)*. All Proposals will be ranked and evaluated. It is anticipated that interviews will be held with finalists. Selection and ranking will be based on the proposers' experience and the quality of the Proposals.

SCOPE OF WORK

(This section is KEY to establishing a mutual understanding of what is required of the vendor. The following is a recommended minimum scope of work.)

1. Provide consulting to the (*Agency Name*) RWIS project manger *(as defined by the Agency)* to:

   a. Develop a mutually-agreed-to plan for establishing RWIS operations.

   b. Develop a communications plan for acquiring and disseminating RWIS data.

   c. Assist with site selection for RWIS sensors.

   d. *(If the Agency has decided that data sharing and interoperability are required, include a provision similar to the following.)* Provide the capability to interface with (*any*) existing RWIS within the (*Agency Name*) area of jurisdiction, or in neighboring jurisdictions.

2. Conduct road thermography *(if desired)*. *(Describe the routes and the number of miles for which the thermography is to be conducted.)*

3. Conduct hardware installation *or train agency staff to do so.*

4. Provide maintenance of hardware (*or train agency staff to do so).*

5. Provide training in data use by operators and data interpretation by managers.

6. Provide operations and maintenance manuals.

7. Provide system calibration (*or procedures for doing so*).

Responders may choose to submit proposals on all or portions of the Scope of Work. (*Agency Name*) reserves the right to negotiate all or portions of the above work with one or more responder.

PROPOSAL REQUIREMENTS

A. Technical Proposal Format

  1. Understanding of Project: Briefly describe the (*Agency Name*)'s considerations, objectives, and problems perceived by the firm.

  2. Statement of Qualifications: Include, at a minimum:

     a. Name of the lead firm (if more than one firm).

     b. General background experience of the proposing firm(s) and any subcontractor(s). Descriptions of other projects that provide insight to the firm's capabilities.

     c. Specific experience of firm(s) and any subcontractor(s) in winter weather information system installations. Descriptions of projects of a similar nature. References for each project.

     d. Names of project team member(s), client contact person(s), and telephone numbers. Description of each team member's related experience.

  3. Scope of Work: Provide a detailed description of how the firm views the tasks and subtasks to be performed. This description should include:

     a. A detailed description of a typical RWIS sensor site configuration, including the types of sensors and their uses;

     b. A description of remote and central data processing hardware requirements;

     c. Options for satisfying the requirement for data dissemination:

1) Protocols and data formats to be used in an open system, *if so required*, or

2) *If a proprietary system is to be used*, a detailed discussion of how the responder expects to meet the requirement for interfacing with other RWISs;

d. A statement that the vendor understands and acknowledges that the RWIS data will be in the public domain, *if so required*;

e. A list of any upgrade requirements of existing RWIS technologies to ensure interconnectivity between new and old equipment;

f. A list of equipment and labor requirements for:

1) site selection,

2) equipment installation,

3) road thermography (*if applicable*),

4) sensor calibration, and

5) operator and maintenance training.

B. Cost Proposal: A proposal detailing the costs of each task and subtask shall be prepared separately, sealed, and attached to the Technical Proposal *(Copy #1, if more than one is required)*. The Cost Proposal will not be used as a criterion in the technical evaluation process. The Cost Proposal will be opened after the selection of the best firm, prior to negotiations, or to choose between equally qualified responders. The cost proposal will serve as a basis for contract negotiations.

C. All pages of the proposals shall be numbered and indexed.

The selected firm or firms will be expected to execute a contract with the (*Agency Name*). The contract will be based on performing the services as proposed in the Scope of Work. Project control procedures, i.e., progress reports, cost reporting methods, and billing format must conform with (*Agency Name*) requirements.

Appendix D

Sample Request for Proposals for Weather Forecasting Services

The following is a sample format for a Request for Proposals (RFP) for use by highway agencies desiring to contract for weather forecasting services. A consultant selection committee should review the proposals, interview the top two or three responders (based on technical merit), and negotiate a price with the top-ranked responder.

The RFP should be published in accordance with agency guidelines, but at a minimum, it should be published in an appropriate local journal of trade or commerce. The RFP can also be mailed to meteorological services providers. A recent *Bulletin of the American Meteorological Society*, the National Council of Industrial Meteorologists, and the National Weather Association will provide the names and addresses of potential responders.

Excellent forecasting support need not come from the local area. However, forecasters must be familiar with the climatology, weather, terrain, and road systems of an area. In addition, continuing dialogue with highway maintenance personnel will foster improved understanding and is one of the major reasons for desiring a consultant arrangement with a forecasting service.

The sample RFP on the following pages is not intended to be used verbatim, because each agency will have its own rules and procedures for issuing RFPs. It is intended, however, to suggest the kinds of items which should be considered for inclusion in an RFP for tailored weather forecasting services.

(Agency Name)

NOTICE TO WEATHER FORECASTING SERVICES

<u>SAMPLE</u> REQUEST FOR PROPOSALS

ISSUED *(DATE)*

The (*Agency Name*) is soliciting proposals from vendors of weather forecasting services and consultants with special expertise in providing detailed forecasts of road and weather conditions in support of (*Agency Name*) snow and ice control activities.

PROJECT DESCRIPTION

(Describe here the purpose of tailored weather forecasts for anticipatory decision making for deploying snow and ice control resources. A description of the types of snow and ice control practices employed by the Agency should be included here. It should also be stated that research has indicated that weather and road condition forecasts help to ensure that resources are deployed in a more efficient and timely manner. As a result, these forecasts save money and improve the service level to the traveling public.

The area(s) requiring tailored forecast support should be described. For instance, if the Agency is divided into maintenance districts, the districts, subdistricts, or subareas to receive forecasts should be named.)

