FINAL REPORT

EVALUATION OF THE AVAILABILITY AND ACCURACY OF THE VIRGINIA DEPARTMENT OF TRANSPORTATION'S ROAD WEATHER INFORMATION SYSTEM

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ABSTRACT

The Virginia Department of Transportation (VDOT) has road weather information system (RWIS) stations at 40 locations throughout the state. Each station consists of equipment to measure and record meteorological data, and from one to five sensors to measure certain pavement and subsurface conditions. Until recently, VDOT had two contracts in place to: (1) maintain and repair the RWIS station equipment; and (2) provide twice-daily 24-hour weather forecasts. These contracts have expired, and VDOT is now preparing to readvertise them. The purpose of this study is to assess the quality of those services, and to identify, where possible, performance measures that should be included in future contracts.

The study concludes that maintenance service contracts that do not include performance measures with enforceable penalties result in inadequate maintenance and unreliable data. While this study does not recommend specific performance measures or penalties, examples from other states' contracts are included. The accuracy of surface temperature and precipitation forecasts at two stations is reviewed. The results indicate that although they do not guarantee forecast accuracy, accurate and available surface sensor data are necessary to provide reliable surface temperature forecasts. The study recommends that contracts for weather forecasts include the requirement that VDOT be notified prior to important precipitation events. Examples of suggested events and notification lead times from other states' contracts are included in the study.

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INTRODUCTION

Over the past five years, the Virginia Department of Transportation (VDOT) has placed road weather information system (RWIS) stations at 40 locations throughout the state. These stations were installed to assist VDOT in managing its roadway snow removal and ice control program. Each station consists of equipment to measure and record meteorological data, and from one to five sensors to measure certain pavement and subsurface conditions. VDOT purchased all 40 RWIS stations from Surface Systems, Inc. (SSI). In addition, VDOT hired SSI to (1) maintain and repair the RWIS station equipment, and (2) provide twice-daily 24-hour forecasts of certain weather information. The forecast requirement covers only the 6-month period from October 15 to April 15, when weather conditions that produce snow and ice are most probable.

VDOT plans to readvertise the contract for maintenance and repair of the RWIS equipment and weather forecasting service. Concern has been expressed that the current contract does not provide VDOT with accurate forecasts or real-time information concerning conditions at specific sites. While real-time information is perceived to be unavailable or is found to be inaccurate, no study of the extent of these problems has been performed. VDOT is considering how best to structure a RWIS station maintenance request for proposal. It is also considering options for local weather forecasts. Knowledge of the current state of VDOT's RWIS, as well as how other transportation agencies' deal with the issues of maintenance and forecast accuracy, would be of value.

PURPOSE AND SCOPE

This study consists of two parts. The first part investigates the availability and accuracy of information transmitted by VDOT's RWIS stations. It reviews the performance of the system, discusses the effects of this performance and develops recommendations for future achievement measures and requirements. Recommendations for service maintenance requirements are also developed. The second part assesses the accuracy of forecasts generated for the RWIS stations.

This part of the study reviews the performance of the current system and develops recommendations for performance measures and requirements.

METHODS

Literature Search

The researchers searched the TRANSPORT database, via Silver Platter, for all relevant studies completed or started since 1988. TRANSPORT contains references to over 530,000 documents, including those in the Transportation Research Information Service (TRIS) database of the Transportation Research Board (TRB). The researchers looked for studies of RWIS data accuracy and availability, and forecast accuracy. Key words for the search were "RWIS" and "road weather forecasts." The researchers also queried the World Wide Web, using the Yahoo, Alta Vista, InfoSeek, Excite, Webcrawler and Lycos search engines. The key word for this query was "RWIS." The team also searched the Gopher directories by word title, and the Gopher space via SCS Nevada and PSI Net. The key word used was "RWIS." No matches were found.

Survey

The research team surveyed the departments of transportation in 46 states and the Canadian provinces to determine which states and provinces have RWIS stations, and how they deal with the information generated. The questionnaire focused on requirements for minimum sensor availability, data accuracy, and forecast accuracy. It also asked how these were measured. Those agencies with performance measures and methods for monitoring them were requested to forward that information. The researchers also requested any studies used to set these requirements. The survey also asked for similar information for forecast accuracy. Finally, the survey requested information on how each state uses the historical RWIS data. Appendix A contains a copy of the survey form.

The researchers contacted individuals outside state and province organizations on the Winter Maintenance Mailing List who deal with RWIS (via the Internet at snow-ice@list.uiowa.edu). The inquiry contained questions similar to those in the survey sent to the states and provinces.

