EVALUATION OF ICE WARNING SYSTEMS

FINAL REPORT

Research and Development Division
Oklahoma Department of Transportation

EVALUATION OF ICE WARNING SYSTEMS

by

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16. ABSTRACT

Two ice warning systems were installed on the Interstate highway system in the Oklahoma City area. A Boschung Company, Inc. Ice Early Warning System was installed on three elevated structures or bridges. A Surface Systems Inc. SCAN System was installed on one of the structures.

The systems were evaluated for two winter seasons. The primary objective of the evaluation was to determine the data accuracy and reliability and the durability of the equipment in the operational environment. The Boschung system was used by a field maintenance division to augment their weather surveillance methods and as an aid to gain knowledge on icing conditions.

The relatively few icing events which occurred during the evaluation period limited the amount of data available for analysis and equipment evaluation. The basic sensor responses to weather and surface conditions appeared to be accurate and reliable. The logic derived early warning alarms or surface condition status alerts were not as easy to interpret or verify due to the lack of repeatable weather conditions.

The systems demonstrated the potential to be of value as a decision support tool. Further operational experience and evaluation by the maintenance supervisors responsible for deicing operations would be beneficial in order to better assess the feasibility of future system expansion.

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INTRODUCTION

The increasing dependence of the public on highway transportation has increased the maintenance measures required during the winter season for the timely removal of snow and ice from roadway and bridge surfaces. The weather surveillance methods presently used to determine when to dispatch maintenance crews and equipment rely for the most part on weather forecasts from various sources and on posted watches or road patrols. In the highly variable weather conditions experienced in Oklahoma, it is difficult to determine when and where icing conditions may occur. This is especially true of unexpected "black ice" conditions on elevated structures.

Considerable non-productive overtime can be expended in watching and waiting for events to happen. Also a tendency may be to take a conservative approach in preventative measures and treat the bridges more often than necessary. The total approach can be expensive in labor, equipment, and materials.

To augment the weather surveillance methods and to determine site specific icing conditions, the Oklahoma Department of Transportation (ODOT) installed a new generation of ice detection and early warning equipment in the Oklahoma City area. It was evaluated as to its effectiveness and benefits as a maintenance management tool for use by field maintenance divisions.

OBJECTIVES

The primary objective of the project was to evaluate an ice detection and early warning system. The evaluation was to determine:

1. The accuracy and reliability of the sensors used to detect bridge deck surface and atmospheric conditions,
2. The accuracy and reliability of the early warnings or alarm levels and,
3. The durability of the equipment in the operating environment.

An additional objective was to gain knowledge on complex weather conditions which can lead to icing conditions on roadways and bridges.

A long range goal towards which this project was aimed was the feasibility and practicality of implementing a statewide grid of equipment which would aid all the field maintenance divisions in their snow and ice removal activities. Secondary objectives, or areas of interest, looked into on the project directed towards this goal were:

1. To see if storms could be tracked using the three instrumented structures in a county sized area,
2. To determine from this installation if one instrumented bridge would define the general icing conditions over the area,

3. To determine from the data from each structure the optimum number of sensor locations which would be required to determine general or overall deck icing conditions, and

4. To check into the feasibility of using the Department's mainframe computer in lieu of the PC's to reduce costs and duplication of equipment. This computer link would also make the information more widely available between the field Maintenance Divisions.

Elevated Structure Locations

For the project, three elevated structures, or bridges, in the Oklahoma City area (Figure 1) were selected for installation of the ice detection equipment. The selections were made based on several factors including traffic volume together with their strategic location in the highway system. Also an attempt was made to locate the sensors in quadrants to help provide storm tracking capabilities across the city area.

One structure was the bridge across the North Canadian River on I-40 at the western edge of the county. Only one sensor station was located on the deck because of its short length. This structure is located near a steam powered electrical generating plant which has contributed to icing problems in the area due to condensation and freezing of vented stream.

Another structure selected was the elevated section of I-40 through the downtown city area, referred to as the "Crosstown".

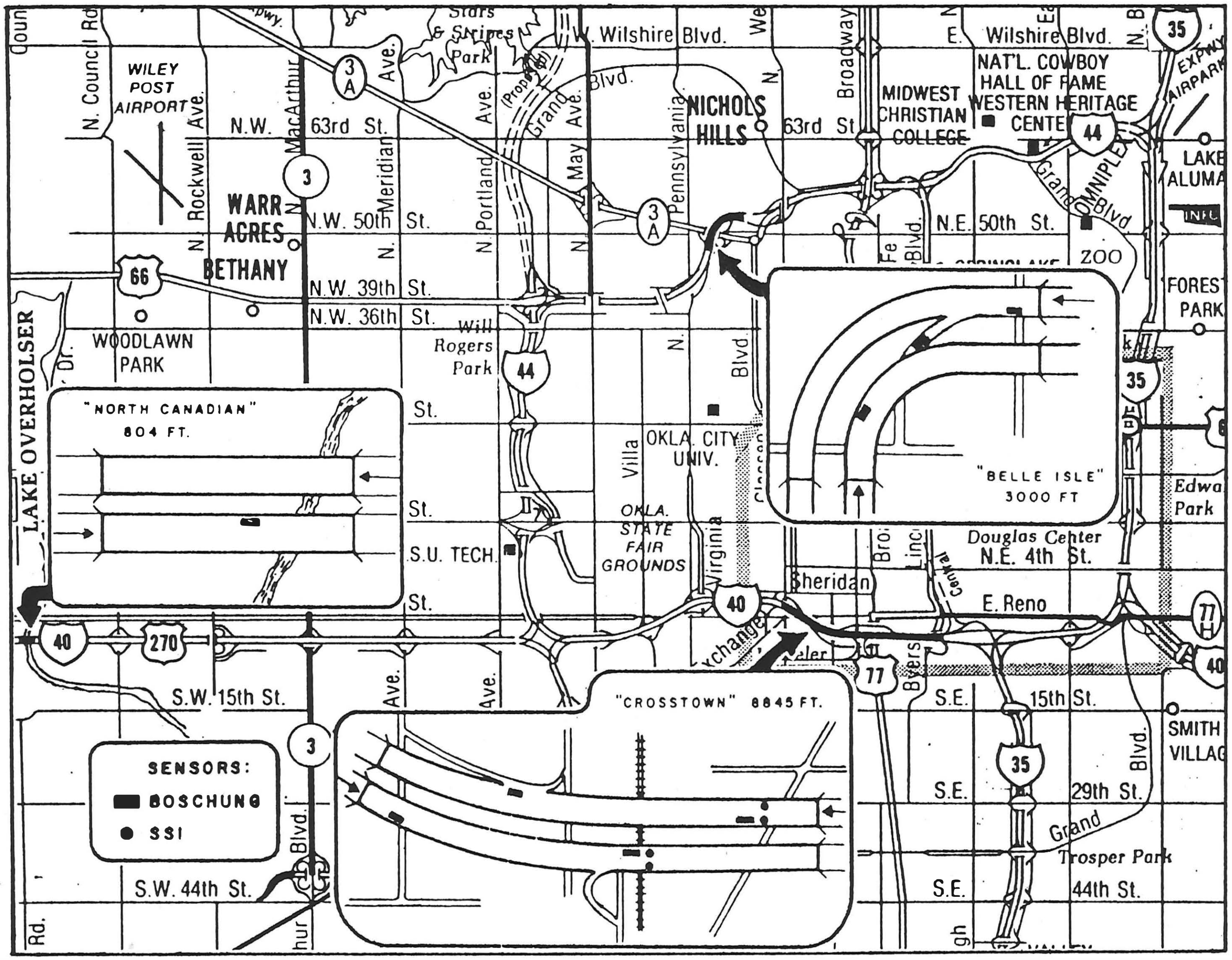

Figure 1. Location of Instrumented Structures in Oklahoma City Area.

This section of I-40 has one of the highest ADT in the metropolitan area. The structure is 1.63 miles in length and carries six lanes of traffic. It has many entrance and exit ramps to the downtown area which contribute to traffic congestion and problems during bad weather. Four sensor stations were placed at potential trouble spots due to traffic congestion. They were to be used also as an aid to determine the micro-climes experienced along its length.