TIME OF PERFORMANCE

Work under this agreement is anticipated to begin on *(a date which coincides with the usually expected first occurrence of winter weather events or earlier. Depending on the area, this could be anywhere from October 1 to December 1)* and end on *(a date which coincides with at least the latest expected occurrence of winter weather events)*. A one-month evaluation effort will follow, with the provider of the forecasting services participating in a detailed review of RWIS performance.

BACKGROUND

Weather services submitting proposals for this project must thoroughly understand winter weather and winter forecasting, have demonstrated successful winter weather forecasting experience in support of highway snow and ice control activities, and be able to provide 24-hour-per-day forecasting and consultant services seven days per week.

REQUIREMENTS

___ copies of the Proposal are to be submitted to:

(Name)
(Title)
(Organization)
(Address)

Proposals will be received until *(date at least 30 days prior to the commencement of the services, or a date in advance as specified by contracting officers)*. All Proposals will be ranked and evaluated. It is anticipated that interviews will be held with finalists. Selection and ranking will be based on the proposers' experience and the quality of the Proposals.

SCOPE OF WORK

(This section is <u>KEY</u> to establishing a mutual understanding of what is required of the vendor. It is impossible to describe all the potential needs, but each highway agency should review its practices, establish critical weather or road condition thresholds, then specify those as the forecast needs with the appropriate lead time. Examples follow.)

A. Perform preforecasting tasks.

   1. Become thoroughly familiar with the:

      a. Climatology and geography of the area(s).

      b. Roads for which the (*Agency Name*) has responsibility for snow and ice control.

      c. Snow and ice control decision structure and practices of (*Agency Name*).

   2. Develop procedures to access specially-installed road weather information system sensors for use in atmospheric and road condition monitoring.

   3. Develop a communications plan for approval by the (*Agency Name*) for implementing the forecast services.

B. Provide weather and road condition forecasts. Forecasts are required by (*Agency Name*) for deciding when to commence or terminate snow and ice control activities. *(Examples of requirements follow. Actual forecasts to be provided will be negotiated with the successful proposer.)*

   1. Issue 24-hour forecasts at least twice daily, at 6:00 a.m. and 3:00 p.m. local time. Separate forecasts shall be provided for each area unless the expected

weather conditions apply to more than one area. In the event the weather varies within an area, the area forecast will reflect that variation. Forecasts shall include, at a minimum:

a. Four-hour lead time for the occurrence and the duration of two or more inches of snow on roads, freezing rain, heavy rain which may cause flooding, extreme cold temperatures, *(etc., as required by the Agency).*

b. Two-hour lead time for the occurrence of any accumulation of snow, ice, or frost on roads; snow not expected to accumulate; rain or rain showers; *(etc., as required by the Agency).*

c. Surface wind direction,
Surface wind speed,
Ambient air temperature,
Ambient relative humidity and dew point, and
Pavement surface temperature. *(This capability may need to be obtained from a different vendor that possesses a pavement temperature forecast model.)*

Forecasts will be amended whenever the criteria in 1.a and 1.b, above, are missed, including the lead time.

2. Issue 72-hour forecasts at 3:00 p.m. local time which include the occurrence of snow or ice, the expected duration of these conditions, and the potential for requiring snow and ice control, minimum and maximum temperatures expected each day, *(etc., as required by the Agency).*

3. Issue five-day outlooks highlighting the potential for snow or ice, prolonged periods of inclement weather, *(etc., as required by the Agency).*

C. Provide monthly forecast verification statistics, including the occurrence of and timing of the onset and duration of winter events, minimum and maximum ambient temperature forecasts, and minimum and maximum pavement temperature forecasts *(if required).*

D. Participate in, and prepare a report on, a review of the winter forecast support at the end of the winter season. The purposes of this review are to document ways to improve the winter weather forecasting support, to promote dialogue between the provider and user of the forecasting services, and ultimately, to improve snow and ice control decision assistance.

PROPOSAL REQUIREMENTS

A. Technical Proposal Format

1. Understanding of Project: Briefly describe the (*Agency Name*)'s considerations, objectives, and problems perceived by the firm.

2. Statement of Qualifications: Include, at a minimum:

    a. Name of the lead firm (if more than one firm).

    b. General background experience of the proposed firm(s) and any subcontractor(s). Descriptions of other projects that provide insight to the firm's capabilities to provide detailed, tailored weather support.

    c. Specific experience of firm(s) and any subcontractor(s) in winter weather and road condition forecasting. Descriptions of projects of a similar nature. References for each project.

    d. Names of the Chief Meteorologist, and a resume of his/her experience in winter weather and road condition forecasting.

    e. Experience of the team of meteorologists proposed on the project. Information for each should include, at a minimum:

        1) Educational background.

        2) Experience in weather forecasting, and tailoring forecasts to small areas and operational requirements.

        3) Experience in winter weather and road condition forecasting.

        4) References of past employers or clients. Include names and telephone numbers.

3. Scope of Work: Provide a detailed description of how the firm views the tasks and subtasks to be performed.

B. Cost Proposal: A proposal detailing the costs of each task and subtask shall be prepared separately, sealed, and attached to the Technical Proposal *(Copy #1, if more than one is required)*. The Cost Proposal will not be used as criterion in the technical evaluation process. The Cost Proposal will be opened after the selection of the best firm, prior to negotiations, or to choose between two or more equally qualified responders. The cost proposal will serve as a basis for contract negotiations.

C. All pages of the proposals shall be numbered and indexed.

The selected firm will be expected to execute a contract with the (*Agency Name*). The contract will be based on performing the services as proposed in the Scope of Work. Project control procedures, i.e., progress reports, cost reporting methods, and billing format must conform with (*Agency Name*) requirements.