The researchers also contacted the RWIS coordinator in each VDOT district to determine the procedure for managing RWIS performance problems. They asked coordinators to describe their formal management procedures and how they record the nature and number of any problems experienced.

Observations Concerning VDOT RWIS Sites

Station Availability

Real-time data for each of the 40 RWIS stations is recorded at one of seven central processing units (CPU). The researchers accessed these CPUs to determine the availability of real-time data for all 40 stations for the period October 1, 1996, to April 1, 1997. The researchers reviewed the percent of time data from each station was available. If data from any surface or atmospheric sensor were transmitted, the station was considered to be available. Additionally, the research team determined the median percent of time, the mean percent of time and the standard deviation of the time that data were available throughout the state.

Data Availability and Data Accuracy

Managers use their RWIS station data to monitor real-time local weather conditions. High priority among the conditions monitored is air and pavement temperature, precipitation (yes/no), and surface condition (wet/dry, and relative amount of de-icing chemical present). The station sensors also monitor relative humidity, dew point, wind speed and direction, and subsurface temperature.

VDOT receives a 24-hour weather forecast for 32 RWIS station locations at least twice daily between October 15 and April 15 each year. Along with data from other sources, the SSI forecaster uses current station data to develop the weather forecast.[1] This forecast includes estimates for pavement temperature at 20-minute intervals as well as estimates of when precipitation will begin.

It is not the purpose of this study to determine the absolute accuracy of the data produced by the stations. Rather, it is concerned with the availability of sensor information, the frequency of obvious discrepancies in that information, and their effect on the forecasts. An obvious discrepancy is defined as a change or spike in the sensor data that is inconsistent with conditions or data from a similar sensor.

The researchers analyzed the atmospheric information and the data from one pavement or bridge surface sensor at ten stations. They compared the air temperature and surface sensor temperature to look for obvious discrepancies. They also looked for discrepancies between the surface condition and the precipitation sensor data. Finally, the researchers recorded and reviewed the number of instances in which obvious discrepancies existed for either set of sensors between October 1, 1996, and April 1, 1997, at each station.

Forecast Accuracy

In order to determine the accuracy of the forecasts to the recorded data, the researchers compared the forecast and actual RWIS station remote processing unit (RPU) data readings for the period from October 1, 1996, to April 1, 1997. The two stations are located at the following

points on I-64: mile post 124 (at the Rivanna River) in Albemarle County (Culpeper Station 3); and mile post 100 (at the top of Afton Mountain) in Augusta County (Staunton Station 2). These two locations were chosen because they were the only locations where a large quantity of historic forecast data already existed. The team analyzed the actual and forecast data for each site in two ways:

1. Under the SSI contract, the forecasts were due at 3 A.M. and at noon every day during the study period. These were used as the zero hour for each comparison, depending on forecast time. The researchers reviewed the forecast and actual temperature readings for two, four, six, and eight hours after the zero hour of the forecast and determined the mean temperature difference and the standard deviation for all the data points and for the data points at the two-hour intervals.

2. Field managers need to know the time at which freezing pavement temperatures and precipitation first occur in order to schedule resources to combat a storm. The researchers identified the times when forecast and actual data met this criterion, and determined the difference in time between the forecast and actual time precipitation started.

RESULTS

Literature Search

The researchers' inquiry of the TRANSPORT database using the keyword "RWIS" produced 18 references, of which eight are final reports or presentations at technical meetings involving weather information systems. None of these documents covers in detail the issues of availability or obvious inaccuracy of RWIS information that are the focus of this study. Some cover the issues of system maintenance and requirements for road weather forecast performance. The most comprehensive report is the Strategic Highway Research Program (SHRP) report on RWIS.[2]

The SHRP report recommends that RWIS contracts include preventive and recurring maintenance requirements. At a minimum, RWIS maintenance programs should require annual calibration of the meteorological and pavement sensors. As regards road weather forecasting, the SHRP Report provides a sample RFP to guide states contracting for weather forecasting services. The sample RFP includes a number of performance criteria that can be monitored. Among them are:

- specific times for forecasts
- lead times for the occurrence of certain events (such as the start of freezing rain)
- conditions that require amended forecasts
- monthly forecast verification statistics.

The sample RFP also recommends an annual meeting between the contracting agency and the forecasting contractor.

An inquiry of the TRANSPORT database using the keyword "road weather forecasts" cited three references. None of these contained any additional information concerning forecast performance measures not already covered by the SHRP report.

A search of the World Wide Web on the Internet using six different search engines and the key word RWIS produced a total of 223 locations, many of which were repeats. None of the locations contained detailed information concerning data availability or accuracy, service performance, or forecast accuracy.