The third structure selected, referred to as the "Belle Isle", is on I-44 in the northern section of the city. It is a curved, super elevated structure and also carries a high ADT. At the time of its selection, a portion of the structure was over a small lake. The lake has since been drained but the structure is still partially over water from a creek which runs underneath one end. Three sensor locations were used on this structure. Two, one in each direction of travel, were placed at the high points of the structures and at the upper elevation. The third sensor was placed in an exit ramp. Because it runs underneath one of the overhead structures and is closest to the marshy overflow area of the creek, it can experience icing conditions different than those of the other structures.

BOSCHUNG ICE EARLY WARNING SYSTEM

System Description

The basic Boschung system configuration along with optional equipment for ODOT's installation is illustrated in Figure 2. The deck surface conditions are determined by a multiple function probe which is installed in the deck, flush with the surface. The atmospheric sensors are an air temperature sensor and precipitation sensor. The precipitation gage is a moisture conductivity measuring device which detects only the presence (Y,N) of precipitation.

The deck probe measures the deck surface temperature and determines the surface moisture conditions using three individual electrical conductance type sensors. One sensor is passive in that it always reflects the current temperature and moisture status of the deck. These are used as reference values for comparisons with the two active sensors. One sensor is cyclically heated in order to melt, and thus detect the presence of, dry snow or sleet at deck temperatures below freezing. The third sensor can be cooled and heated relative to the deck temperature. The undercooling function provides the basis for alarm level A2. Altogether, these sensors determine the icing conditions of the deck and with the atmospheric sensors provide the warnings of the formation or possible formation of an icy or slippery surface. These early warnings are alarm levels A1, A2,

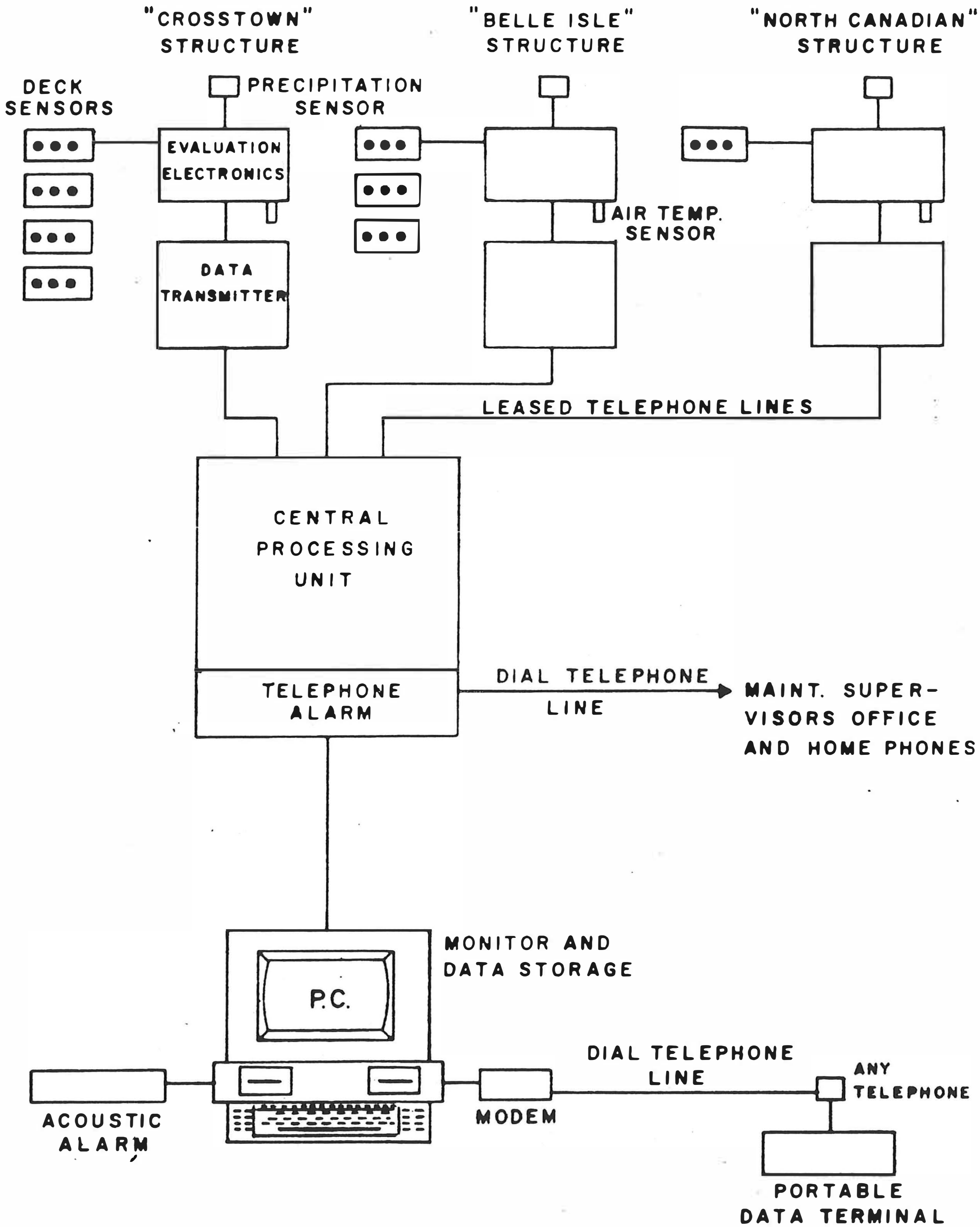

Figure 2. Boschung Ice Early Warning System Configuration.

and A3. The functioning of the alarms is shown in Figure 3. A normal explanation of the alarms is provided for viewing on the PC monitor or printing on the portable data terminals. See Figure 4. The system software allows the user to change these explanations for each measuring station.

The sensor signal levels are initially analyzed at the site with electronic instrumentation. They are then transmitted over dedicated telephone lines to a central processing unit (CPU).

The incoming data is further analyzed at 1 minute intervals to determine the deck surface conditions and if a defined alarm level exists.

The CPU has a user programmable interface which provides two functions. Two output lines or ports are provided which can be used to activate external devices or equipment. These outputs can be programmed to respond to any or all of the alarm levels. In ODOT's installation, these outputs activate the telephone alarm equipment. The user can also define and program another alarm called Merck (M). This can be used to monitor some event at any of the measuring stations which meets some special criteria other than the three predefined alarm levels.

FUNCTIONING OF ALARMS

A1	Ground temperature or Air temperature less than 32°F and wet	
A2	a) Ground temperature less than 35.6°F and wet	(means ice on artificially cooled sensor)
	b) Ground temperature less than 32°F and wet and precipitation	(No salt)
	c) Ground temperature less than 32°F and no precipitation and wet - changed from No to Yes	(Frost on artificially cooled sensor)
A3	a) Ground temperature less than 32°F and wet and ice on sensor Nr. 1	(Ice on road)
	b) Ground temperature less than 32°F and wet and precipitation - changed from Yes to No same as (A2 b) and precipitation changes from Yes to No	
M	Programmable alarm	
S	Snowdepth alarm	
D	Disturbance	

Figure 3. Functioning of Alarms.

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ICE EARLY WARNING SYSTEM      EXPLICATIONS 1 / F 1              09-09-1987/ 10:31a
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A1: TEMPERATURE OF GROUND OR AIR ZERO DEGREES OR BELOW AND GROUND HUMID OR WET.
    EXISTENCE OF SALT DOES NOT EFFECT THIS ALARM

    IMPORTANT: THIS ALARM IS CRITICAL
            a) WHEN IT OCCURS AT BEGINNING OF WINTER SEASON
            b) AFTER A PERIOD OF NO SALTING
    DANGER OF BLACK ICE OR HOAR FROST - ATTENTION

A2: DANGER OF HOAR FROST OR ICE ON ROAD SURFACE.
    DANGER OF ICE DUE TO PRECIPITATION DILUTING THE SALT ON ROAD SURFACE.