Survey

The researchers sent a survey form (presented in Appendix A) to the maintenance engineer, or equivalent, in 46 states and six Canadian provinces. Thirty states and three provinces responded. For ease of review and presentation of the findings, this section is divided into two subsections: system maintenance and forecast accuracy. Each subsection begins with a description of how VDOT addresses the issue, followed by the findings from the survey. The state and province responses to the questions are provided in tabular form in Appendix B.

System Maintenance

VDOT entered into a SCAN™ System service agreement (standard agreement) with SSI in 1993. The standard agreement covered "certain sensing equipment, computer equipment, computer software and other equipment manufactured or provided by SSI, including the SCAN™ System" (referred to in the standard agreement as "Equipment"). The scope of the standard agreement states:

> Subject to the conditions contained herein, SSI hereby agrees to provide replacement of equipment and/or on-site maintenance and repair of the Equipment to return the Equipment to normal operating order . . . .

Under the agreement, VDOT was responsible for identifying defects in the equipment and for notifying SSI of a need for service. SSI had to "attempt to access the Equipment by phone . . . once per week to verify proper operation of the Equipment as can be determined by such access." SSI was also responsible for "an annual preventive maintenance [check] on the Equipment that requires preventive maintenance." The agreement contained no additional details concerning either of these items.

The standard agreement also contained sections concerning response to calls for service and delayed performance. As regards response time, SSI was to "make a best effort attempt to return the Equipment to normal operating order within five (5) working days" after a request. Should performance be delayed, the agreement called for prompt notification:

> If performance by either party of any of its obligations under this agreement is delayed due to any cause beyond its reasonable control, such delay shall be excused if the party whose performance is so delayed promptly notifies the other party of the cause of such delay and uses its best efforts to remove or to avoid the cause of such delay and to resume its performance of its obligations hereunder as soon as possible after the cause of the delay has been removed.

No additional language concerning performance of the system and no penalty or consequence for failure to comply were included in the agreement. The original contract covered 36 RPUs and 6 CPUs for one year through December 1996. The cost was $55,760.

Of the 13 agencies that indicated that they use contracts to maintain their RWIS stations, four have contracts that set requirements for the availability and accuracy of RWIS Station real-time information. All four states provided copies of their RWIS maintenance requirements.

Ohio has an RFP pending for maintenance of its RWIS system. The contract will make the contractor responsible for monitoring the system and reporting malfunctions to the state. The agreement will set a maximum of 96 hours for correction by the contractor and a penalty of $3,000 per day for noncompliance. The RFP outlines a requirement for calibration of the system in general terms. Specific service functions and preventive maintenance are left to prospective bidders to present with their bid. No additional system performance standards are included in the RFP.

New Hampshire's DOT also has an RFP pending for RWIS maintenance. The contract makes the contractor responsible for monitoring the system and for reporting malfunctions to the State. The agreement will set a maximum response time by the contractor of 48 hours from November through April and 72 hours from May through October for "maintenance support for failed components which impact the operational capability of the system." A penalty of $120 per day is to be assessed for noncompliance. The RFP sets four major reporting requirements on a twice-yearly schedule. These requirements include (1) the average sensor in-commission rate; (2) the average overall system in-commission rate; (3) the average maintenance response time; and (4) a post-winter conference to discuss system performance. The RFP sets neither performance standards nor penalties for non-compliance with the requirements for these four items.

The Illinois DOT has a contract in place for services with SSI that include "providing on-going maintenance of a component, real-time roadway weather information system which will sense, automatically collect, transmit and provide reports of atmospheric and highway pavement conditions." Under the contract, SSI is responsible for monitoring data from all sites and advising Illinois DOT of any malfunctions. The monitoring requirement is once per day for sites that generate weather forecasts and once per week for non-forecast sites. SSI is required to respond to malfunctions within 24 hours for CPUs and within 48 hours for RPUs and their components. There is a penalty of $100 per day for non-compliance. A weekly report on the status and details of repairs is also required.

Although this is a full service contract, SSI must report all costs incurred for each service performed to the Illinois DOT. This allows the Illinois DOT to keep track of actual costs and to evaluate the value of their maintenance contract. The contract requires an annual on-site maintenance check and preventive maintenance of the CPUs, RPUs, and components. Included is calibration of each atmospheric and pavement sensor. A schedule of services and a listing of conditions for providing maintenance are included in the contract. The contract allows the Illinois DOT to terminate the contract within a 3-week period if it is dissatisfied with the contractor's performance. Unsatisfactory performance is not defined in the contract, although the 21-day process requires the state to notify the contractor of any remedial action necessary to achieve satisfactory performance. As of July 1997, Illinois was paying $352 per month per station and $502 per month per CPU for these services. The contract covers 2 CPUs and 15 RPUs. At these unit costs, the cost per year is $75,408.

The Wisconsin DOT (WISDOT) has a contract for services with SSI to "provide replacement of equipment and/or on-site maintenance and repair of the equipment to return [it] to normal operating order . . . ." This wording is exactly the same as that contained in the standard agreement between VDOT and SSI. SSI is responsible for monitoring all equipment by phone and advising WISDOT of any malfunctions. The monitoring requirement is twice per week year round. The contract requires a weekly report of malfunctions to WISDOT and a monthly report of repairs completed. SSI is required to respond to malfunctions within 48 hours between November and March and within one week between April and October. A penalty of $100 per day is assessed if performance is delayed. The penalty section outlines valid exceptions to the response time requirements.

The WISDOT contract requires an annual on-site maintenance check and preventive maintenance of the CPUs, RPUs, and components, including a calibration of each atmospheric and pavement sensor. The contract establishes a schedule of services and lists the conditions for providing maintenance. An annual meeting is required to review the condition of the system. WISDOT paid $52,148 for this service over a 9-month period beginning in October 1995. This price covered 29 RPUs and 7 CPUs. This price did not cover the cost for twice-weekly phone monitoring of the equipment; this requirement was added as a work order at a later date. Since the inception of the contract, WISDOT has twice reduced its payments to SSI for non-compliance.

Forecast Accuracy

In 1996, VDOT contracted with SSI for its SCAN*CAST Roadway Pavement Condition Forecasting Service at 32 RWIS locations throughout Virginia. SCAN*CAST components included forecasts of pavement temperature, precipitation, and pavement condition, snow accumulation, wind speed and direction, wind/heat index and forecaster's discussion. The contract called for a site-specific twice-daily 24-hour forecast. The contract had no performance measures or requirements for the accuracy or timeliness of the information included in the forecast. The fee for this service was $9,600 per month.

Fifteen agencies contract for weather forecasts for their RWIS station locations. Only New Hampshire indicated that it requires a level of accuracy for the forecasts. Wisconsin also sets "performance requirements" that set notification requirements, but WISDOT does not stipulate a level of forecast accuracy. Both agencies forwarded copies of their weather forecast service requirements.

New Hampshire has an RFP pending for weather forecasting services. The weather forecast information to be supplied is similar to that outlined in the Virginia contract. It calls for a twice-daily forecast for the next 24-hour period, with the forecaster's discussion to give the outlook to 72 hours. Updates are required within 30 minutes of occurrence whenever any of the following occur and were not previously forecast:

- snowfall equal or greater than a trace
- freezing rain or drizzle
- winds greater than 15 miles per hour
- pavement temperature rising above or falling below 0°C.

In addition, a 2-hour advance warning and revised forecast are required when the following is anticipated:

- snowfall greater than a trace
- freezing rain with expected accumulation
- road/bridge frost conditions.

New Hampshire's RFP outlines certain reports to be submitted by the contractor twice each winter season:

- *Average timing error for the forecast start and stop time for snow greater than or equal to one inch, or freezing precipitation*. An average timing error exceeding one hour is grounds to terminate the contract at the end of the first year.
- *Average advance warning time for forecasts of snow greater than one inch, freezing precipitation, and pavement temperature going above or below 0℃ during storm events*. An average advance warning time less than two hours is ground to terminate the contract at the end of the first year.
- *Forecast verification rates for snowfall greater than or equal to one inch or freezing precipitation*. A forecast hit is defined as an event that is forecast and did occur within the forecast range. A forecast miss is defined as a forecasted event that did not occur,

or an event that occurred and was not forecast. A level of forecast hits less than 80 percent is grounds to terminate the contract at the end of the first year.

WISDOT has an agreement with SSI for weather forecasting services. The weather forecast information to be supplied is similar to that outlined in the Virginia contract. It calls for a twice-daily 24-hour forecast, with the forecaster's discussion to give the outlook to 72 hours. Requirements for updates of forecasts are similar to those required by New Hampshire. However, lead-time for snows exceeding four inches or freezing rain is four hours instead of two hours. Statistics for lead-time, timing error and percent accuracy are tracked by WISDOT. Minimum performance levels are not specified in the agreement but are determined by WISDOT prior to each winter season. The contract cost for the SCAN*CAST and forecast for 51 locations is $6,250 per month.

Other Contacts

The inquiry to the Winter Maintenance Bulletin Board resulted in four responses. The respondents reiterated that a formal program to maintain the RWIS stations, RPUs, and CPUs is needed. Such programs should include calibration of the sensors and an annual preventive maintenance program. Concerning road weather forecasts, they recommended use of a local meteorologist in combination with a national forecasting firm. The local meteorologist can monitor and verify the system forecast and usually has a better understanding of local conditions than a national forecaster. He or she can also act as a contact for operations people should they have questions about the forecast.