    IMPORTANT: SITUATION BECOMING DANGEROUS IF TEMPERATURE IS FALLING
               PAY ATTENTION TO PRECIPITATION

A3: DANGEROUS PERIOD,STRONG POSSIBILITY OF ICE ON ROAD SURFACE
                              OR
    END OF PRECIPITATION,TEMPERATURE BELOW ZERO AND NO SALT.
```

Figure 4. Normal Alarm Definitions.

The CPU is interfaced with a microcomputer (PC) which under software control displays the incoming data and stores it for future reference. The incoming data is displayed on the monitor in a selectable numeric or graphic format. These two displays show the data for all eight measuring stations. The graphics display is illustrated in Figure 5. The numeric display is identical to Figure 6(a). A two hour history, in a line graph format, for each individual measuring station can be viewed. The data is displayed from the "present time" and at 10 minute intervals. The same data, but in numerical format, can be output to a portable data terminal. The data is stored, on 20 minute intervals, by the day and by month. A 24 hour history can be recalled for each measuring station. See Figure 7.

Two additional alarm conditions are provided. See Figure 5. The S alarm is used with a snow depth gage which is not used in ODOT's installation. The D alarm means disturbance. If the CPU cannot receive data from any of the measuring stations, this alarm is noted. Possible causes could be loss of electrical power at the site or a bad telephone line.

The manufacturer recommends that the monitoring equipment should be located in a maintenance operations office for normal use of the system. In this mode of operation, the weather conditions would be monitored and the maintenance crews dispatched when needed. For this project the CPU and Monitor were located in the ODOT central office building. A telephone alarm system and portable data terminals were utilized so that

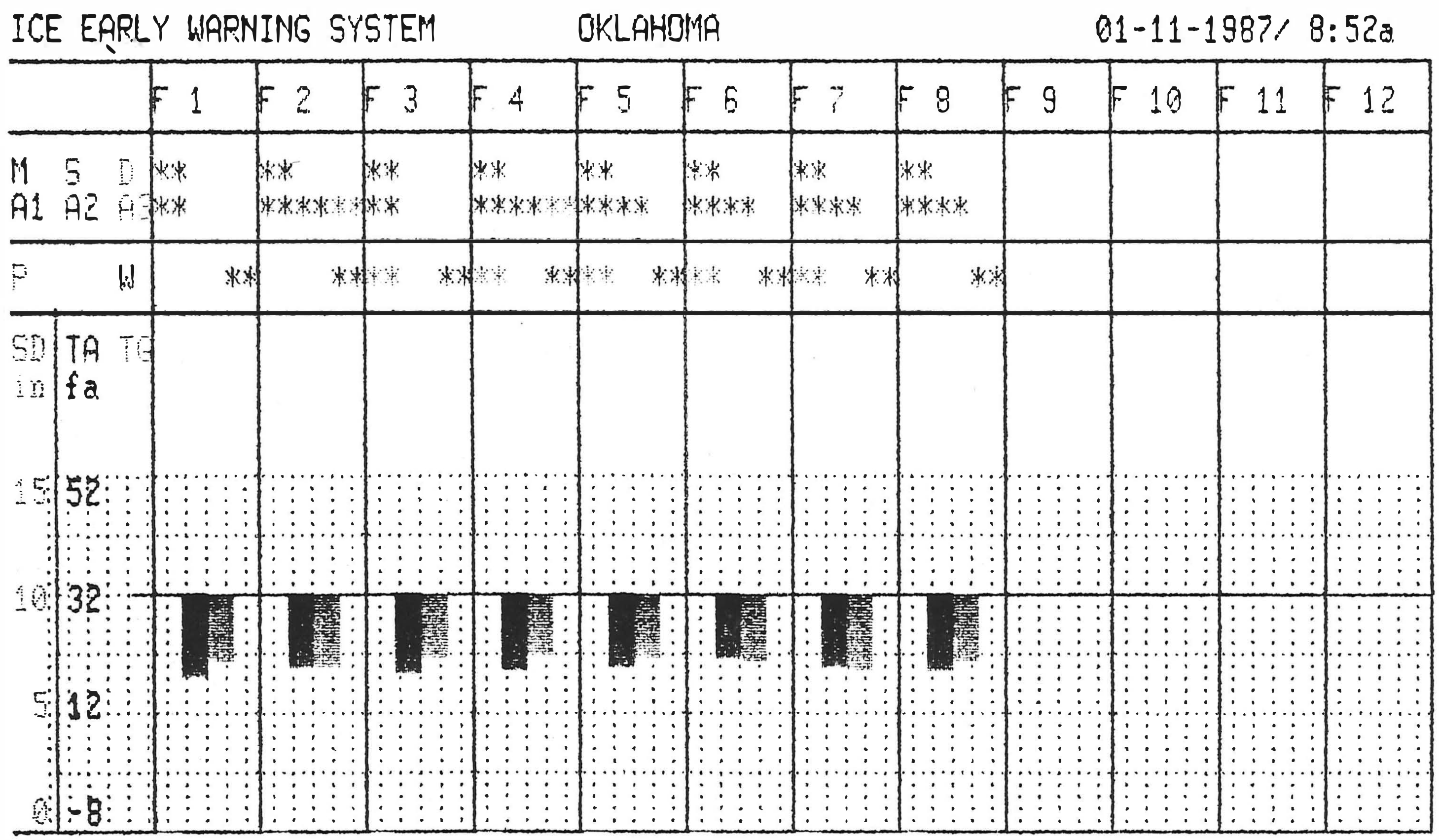

Figure 5. Typical Display of Data from Measuring Stations.

EARLY WARNING SYSTEM OKLAHOMA 01-18-1987/ 11:06a

MEASURING POINT	AIR DATAS TA	DTA	P	SD	GROUND DATAS TG	DTG	W	WARNINGS 1	2	3	M	S	D
1WB X-TOWN	23.7	00	N	0.0	24.4	00	Y	Q			Q		
2EB X-TOWN	22.6	-06	N	0.0	23.0	00	Y	Q	A		Q		
3WB X-TOWN	24.4	00	N	0.0	25.5	00	Y	Q	A	A	Q		
4EB X-TOWN	23.7	00	N	0.0	25.2	00	Y	Q	A		Q		
5WB B.ISLE	23.4	06	Y	0.0	23.0	00	Y	Q	A		Q		
6RP B.ISLE	23.7	00	Y	0.0	25.9	00	Y	Q			Q		
7EB B.ISLE	24.1	00	N	0.0	23.4	00	Y	Q	A	A	Q		
8EB N.CADN	23.0	06	N	0.0	22.3	00	Y	Q			Q		

(a)

EARLY WARNING SYSTEM OKLAHOMA /2EB X-TOWN 01-18-1987/ 11:13a

MEASURING POINT	AIR DATAS TA	DTA	P	SD	GROUND DATAS TG	DTG	W	WARNINGS 1	2	3	M	S	D
0	22.6	00	N	0.0	23.0	00	Y	Q	A		Q		
-10	23.0	06	N	0.0	23.0	00	Y	Q	A		Q		
-20	23.0	00	N	0.0	22.6	00	Y	Q	A		Q		
-30	22.6	00	N	0.0	22.6	00	Y	Q	A		Q		
-40	21.6	00	N	0.0	22.6	00	Y	Q	A		Q		
-50	21.6	-18	N	0.0	22.6	00	Y	Q	A		Q		
-60	21.6	-18	N	0.0	22.6	-06	Y	Q	A		Q		
-70	21.2	-06	N	0.0	22.6	00	Y	Q	A		Q		
-80	21.6	06	N	0.0	22.6	00	Y	Q	A		Q		
-90	21.6	06	N	0.0	22.6	-06	Y	Q	A		Q		
-100	21.6	00	N	0.0	22.6	00	Y	Q	A		Q		
-110	21.6	00	N	0.0	22.6	-06	Y	Q	A		Q		
-120	21.2	00	N	0.0	22.6	00	Y	Q	A		Q		

EARLY WARNING SYSTEM OKLAHOMA /3WB X-TOWN 01-18-1987/ 11:14a

MEASURING POINT	AIR DATAS TA	DTA	P	SD	GROUND DATAS TG	DTG	W	WARNINGS 1	2	3	M	S	D
0	24.4	00	N	0.0	25.9	06	Y	Q	A	A	Q		
-10	24.4	00	N	0.0	25.5	00	Y	Q	A	A	Q		
-20	24.4	06	N	0.0	25.5	18	Y	Q	A	A	Q		
-30	24.4	00	N	0.0	24.4	00	Y	Q	A	A	Q		
-40	24.1	00	N	0.0	24.4	00	Y	Q	A	A	Q		
-50	24.1	00	N	0.0	24.4	0[illegible]	Y	Q	A	A	Q		
-60	24.4	06	N	0.0	24.1	-06	Y	Q	A	A	Q		
-70	24.1	18	N	0.0	24.1	00	Y	Q	A	A	Q		
-80	24.1	24	N	0.0	24.4	00	Y	Q	A	A	Q		
-90	23.0	06	N	0.0	24.4	00	Y	Q	A	A	Q		
-100	22.6	00	N	0.0	24.1	00	Y	Q	A	A	Q		
-110	23.0	00	N	0.0	24.1	-06	Y	Q	A	A	Q		
-120	23.0	00	N	0.0	24.1	00	Y	Q	A	A	Q		

(b)

Figure 6. Typical Data Printout from Portable Data Terminal.
(a) Present Data for all Measuring Stations.
(b) Two Hour History for Individual Measuring Stations.

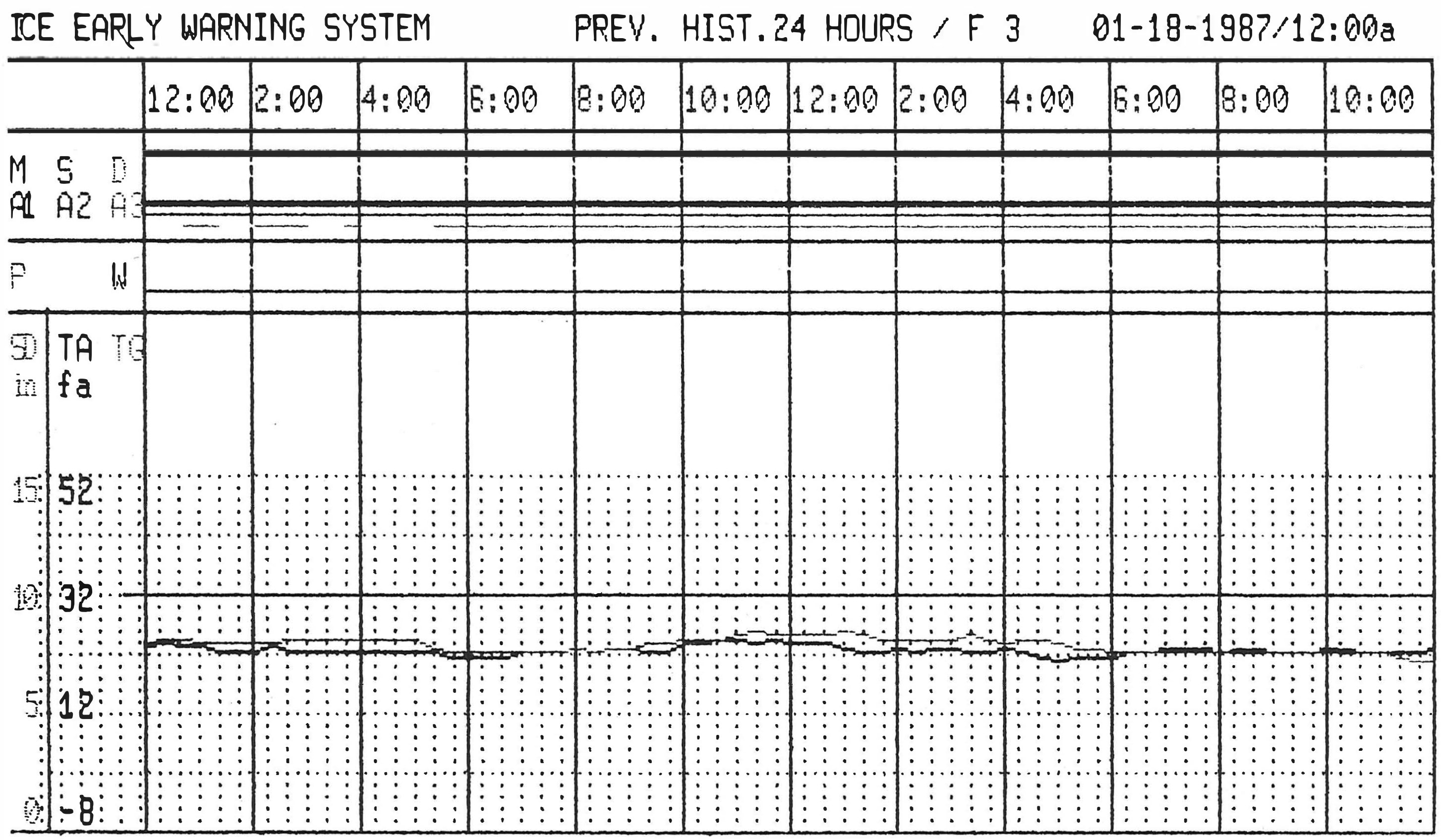

Figure 7. Typical 24 Hour History Display.

the Interstate maintenance supervisors could perform this function within their own maintenance district.

The portable data terminals could be used from any phone. The supervisor could call the system, via an autoanswer modem at the microcomputer, and get a printout (see Figure 6) of surface conditions and alarm status from any of the measuring stations.

The auto dial telephone alarm equipment used by Boschung was a commercial security alarm system. It was tape software operated in that the telephone numbers to be called were programmed on the tape along with the messages it sent. It was designed to call four groups of numbers. For ODOT's operation, three of the groups corresponded to the three instrumented structures. Upon receipt of an alarm condition from any of the eight measuring stations, the appropriate bridge was determined and the appropriate maintenance supervisor called. The first call was to his office and if there was no response, then his home was called. This sequence was repeated until someone answered the call. Upon receipt of a call a message was given, such as, "Ice Early Warning on the Crosstown Bridge". At the end of the message a carrier tone was sent. At the tone the called telephone was to be hung up and within forty seconds the tele-alarm was to be called. Upon hearing a carrier tone again the telephone was hung up which served to acknowledge the alarm. Group four was, in a sense, a failure alarm. If no one answered the alarm calls and an A3 or ice alarm on any structure was detected, all the telephone numbers were called.

The system had a daily clock and a seven day clock. The daily clock could be programmed for the hour of the day the Tele-Alarm was to be activated and deactivated. The seven day clock could be programmed for which days the Tele-Alarm was to be activated. For ODOT's operation the "ON" time was 5 p.m. and "OFF" time was 7 a.m. the following morning for Monday through Thursday. It was set to turn "ON" at 5 p.m. on Friday and turn "OFF" at 7 a.m. Monday morning.

The system also had two time delay relays which were used to control the call-outs in response to the alarm conditions. One relay could be set for the number of minutes an alarm condition had to exist before a call-out was made. Initially a 20 min. delay was used. The other relay set a time delay period before another call could be made. This was initially set for two hours. When the alarm was acknowledged, the delay relay was activated, inhibiting calls for two hours. At the end of the delay time, if the alarm condition still existed, the call-out sequence would start again. The purpose of this delay was to allow time for the maintenance crews to get from their homes to the maintenance facilities.

The equipment was hardwired to the circuitry in the CPU. It was ON when power to the CPU was ON and there was no switch to turn it OFF. The only way to deactivate it was to release the tape cassette thereby preventing calls to be made.

System Installation

All materials necessary for the installation of the equipment on the overhead structures were provided by the Boschung Company. Boschung personnel installed the deck sensors and all other required electronics. The necessary special equipment such as concrete saws, lift trucks, etc and the manpower necessary for mounting the equipment housings and running the wire cable between units were provided by ODOT maintenance personnel from Field Maintenance Division IV. The wire cable was an approved weatherproof outdoor type which could be attached to the structures using standard wiring practices. No major difficulties or problems were encountered during the installation. Since the cable from the deck sensor was laid in a saw cut in the deck, two of the measuring stations had to be relocated to keep from making a cut across three lanes of traffic. Because of traffic control problems, one deck sensor had to be installed in a different traffic lane than initially selected.