The researchers contacted the RWIS coordinators in three VDOT districts to determine the procedure for monitoring problems and reporting them to the maintenance contractor. All indicated that no standing operating procedures for monitoring existed. As system users discover problems, they report them to SSI by telephone. No formal records were kept, and no written confirmation of the report is sent to or received by the company. All three indicated that few reports of problems were made during the past year, since alternate sources of information and forecasts were available.

Observations at RWIS Sites

Station Availability

Historic data for the period October 1, 1996, to April 1, 1997, could be retrieved for only 31 of the 40 RWIS stations. A summary of the percentage of time that these 31 stations had at least one sensor operational is presented in Table 1. Table 2 provides the median, mean, and standard deviation of station sensor availability for the 31 RWIS stations from which historical data could be obtained.

Table 1. Summary of RWIS Station Data Availability

Data Availability (%)	Number of Stations	Percentage of Stations	Cumulative Percentage of Stations
Less than 10	1	3.22	3.22
Between 10 and 50	3	9.68	12.90
Between 50 and 75	3	9.68	22.58
Between 75 and 90	5	16.13	38.71
Between 90 and 95	5	16.13	54.84
Between 95 and 99	5	16.13	70.97
Between 99 and 99.99	4	12.90	83.87
100.00	5	16.13	100.00
Total	31	100.00	100.00

Table 2. Summary Statistics of RWIS Station Data Availability (%)

Median	93.66
Mean	82.76
Standard deviation	24.31

Data Availability and Data Accuracy

The researchers reviewed the historic weather data from 10 of the 31 available RWIS stations. They reviewed the air temperature and precipitation sensors at each site, along with one surface sensor that provided both the surface temperature and surface condition data. Culpeper District's Station 3, sensor 12, and Staunton District's Station 2, sensor 5 were selected as forecast data for these stations were available. Culpeper District's Station 2, Northern Virginia District's Station 8 and Salem District's Station 6 were randomly selected. The team selected the other five stations (all in the Northern Virginia District) because they were the stations that had Station availability of 100 percent from Table 1. Table 3 presents the percentage of time that a specific sensor was available and that there were no obvious discrepancies in the data from the sensors at each Station.

Table 3: Percentage of Time Data are Available with No Obvious Discrepancies in Data Accuracy

Station	Air temperature (%)	Surface temperature (%)	Precipitation (%)	Surface condition (%)
Culpeper 2	100	100	100	100
Culpeper 3	93.74	100	3.55*	87.22
NOVA 8	100	100	100	100
Salem 6	0*	100	0*	0*
Staunton 2	100	100	100	100
NOVA 2	100	100	100	100
NOVA 5	100	100	100	100
NOVA 7	100	100	34.04*	100
NOVA 9	100	0*	100	0*
NOVA 10	100	99.95	10.00*	13.84*

* The sensor was not producing and/or transmitting data for the rest of the time.

Of the ten stations reviewed, five stations had a combined total of nine sensors that were not producing and/or transmitting data at least 50 percent of the time. Additionally, the data from at least three other sensors at these stations showed obvious discrepancies in the data for part of the study period. There were no sensor malfunctions or obvious discrepancies at the other five stations reviewed.

Forecast Accuracy

Forecast data were available for only two stations. SSI uses professional forecasters to predict air temperature and precipitation at 32 of VDOT's 40 RWIS stations. The forecast for pavement temperature is based upon an algorithm proprietary to SSI. The algorithm does not use historic information from the site to develop the forecast. The current RWIS station's sensor readings for air, pavement and subsurface temperature, and relative humidity are used as a starting point for the forecast. The algorithm then incorporates forecast information from other sources to forecast the pavement temperature.[1]

Because the accuracy of pavement temperature forecasts is important in planning future operations by field managers, the researchers reviewed the accuracy of the forecasts for surface temperature. In particular, the researchers compared the 3 A.M. forecast for surface temperatures at 5 A.M., 7 A.M., 9 A.M. and 11 A.M. to the actual RWIS station surface temperature sensor readings at these times.

The researchers performed paired-samples t-tests to determine if the mean forecast surface temperature was statistically equivalent to the mean actual surface temperature at Staunton District's Station 2, sensor 5 and at Culpeper District's Station 3, sensor 12. The t-tests excluded cases where data were not available for either the forecast and actual surface temperatures. The paired-samples t-tests resulted in a mean difference between the actual and forecasted surface temperature at Culpeper District's Station 3, sensor 12 of 2.78°C, with a standard deviation of 3.45°C. The mean difference between the actual and forecasted surface

temperature at Staunton District's Station 2, sensor 5 was 0.49°C, with a standard deviation of 2.39°C.

The researchers performed additional paired-samples t-tests for Culpeper District's Station 3, sensor 12 and Staunton District's Station 2, sensor 5 to determine the accuracy of the forecasts over different periods of time. In particular, a separate paired-samples t-test was performed on the accuracy of the 3 A. M. forecast for actual surface temperatures at 5 A.M., at 7 A.M., at 9A.M. and at 11A.M. for each of the two sensors. Tables 4a and 4b present the results of these paired-samples t-tests.

Table 4a. Paired-Samples t-tests at Culpeper District's Station 3, Sensor 12

Difference Tested: Actual – Forecast	Paired Differences				t-test Value	Degrees of Freedom	Significance
	Mean	Standard Deviation	95% Confidence Interval of Difference Lower	Upper			
2-hour forecast	1.36°C	2.16°C	0.85°C	1.87°C	5.323	70	0.000
4-hour forecast	2.23°C	2.64°C	1.59°C	2.87°C	6.953	67	0.000
6-hour forecast	3.83°C	3.47°C	2.94°C	4.71°C	8.696	61	0.000
8-hour forecast	4.37°C	4.85°C	2.93°C	5.81°C	6.116	45	0.000

Table 4b. Paired-samples s-tests at Staunton District's Station 2, Sensor 5

Difference Tested: Actual – Forecast	Paired Differences				t-test Value	Degrees of Freedom	Significance
	Mean	Standard Deviation	95% Confidence Interval of the Difference Lower	Upper			
2-hour forecast	-0.16°C	1.47°C	-0.53°C	0.20°C	-0.893	64	0.375
4-hour forecast	-0.11°C	1.83°C	-0.55°C	0.33°C	-0.511	68	0.611
6-hour forecast	0.92°C	2.33°C	0.34°C	1.49°C	3.202	65	0.002
8-hour forecast	1.44°C	3.33°C	0.57°C	2.32°C	3.303	57	0.002

In general, the results of the t-tests presented in Tables 4a and 4b indicate that the forecast surface temperature tends to become less accurate as the length of the forecast period increases. The forecast surface temperature does not appear to be an accurate estimator of the actual surface temperature during any time block at Culpeper District's Station 3. The paired-samples t-tests indicate that there is less than a 0.1 percent chance that an unbiased forecast would generate a

pattern of paired differences centered as far off zero as the pattern actually observed at Culpeper District's Station 3. Therefore, it is reasonable to assume that the surface temperature forecasts at this site are biased—they consistently fail to accurately estimate the actual surface temperature.

The paired-samples t-tests presented in Table 4b indicate that the 6-hour and 8-hour surface temperature forecasts at Staunton District's Station 2 appear to be biased as well. There is a high probability that the 2-hour and 4-hour surface temperature forecasts (37.5 percent chance and 61.1 percent chance, respectively) provide unbiased estimates of the actual surface temperatures.

The researchers compared forecast data to actual data for the occurrence of precipitation when the surface temperature was at or below 0°C at Culpeper District's Station 3 and at Staunton District's Station 2. Forecasts for the two stations were reviewed to determine when the joint condition of precipitation and freezing (or below freezing) temperatures were predicted to occur. Additionally, the researchers reviewed RWIS historical weather information to determine when the joint condition of precipitation and freezing (or below freezing) temperatures actually occurred. The forecasts and historical data were then jointly analyzed to determine the accuracy of the forecasts.

The researchers had also planned to perform statistical analyses to determine the confidence interval on the time difference between the forecasted and actual joint event of precipitation and freezing temperature at each of the two stations. However, because few of the forecasts were saved and because of RWIS communications failures, there were insufficient data to perform detailed statistical analyses.

The review of the available data for Culpeper District's Station 3 and Staunton District's Station 2 resulted in a total of 170 data points for which both forecast and actual data were available. For the purposes of the analysis performed, an event was defined as being the joint occurrence of precipitation and freezing air temperature. The 170 data points are summarized in Table 5.

Table 5. Summary of Forecasted and Actual Weather Events

	An Event was Forecast	No Event was Forecast
An Event Occurred	8	8
No Event Occurred	3	151

The data presented in Table 5 indicate the following:

- 73% (8 out of 11) of the SSI-predicted events actually occurred

- 5% (8 out of 159) of the time SSI correctly predicted that no event would occur
- 50% (8 out of 16) of the events that actually occurred were correctly predicted to occur by SSI
- 2% (3 out of 154) of the time that no event occurred, SSI predicted that an event would occur.