Installation of the electric and telephone service by the respective companies presented no major difficulties or above normal expense. All of the structures were located close to existing service lines so that special lines did not have to be installed. A considerable delay was experienced from the time the requests were made for the services until they were actually provided at all three structures.

System Cost

The cost of the system is itemized as follows:

Basic system equipment, including:	
8 measuring stations & ground probes,	
3 Transmitters,	
1 Central Processing Unit,	
Installation cable	$ 98,800
3 Portable Data Terminals with Modem	2,795
1 Tele-alarm with software	2,730
1 TI Professional Computer with	
(1) floppy disk drive,	
(1) 10M byte Winchester drive	5,950
Color Graphics Software	6,000
Total Cost	$116,275

The above cost does not include the three 120 volt service lines required and the necessary phone lines. The dedicated lines from the 3 transmitters to the CPU cost $80 per month. The connect charge was $500.00. Also needed were two regular dial phone lines.

The Boschung Company also has an annual service agreement. For the present study, Boschung extended the first year warranty to cover the second year also.

Evaluation

The basic sensor responses and the early warnings or alarms were evaluated by comparison to visual observations of deck surface and atmospheric conditions. The purpose of this method of evaluation was two-fold. First it was to help determine the accuracy and reliability of the sensors. The second purpose was to help the maintenance people to use their own experience and observations to interpret the alarms so that well informed decisions could be made.

The observations were recorded on a form as shown in Figure 8. The surface condition categories used were decided upon with the aid of the field maintenance people. They were the ones who had the experience dealing with the myriad of ice formations and weather conditions which are encountered in Oklahoma. Although the equipment was not designed to detect all of the listed ice formations, it was felt that the information would help document observed icing situations vs. equipment response.

It was assumed initially that the temperature sensor data was correct within the specified tolerances of the instrumentation. The air temperature sensors were compared periodically with National Weather Service weather forecast information realizing that they would not be in exact agreement because of temperature variations in urban areas but as an aid to help spot any gross discrepancies or malfunctions of the equipment.

BRIDGE DECK SURFACE CONDITIONS I-40 'CROSSTOWN' Structure

Date:	Time: AM PM	Observer:

Eastbound Lanes				Westbound Lanes				Yes	No	Precipitation?
Inside	Center ④ @ Classen	Outside	On Ramp ② 4 Robinson	Inside	Center ③ @ Lee St.	Center ① 2 East End	Outside 1	(✓)		Surface Conditions (✓)
										Dry
										Damp (Dew)
										Wet (Rain)
										Chemical Wet (Salted)
										Slush
										Frost
										Snow
										Sleet
										Ice Patches
										Ice Covered
										Snow over Water
										Water over Ice

Remarks: ______________________________

Sand/Salt Applied
Time: AM PM

Figure 8. Typical Visual Observation Form.

The visual observations were not made on a routine or scheduled basis. Those made by personnel from the Research Division were during normal working hours. Because of the sensor locations on the decks and the safety requirements imposed on non-emergency operations it was not possible to make closeup observations of the deck sensors. The observations had to be made from a moving vehicle using safe driving practices. Judgements were made by the driver and observer as to icing conditions present by noting the response of their own and other vehicles.

Inspections were made when rain, snow, dew, or other moisture was evident. Follow-up observations were made when the monitor indicated that the sensors were dry. The decks were also checked when it was observed that a sensor or sensors were indicating conditions that were at variance with observed weather conditions.

The visual observations by the maintenance personnel were made when responding to an early warning alarm call or their own road patrols or other weather watch activities. Also observations were noted as they were working to remove snow or ice.

The evaluation period for the project was to be two winter seasons divided into three phases. During Phase 1, the equipment was monitored by personnel from the Research Division. It was necessary to determine that the equipment was working properly and sensor responses accurate before being used by the field maintenance people in their operations.

Phase 2 was to be a period when the Interstate maintenance supervisors would have use of the portable data terminals. This would allow them to gain familiarity with the equipment and gain confidence in its use. Also, they could start using the data to aid in their decisions.

Phase 3 was to be the full evaluation of the equipment and its use in the snow and ice removal activities with the telephone alarm system being used.

First Winter Operation

During the first winter of operation the weather could not be considered normal for the Oklahoma City area. For the entire season, from November through March, only twelve days of weather conditions were experienced which required snow and ice control activities. The season started at the end of November with a typical icing situation. The two day period started with rain and rapidly falling temperatures. The rain then began to be mixed with freezing rain and sleet which eventually began freezing on the decks. The system was not operational at this time because the electrical services had not been connected and therefore no data could be collected.

The next event was near the middle of December with 2.9 in of light intermittent snow occurring over a four day period. The sensor responses appeared to be accurate and correspond to observations. A few of the alarms noted on the monitor when looking at the history data were verified to some degree with information received from the maintenance crews about their activities and observations during these time periods. A review of the historical data also disclosed responses from some of the sensors, which were generally of short duration but at variance with roadway conditions. A few short duration alarms were also noted for which no explanation could be determined from the data available.

It was necessary to observe the system responses for another icing situation to monitor the equipment more closely in order to determine the reason for these few apparent "false alarm" conditions. This opportunity did not occur until early February. After over a month of above normal temperatures and no precipitation in any form, a near monthly record 10.0 in. of snow fell over a six day period. Throughout the removal activities the basic sensor responses were considered accurate. A few alarm situations were observed during the day. It was during these snow removal activities that a discrepancy was observed between the precipitation sensors on the Crosstown structure and the observed weather conditions. This necessitated a modification to the equipment as installed on the deck. The precipitation sensors were noted to be indicating precipitation in a random pattern when there was no precipitation occurring. A drive across the deck disclosed that traffic was splashing the heavy melting snow runoff, which was accumulating along the gutter line, up over the precipitation sensors. This problem was solved by the manufacturer by extending the height of the precipitation sensors above the deck surface.

The portable data terminals were provided to the Interstate maintenance supervisors at this time. No further icing situations were recorded for the remainder of the season however.

A problem of major concern was encountered when calling in to get data with the portable data terminals. On occasions the PC operations would be disrupted during a call in. This in effect shut the system down and therefore no data was available until the operational software was reinstalled. The problem was finally attributed to noise on the telephone lines. A change in the PC operational software reduced the number of future occurrences of the problem.

The only apparent sensor malfunction experienced occurred in March during a rain storm. One of the deck sensors was indicating dry when the deck was wet. A cleaning of the deck sensor corrected the problem.

Early in the season numerous disturbance alarms were noted at the North Canadian River bridge. They appeared, to be erratic in duration but to some extent, have a daily pattern. This made it difficult to find the problem but it was eventually found that a loss of electrical power to the system was the problem. A service call by the electrical utility company apparently corrected the situation since no further problems of this nature were observed.

A problem of a more serious nature occurred during March during one of Oklahoma's typical spring thunder storms. The whole system at the Belle Isle structure quit sending data. A check of the equipment disclosed that power was available but all three measuring stations were not operating and the transmitter or modem was not communicating with the CPU. The equipment was checked by the manufacturer and it appeared that the system had been damaged by lighting. It could not be determined from the damaged circuitry whether the cause was from some type of lightning phenomenon induced through the sensors and wiring or had been induced through the electrical service line as a voltage spike or surge. At any rate, the system was repaired. Additional lightning protection devices were also installed at the 3 bridge sites. At this time also the telephone alarm system was reinstalled and made functional. Again the use of telephone lines with data equipment was found to be the problem and not the equipment. Apparently the dial telephone line had not been configured properly by the telephone company when it was installed. The situation was corrected by the telephone company.

Second Winter Operation

The weather conditions experienced the second winter of operation were somewhat more typical of Oklahoma's climate. During December there were several days with typical frost conditions. The first alarms early in December responded to by the maintenance people were considered by them to be false alarms. They would report what appeared to be a dry deck and not slick when the A2 (frost) alarm was indicated by the equipment. It was eventually confirmed on one occasion that a thin layer of "black" ice was present but that it did not present a traffic problem. This was in effect a valid early warning condition but was considered to be too sensitive for the maintenance people's needs.

The manufacturer came and checked the complete system to determine if the measuring stations were operating properly. The moisture sensors were checked for proper response and also the calibration of the temperature sensors checked.

The highly sensitive response of the ice detectors was by design. The sensitivity could be reduced to some degree but was not recommended by the manufacturer. Instead, they configured the second free output at the CPU to also control the telephone alarm equipment in response to the Merck (M) alarm. This would provide a means to define an alarm status to be used together with the predefined levels which were felt would best suit the needs. A few malfunctions in operation were experienced initially. One problem was traced to a loose wire at a cable junction terminal block which in effect did not allow the programmed alarm function to activate the tele-alarm. Eventually the "bugs" were worked out, and the system was considered operational.

A circuit modification was also installed at the measuring stations. The purpose was to expand the temperature scale which would allow deck and air temperatures to be monitored during warm weather months. This feature began to cause problems later on in the winter season which will be discussed later.

During the remainder of December and up to January 16th a few more frost occurrences were experienced. One hard frost was experienced with temperatures down in the low 20's. The frost was observed to be essentially city wide, and so all three instrumented structures were affected. The sensor responses with the exception of one on the Crosstown structure were observed to be accurate as was the A2 (frost) alarm. The one Crosstown station did not give the A2 (frost) alarm.

The other experiences with frost conditions generally occurred with air and/or deck temperatures hovering around freezing. Under these conditions spotty random frost occurred around the city area, a situation with which any maintenance person is well familiar. The maintenance people had mentioned past experiences in watching temperatures drop to near freezing and then seem to hang there. It was interesting to note, with instrumentation available to verify it, how often this borderline freeze/thaw phenomenon occurs in the climatic zone that includes Oklahoma, particularly with regard to the presence of frost.

The effect on the maintenance operations under these conditions is that a response could be made to a supposed valid alarm condition only to have it lift by the time a crew arrived at the bridge.

This same difficulty in determining how to react to the A2 alarm conditions at constant temperatures was experienced on other occasions later in the season when ice or snow existed and at temperatures well below freezing. As has been noted, the undercooled sensor provides the basis for the A2 alarm. This sensor cools 3.6^{O}F below the deck temperature. It is initially activated at a deck temperature of 35.6^{O}F to give the early warning of the possibility of ice formation when water is present on the deck, such as rain and no deicing chemicals present. This alarm condition gives the maintenance people time to react before the formation of ice occurs. The alarm is also useful in other situations such as after a deck has been salted and the possibility of refreezing exists.

On one occasion, after the decks had been salted, the melting of the ice was diluting the salt in solution and the A2 alarm was issued. However the deck temperature remained within this 3.6^{O}F range which kept the A2 alarm activated for an extended period of time.