DISCUSSION

A review of the data from 31 stations indicates that the information generated can be available and consistent close to 100 percent of the time. However, almost 40 percent of the stations were able to transmit data less than 90 percent of the time during the winter season (over 20 percent of the stations were able to transmit data less than 75 percent of the time). Further, even when an RWIS Station was available to transmit data, not all of the sensors were necessarily functioning, nor were all the sensors necessarily providing accurate information. For example, even though all ten of the RWIS stations reviewed for sensor availability had a station availability of more than 67 percent, five had at least one sensor (air temperature, pavement temperature, precipitation or surface condition) that was not functional for at least 65 percent of the time. Some sensors were not functional for the whole six-month period.

Several sources indicate that routine maintenance and monitoring of the system hardware and data stream are necessary if data is to be available and accurate close to 100 percent of the time. Maintenance of the system and enforcement of performance standards can be expensive, as can be seen in the contract maintenance cost information for Illinois, Wisconsin, and Virginia (presented in Table 6).

Table 6. Contract RWIS Maintenance Cost Comparison

State Agency	RWIS System	Cost/Year
Virginia	36 RPUs 6 CPUs	$55,760
Illinois	15 RPUs 2 CPUs	$75,408
Wisconsin	29 RPUs 7 CPUs	$69,530

Performance monitoring requires outputs that can be measured. There have not been any studies undertaken within the United States or Canada to determine the level attainable for either system performance (accuracy and availability) or forecast accuracy. The SHRP study[2] of RWIS recommends a number of criteria for performance-based maintenance contracts, and some states,

most notably Illinois and Wisconsin, have practical experience establishing performance standards and obtaining, monitoring and administering contracts.

Although the researchers were able to review the accuracy of forecasts at only two stations, the review and statistical analyses indicate that the 6- and 8-hour surface temperature forecasts were unacceptable and of little, if any, use to VDOT's personnel at the two locations studied. Additionally, both the 2-hour and 4-hour surface temperature forecasts at the Culpeper Station were also of little value.

The review of the precipitation forecasts when the temperature is at or below freezing at the same two locations determined that 27 percent of the SSI-predicted events did not occur and that 50 percent of the events that occurred were not predicted by SSI. These percentages are very significant. If VDOT relied on and acted upon the SSI forecasts, VDOT would incorrectly mobilize hired equipment 27 percent of the time and, more importantly, VDOT would not be prepared for 50 percent of the weather events that occurred.

CONCLUSIONS

1. Based upon the review of station availability and the review of individual sensor availability and obvious discrepancies in sensor data, VDOT's former RWIS maintenance contract did not result in adequate maintenance of the RWIS.

2. On any RWIS maintenance contract, it is feasible to require that the contractor be responsible for monitoring the availability and consistency of RWIS data.

3. To improve system availability and accuracy of sensor data, a RWIS maintenance contract should contain defined maintenance requirements, performance levels, penalties for non-compliance and standing operating procedures.

4. The accuracy of the SSI forecast for surface temperatures deteriorates as the length of the forecast interval increases.

5. Surface temperature forecasts cannot be expected to be accurate when information used to generate the forecasts is frequently unavailable or erroneous. However, although having available and accurate information is necessary to make accurate forecasts, it may not necessarily be sufficient—other factors affect the accuracy of the forecasts.

RECOMMENDATIONS

1. Future VDOT RWIS maintenance contracts should contain quantifiable performance measures and enforceable penalties for non-conformance to the contract. As a minimum, such maintenance contracts should:

- make the contractor responsible for detecting malfunctions
- outline procedures for reporting malfunctions and the progress of the repairs
- set maximum response times for repair-work to begin
- require calibration of each site once per year
- require specific preventive maintenance activities to be completed.

2. Contingent on the implementation of Recommendation 1, VDOT should repair the existing RWIS stations.

3. Future VDOT contracts for forecast services should contain quantifiable performance measures and enforceable penalties for non-compliance. As a minimum, these contracts should specify:

- specific times for forecasts
- lead times for the notification of the occurrence of certain events
- conditions that require amended forecasts
- monthly forecast verification statistics.

4. In order to determine whether accurate pavement temperature forecasts are obtainable, VDOT should pilot-test different pavement temperature forecast services at several RWIS stations throughout the state.

ACKNOWLEDGMENTS

The departments of transportation (DOTs) in the states of Ohio, New Hampshire, Illinois, and Wisconsin have invested considerable time and energy developing contracts for RWIS maintenance and weather forecasts. Many people associated with these DOTs supplied copies of contract documents or proposals and their results. While too numerous to list by name, the authors thank all who were of assistance. The collection of recorded data from the CPUs, and the preparation of that data for review required many hours. The authors thank Amy Weddington for her willing cooperation and attention to detail in accomplishing this task. We also thank W. T. McKeel, Jr., J. S. Gillespie, W. H. Bushman, and Morteza Salehi for their review of the draft report, and Margaret Edwards for editing the final document.

REFERENCES

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2. National Academy of Sciences. 1993. *Road Weather Information Systems Volume 1: Research Report*, SHRP-H-350, and *Volume 2: Implementation Guide*, SHRP-H-351. Washington D.C.

APPENDIX A

SURVEY OF RWIS AVAILABILITY AND ACCURACY

Please complete and return this survey to D. S. Roosevelt at Virginia Transportation Research Council, 530 Edgemont Road, Charlottesville, VA 22906. Please return by June 6, 1997.

State/Province Organization: _____

Contact Person: _____ Phone: _____

For this survey, RWIS stations are defined as weather stations located at roadway sites that generate information that includes surface temperature and for which a site-specific weather forecast is produced.

1. Does your organization have RWIS stations? ___ Yes ___ No How many? ___

2. Does your organization have an agreement with a private firm to maintain the RWIS stations?
   ___ Yes ___ No If yes, what is the name of the firm? _____

3a. Does the maintenance agreement set requirements for availability of access to and accuracy of the RWIS Station real-time information?
   ___ No. (Go to Question 4)
   ___ Yes, copy of agreement attached.
   ___ Yes, contact for more information. _____
   Phone # _____

3b. If yes, are these requirements based on a study?
   ___ No.
   ___ Yes, copy of study attached.
   ___ Yes, contact for more information _____
   Phone # _____

4. Does your organization have an agreement with a private firm to provide weather forecasts the RWIS stations? ___ Yes ___ No. If yes, what is the name of the firm?_____

5a. Does the weather forecast agreement set requirements for accuracy of any elements of the forecast?
   ___ No.
   ___ Yes, copy of agreement attached.
   ___ Yes, contact for more information. _____
   Phone # _____

5b. If yes, are these requirements based on a study?
   ___ No.
   ___ Yes, copy of study attached.
   ___ Yes, contact for more information: _____
   Phone # _____

PLEASE ANSWER THE QUESTIONS ON THE BACK OF THE SURVEY

6a. Does your organization's RWIS system save the real time information in historical files?

___ Yes
___ No

6b. If yes, what use is made of the historical information by your organization or others? (Check those that apply.)

___ Forecasting
___ Contract Administration.
___ Other (Please specify) _____
_____
_____
_____
_____

APPENDIX B

RWIS Availability and Accuracy - Survey Results

State/Province	RWIS Stations	Maintained By Contract	Contract Requires Accuracy	Based on Study	Contract Forecast Service	Contract Requires Accuracy	Based on Study
Alabama	0	No	No	No	No	No	No
Arkansas	0	No	No	No	No	No	No
California	35	Yes	No	No	Yes	No	No
Connecticut	4	No	No	No	No	No	No
Idaho	11	Yes	No	No	Yes	No	No
Illinois	51	Yes	Yes	No	Yes	No	No
Indiana	8	Yes	No	No	No	No	No
Kansas	41	No	No	No	Yes	No	No
Kentucky	3	No	No	No	Yes	No	No
Maine	0	No	No	No	No	No	No
Maryland	27	Yes	No	No	No	No	No
Massachusetts	9	Yes	No	No	Yes	No	No
Mississippi	0	No	No	No	No	No	No
Montana	58	Yes	No	No	Yes	No	No
Nebraska	5	No	No	No	No	No	No
Nevada	?	No	No	No	Yes	No	No
New Hampshire	RFP	Yes	Yes	No	Yes	Yes	No
New Jersey	27	No	No	No	No	No	No
New Mexico	0	No	No	No	No	No	No
New York	40	Yes	No	No	Yes	No	Yes
North Carolina	0	No	No	No	No	No	No
North Dakota	15	No	No	No	No	No	No
Ohio	?	Yes	Yes	No	Yes	No	No
Utah	7	No	No	No	Yes	No	No
Vermont	0	No	No	No	No	No	No
Virginia	40	Yes	No	No	Yes	No	No
Washington	25	No	No	No	No	No	No
West Virginia	0	No	No	No	No	No	No
Wisconsin	51	Yes	Yes	No	Yes	No	No
Wyoming	27	Yes	No	No	Yes	No	No
New Brunswick	?	No	No	No	No	No	No
Newfoundland	0	No	No	No	No	No	No
Ontario	?	No	No	No	No	No	No