It was during this time period that the above mentioned problems with the "summer operation" circuitry began to appear. The malfunctions started with one of the measuring stations on the Belle Isle structure. Since this was the measuring station which seemed to have had the most extensive damage from the previous electrical storm, the first thought was that the deck sensor may have also been damaged and the effects were just now showing. It was noted that when temperatures were around 50^{O}, other sensor responses occurred which were at variance with observed weather and deck surface conditions, such as a wet deck response when it was observed to be dry. Over a period of time it was verified that the erratic responses or malfunctions of the sensors occurred only when the deck temperatures reached 48^{o} to 50^{o}. This effect also began to occur later at some of the other measuring stations but not as consistently as at the station at the Belle Isle structure. The Belle Isle station also on occasion would send alarm conditions at these elevated temperatures. Fortunately they did not occur at times which the tele-alarm would call the maintenance supervisor. The problem could not be resolved on site and was to be checked into at the Boschung facilities in Switzerland.

Throughout the remainder of the winter season it was confirmed that the measuring stations continued to function properly as long as temperatures remained below 50^{o}. There were times when the data seemed erratic. Since these were generally of short duration, it was difficult to determine a cause as had been noted the first winter. The likely cause was thought to be noise on the telephone lines.

During the middle of January the only major period of snow and other icing weather conditions of the entire winter season occurred. Throughout the situation, the basic sensor responses were considered accurate and reliable with the exception of the precipitation sensors. The type of precipitation sensors used do not detect fine blowing snow very well. Since this was the type of snow experienced, the precipitation sensors detected it on very few occasions.

A problem came up with the function of the telephone alarm equipment during the snow removal activities. The problem was not a malfunction of the equipment, which operated properly, but rather that during extended snow removal operations alarms are not needed. The bottom line to the problem was that there was no way to control the telephone alarm operation except to turn it off at the CPU. The following account illustrates this type of situation.

The weather conditions started out in a typical fashion with rain, occasional light snow, and sleet mixed with freezing rain. The air temperatures started to decline rapidly. The maintenance crews were responding with the prescribed procedures for combating these icing conditions. After two days of this activity, it started to snow late one night. The snow was a fine dry snow and was drifting due to the variable wind speeds associated with the weather system. At one observed station the snow fell steadily, at varying intensities for approximately 12 hours. The official amount recorded at the National Weather Service station was 10 in. with reported amounts of 7 to 12 in. around the city area. Some observed drifts on the roadways and bridges were estimated to be around 5 to 7 ft deep. The maintenance crews had to switch from sand/salt operations to using snow removal equipment. In the process of clearing and opening lanes of traffic on the roadways and structures, a layer of ice, up to 2 in thick in some locations, was found under the snow. Until the lanes where the sensors were located were cleared, the sensors were detecting ice and giving the appropriate A3 alarm, which in turn was activating the telephone alarm every two hours and calling the maintenance supervisor. The problem was that the crews were working around the clock and no one was at the office, or home, to acknowledge the alarms. In essence, the telephone alarm function was not needed under these conditions, but there was no way to deactivate it temporarily.

The after effects of the storm existed for over a week. The bladed snow was still piled along the bridge parapet walls and slowly melting in the sun and cold temperatures. The telephone alarm was left activated as long as re-freezing conditions could still occur. After this threat was cleared, the decision was made by all involved to shut down the telephone alarm and operate for the rest of the season with the portable data terminals only.

With the exception of a one in. snow in February, no icing situations other than light frost occurred for the remainder of the winter season. Since they also occurred at temperatures hovering around freezing the same problems were experienced as at the start of the season in how to respond to the few alarm conditions noted.

During the study various sensor responses were noted which were found not to be caused by weather conditions. Two are noted as representative of problems encountered at times in interpreting the sensor responses to determine what is occurring on the decks.

On one occasion, a deck sensor started showing wet, with no precipitation and the other sensors on the deck indicating dry conditions. An inspection of the deck showed a stream of water down the deck which had happened to pass over the deck sensor. It was also observed that other vehicles, particularly trucks on the bridge at the time had snow on top of the trailers which was evidently melting and running off onto the deck surface with occasional large chunks of snow falling off and splattering in spot patterns.

The other occasion involved a precipitation sensor. It was noted that the measuring station on the Belle Isle ramp began indicating precipitation, with no precipitation occurring, particularly during early morning hours. It was thought initially that the sensor was sensing dew or fog. At a routine maintenance inspection of the equipment, bird droppings were discovered on the precipitation sensor. When the same conditions were noted again it was noted, from surrounding evidence that evidently some type of bird had chosen that precipitation sensor housing as a roost.

Equipment Durability

As has been noted, various equipment problems and malfunctions of the equipment located at the bridge sites plagued the operation and use of the system during the study period. All of the original circuit boards in the AMS units on the decks had been replaced at the end of the first winter season because of the addition of the "summer operation" feature. Various circuit boards were replaced during the second winter's operation to correct the various problems and malfunctions experienced. Consequently, the long term durability of this portion of the system could not be determined.

One circuit board in the transmitter unit at the Crosstown structure was replaced due to a burnt component. The cause was not determined. No problems were noted with the replacement.

All three of the transmitters or modems at the three bridges were replaced once. The reason at the Belle Isle structure has been noted previously. Again the cause of the failure at the other two structures was not determined. The occurrence of lightening at the Belle Isle installation indicates it to be the probable cause for the equipment failure.

It is suspected that two of the deck sensors may have partially failed. During the winter one of the sensors on the Crosstown structure began to randomly miss some valid alarm conditions. Eventually it failed to give any alarms altogether when it should have. However the temperature and moisture sensor portion continued to give accurate responses in keeping with the others on the deck. It has previously been noted of the suspected problems with the one deck sensor on the Belle Isle structure. Because of the problems experienced with the summer operation circuitry, the possibility exists that this could be a contributing cause to the apparent sensor failure.

Mechanically, the deck sensors looked good at the end of the study period. The grouting compound with which they were installed showed no signs of disbonding or other distress. No surface distress was noted due to traffic. It was surprising at the last inspection how clean the sensor surfaces were.

The Boschung CPU unit and the TI Professional Computer operated throughout the study period without any component problems or failures. Despite the problems associated with the telephone alarm the equipment itself did not malfunction or fail. The transmitter/receiver unit at the CPU, which is identical to the units at the bridge sites did not give any problems.

Discussion of Results and Conclusions

During the study period the accuracy and reliability of the equipment had to be determined using relatively few icing events from which to collect data. With this limited experience however the ice early warning system demonstrated its usefulness as a decision support tool in the winter maintenance operations. It was found however that human observer or operator intervention is required in some situations to interpret the system data to make the final decision on when to dispatch personnel.

It was concluded by participants in the study that:

1. The equipment provided accurate and reliable information on deck surface conditions.
2. The sounding of the alarms were in general agreement with visual observations.
3. The equipment appears to be a workable system but more operational experience and training would be beneficial in order to determine a reliability rate or confidence level of the alarm conditions with which to effectively initiate snow and ice removal actions.

It was difficult throughout the study period to determine from the alarm conditions alone, in certain icing situations, when to dispatch personnel. This in turn made it difficult to determine the effectiveness of the system in the maintenance operations. Special areas of interest were, reducing non productive overtime and a more effective use of equipment and materials.

The system cannot forecast or predict weather or deck conditions. Therefore the alarm conditions cannot be used in all weather conditions to make cut and dried decisions. This was very much in evidence during experienced borderline freezing conditions and also when the deck temperatures hovered in the moisture freezing range of the undercooled sensor. Under these conditions, human intervention was a necessity in order to interpret the data and determine the overall conditions in the maintenance area. In these situations the maintenance people found the deck temperature information to be of value. This provided information they needed but could not get from other sources.

On some occasions the maintenance units were responding to calls from State Troopers of icing conditions on structures. It was noted that in general the structures in question were those in the area which by statistical nature are the trouble spots when certain environmental conditions exist, such as frost. It is felt that a more effective use of the ice warning system in the maintenance procedures could have been realized if these structures had been instrumented.

Some of the situations encountered with the use of the telephone alarm system have been noted previously. It was initially programmed to call the maintenance supervisor in response to an A2 alarm. This in effect was using the telephone alarm as the dispatching agent. For the project this was considered part of the learning experience. The majority of the calls made supported the usefulness of this method of dispatching personnel. However, the finding that the human operator is necessary at times to make decisions affected the usefulness of the telephone alarm system. It was concluded that it could still be a useful feature of the ice warning system if its operation could be controlled by the maintenance supervisor.

With the limited types of weather patterns experienced during the study, it was not possible to detect any storm tracking capabilities of the ice warning system over the Oklahoma City area. From the two major snow storms experienced, information from one of the three structures, in particular the Belle Isle, would have defined the general snow conditions over the city area.

From the results of the study it would appear that the number of sensors on the individual structures was the minimum required to determine overall deck icing conditions. It was noted when the snow was melting that, because of the orientation and super elevation of the Belle Isle structures, the surface conditions of each structure could be entirely different. One sensor would not define adequately the overall surface conditions.

Based on the results of this study it would be premature to recommend an expansion of the ice warning system. A few observations were noted which would apply towards evaluation of any expansion.

The ice warning system used in this study appears to be best suited for installation in small areas such as in and around cities. The limiting factor appears to be the number of transmitter sites the CPU will support. Also the number of measuring stations is limited to twelve. It would be recommended that known trouble spots such as frost prone structures take first priority in the selection of structures or roadways to instrument. Instrumented structures in selected cities in each Maintenance Division could provide some measure of tracking storm systems across the state.

During the study, note was made of possible other uses of the information supplied by the deck sensors and alarm conditions. One was the possibility of using the supercooled sensor function to assess the effectiveness of present salt application rates for different types of icing situations. In a sense this is what the A2 alarm is indicating to the maintenance people after salt has been applied. It gives them an early warning that if the current trend of salt dilution and temperature changes persist, refreezing will occur. Also this information may aid in the evaluation of other types of deicing agents. It was not in the scope of this study however to do a detailed analysis of this feature.

Recommendations

It is felt that not enough operational experience and training was gained during the project to fully evaluate all aspects of the effective use and benefits of the ice warning system in ODOT's snow and ice removal procedures and activities. It is recommended that Maintenance Division IV use the system for another winter season to obtain more operational experience and knowledge of icing situations. More exposure would also aid in defining the type of data required to support the decisions to be made within their maintenance operations organization. Another seasons operation would also aid in determining the long-term accuracy and reliability of the data and the durability of the equipment.

APPENDIX

SURFACE SYSTEMS SCAN ROADWAY SYSTEM

Surface Systems, Inc. provided a version of their SCAN System for evaluation on the project. The deck sensors for this system were placed at two locations on the Crosstown structure. See Figure 1. The system was monitored and evaluated by the Research Division in the ODOT central office.

System Description

The system configuration for ODOT's installation is illustrated in Figure A1. The deck surface conditions at each location are determined by two probes installed in the deck, flush with the surface. Atmospheric conditions were monitored with sensors located near one of the deck sensor sites. The atmospheric conditions monitored were wind speed and direction, precipitation, air temperature and humidity.

The deck, or surface mounted probe, is a capacitance type and detects moisture or ice on its surface by a change in capacitance compared to the capacitance of air. It discriminates between ice and moisture with the aid of an electrical conductivity probe. A temperature sensor is included in the probe to measure the surface temperature. The sensor outputs are routed by cable to a remote processor unit (RPU). For ODOT's installation, data transmission between RPU and CPU was accomplished by radio telemetry.

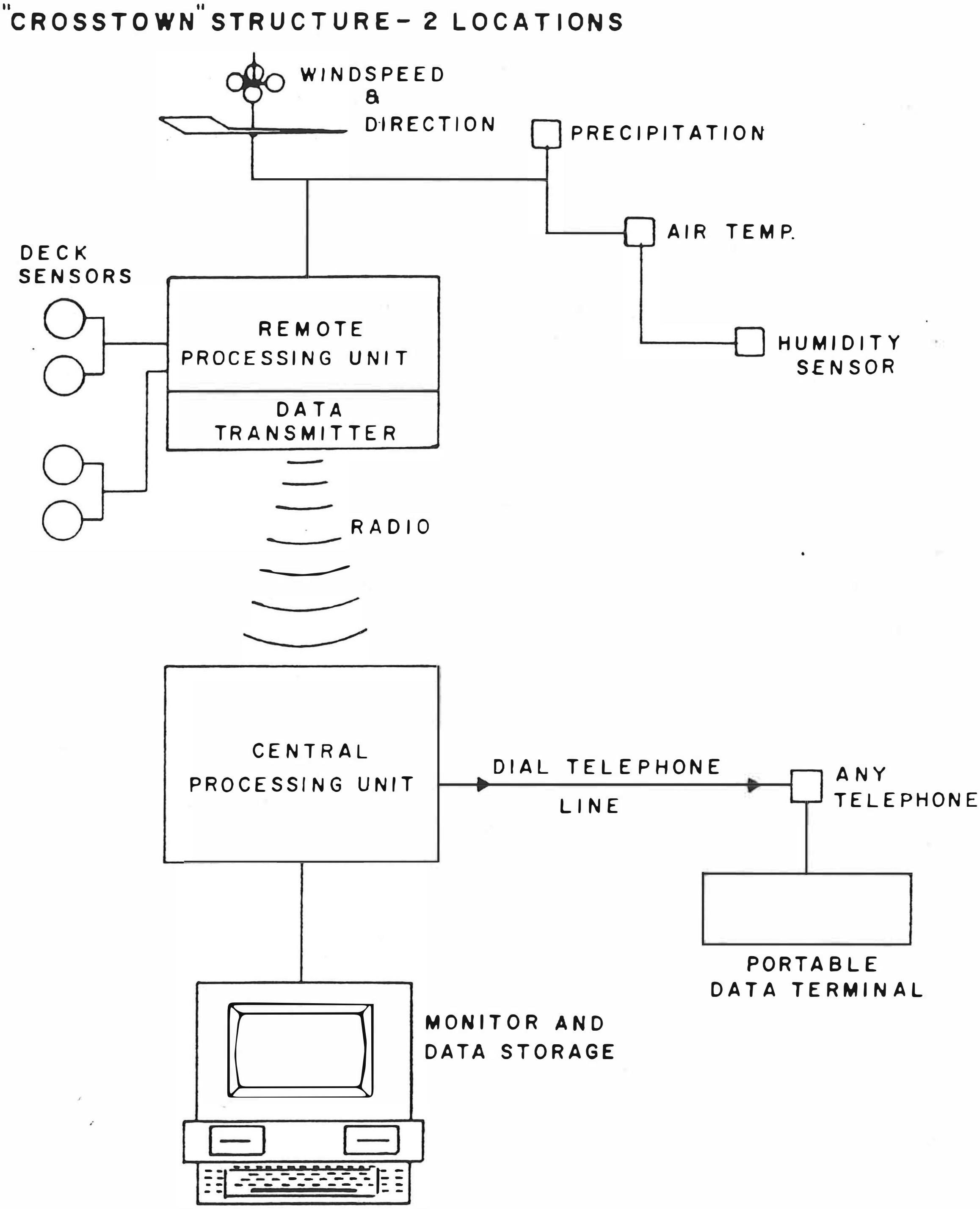

Figure A1. Surface Systems SCAN system configuration

The CPU further processes and stores the sensor data received from the RPU. A microcomputer (PC) is interfaced with the CPU for viewing the sensor data. The data could also be accessed by use of a portable data terminal from any telephone.

The data is displayed on the PC in various formats. A typical status page and history page are shown in Figure A2.

Also available was a graph of the air or surface temperature over a selected time period. The status page displayed the current atmospheric and deck conditions. The dew point temperature is a calculated value as is the chemical factor. The deck surface conditions are indicated by a status title. An explanation of the status titles and chemical factor is shown in Figure A3.

The CPU stores the data for each deck sensor by significant events or changes. An example of a significant change would be if the deck surface changed from "dry" to "wet" or "wet" to "Ice Alert". The CPU tape drive had the capacity to store fifteen (15) events for each of the four deck sensors. A printer was provided to obtain a hardcopy of the history data. To obtain a continuous history profile, the PC could be programmed to print succeeding pages of fifteen new events for each of the four sensors.

During the second winter of operation, a personal computer was provided with a 20MB disk drive. The history data was then stored automatically in a disk file. It could then be post viewed on the monitor or printed over a selected time period.

OKLAHOMA DEPARTMENT OF TRANS. Status Page Time 17:24 December 11, 1985
Power on at: 17:21 on 12/11/85
Crosstown bridge RPU # 1 Last report: 17:21 on 12/11/85

Atmospheric conditions

Air Temperature	Dew point Temperature	Relative Humidity	Wind Dir. Min.	Wind Dir. Avg.	Wind Dir. Max.	Wind Speed Avg.	Wind Speed Gust
27	* 27.0	100	360	360	360	13	13

Surface conditions

Sensor No.	Sensor location	Status	Precip	Surface Temperature	Chem. Factor
1	W. B. Driving	Snow/ice alert	N	28	
2	W. B. Passing @ B-1	Snow/ice alert	N	27	
3	E. B. Driving-ramp	Chemical wet	N	28	85
4	E. B. Driving @ B-2	Snow/ice alert	N	32	

(a)

OKLAHOMA DEPARTMENT OF TRANS. History Page Time 17:26 December 11, 1985
Power on at: 17:21 on 12/11/85
Sensor # 1 W. B. Driving

Time	Day		Status	Precip	Rel. Hum.	CF	Surf.	Air	Dew	Wind Dir/	Wind Vel.
17:21	11	*	Snow/ice alert	N	100		* 28	* 27	* 27.0	360/	11
17:01	11		Snow/ice alert	N	100		* 28	27	27.0	360/	10
16:37	11	*	Snow/ice alert	N	100		* 29	* 27	* 27.0	360/	13
16:28	11		Snow/ice alert	N	100	05	* 29	27	* 27.0	360/	11
16:20	11	*	Snow/ice alert	N	99	05	30	27	26.8	360/	14
16:18	11	*	Communication fail								
15:50	11		Absorption	N	100	05	30	27	* 27.0	360/	13
15:45	11		Absorption	N	99	05	* 30	27	26.8	360/	14
15:12	11		Absorption	N	99	05	* 31	27	26.8	360/	14
14:50	11	*	Absorption	N	100	05	32	28	28.0	360/	10
14:45	11		Dry	N	100		* 32	28	28.0	360/	13
14:12	11		Dry	N	99		* 33	27	26.8	360/	15
14:07	11		Dry	N	100		* 32	27	27.0	360/	18
14:02	11		Dry	N	100		* 33	27	27.0	360/	13
13:45	11		Dry	N	100		* 32	27	27.0	360/	14

(b)

Figure A2. Typical data pages (a) Status page for RPU
(b) History page for one deck sensor

OKLAHOMA DEPARTMENT OF TRANS. History Page Time 17:26 December 11, 1985
Power on at: 17:21 on 12/11/85

Sensor # 1 W. B. Driving

Time	Day		Status	Precip	Rel. Hum.	CF		Surf.		Air		Dew	Wind Dir/	Vel.
17:21	11	*	Snow/ice alert	N	100		*	28	*	27	*	27.0	360/	11
17:01	11		Snow/ice alert	N	100		*	28		27		27.0	360/	10
16:37	11	*	Snow/ice alert	N	100		*	29	*	27	*	27.0	360/	13
16:28	11		Snow/ice alert	N	100	05	*	29		27	*	27.0	360/	11
16:20	11	*	Snow/ice alert	N	99	05		30		27		26.8	360/	14
16:18	11	*	Communication fail											
15:50	11		Absorption	N	100	05		30		27	*	27.0	360/	13
15:45	11		Absorption	N	99	05	*	30		27		26.8	360/	14
15:12	11		Absorption	N	99	05	*	31		27		26.8	360/	14
14:50	11	*	Absorption	N	100	05		32		28		28.0	360/	10
14:45	11		Dry	N	100		*	32		28		28.0	360/	13
14:12	11		Dry	N	99		*	33		27		26.8	360/	15
14:07	11		Dry	N	100		*	32		27		27.0	360/	18
14:02	11		Dry	N	100		*	33		27		27.0	360/	13
13:45	11		Dry	N	100		*	32		27		27.0	360/	14

OKLAHOMA DEPARTMENT OF TRANS. History Page Time 17:27 December 11, 1985
Power on at: 17:21 on 12/11/85

Sensor # 2 W. B. Passing @ B-1

Time	Day		Status	Precip	Rel. Hum.	CF		Surf.		Air		Dew	Wind Dir/	Vel.
17:21	11	*	Snow/ice alert	N	100		*	27	*	27	*	27.0	360/	11
17:06	11		Snow/ice alert	N	100		*	27		27		27.0	360/	12
16:37	11	*	Snow/ice alert	N	100		*	28	*	27	*	27.0	360/	13
16:28	11		Snow/ice alert	N	100	05		29		27	*	27.0	360/	11
16:20	11	*	Snow/ice alert	N	99	05		29		27		26.8	360/	14
16:18	11	*	Communication fail											
15:50	11		Absorption	N	100	05	*	29		27	*	27.0	360/	13
15:40	11	*	Absorption	N	100	05		30		27		27.0	360/	14
15:25	11		Dry	N	100		*	30		27		27.0	360/	13
14:47	11		Dry	N	100		*	31		28		28.0	360/	14
13:27	11		Dry	N	100		*	32		27		27.0	360/	11
13:22	11	*	Dry	N	100			31		26		26.0	360/	15
13:17	11	*	Snow/ice alert	N	100	05		31		26		26.0	360/	13

STATUS TITLES

The Status Titles listed below describe the surface condition at a surface sensor location. The Titles and their descriptions are:

System Initializing: This status is displayed after power-up and before the CPU has made an attempt to call the RPU. It is only displayed upon system power-up.

Dry: An absence of precipitation or moisture on the surface sensor.

Wet: Precipitation/moisture present in liquid form on the surface and surface temperature above 32 degrees Fahrenheit (0 degrees Celsius).

***Dew:** Moisture present on surface, the dewpoint has been reached and surface temperature above 32 degrees.

***Frost:** Frost present on surface, the dew point has been reached and surface temperature below 32 degrees.

***Frost Above Dew Point:** Frost conditions have been reached and the surface temperature is no longer at or below dew point.

***Absorption:** Moisture present on surface in an insufficient amount to present a hazard.

***Absorption @ Dew Point:** Moisture present on surface in an insufficient amount to present a hazard and dew point has been reached.

Chemical Wet: Precipitation/moisture present in liquid form on the surface and surface temperature at or below 32 degrees Fahrenheit (0 degrees Celsius).

Snow/Ice Alert:

A. Precipitation/moisture in liquid form on the surface starting to freeze.
B. Precipitation/moisture on the surface which has frozen.

Sensor Down: An inoperative surface sensor.

Communication Failure: Disrupted communication between the RPU and CPU.

*A precipitation sensor is required for the display of these statuses.

Chemical Factor

The "Chemical Factor" is a feature of the system that may assist you in following the trend of surface conditions. Chemical Factor is a relative indication of chemical presence in the moisture on the surface. Chemical factor is dependent on the amount of chemical present and the amount of moisture present. Chemical Factor is shown in a scale from 5 to 95 in increments of 5. When specific statuses are present, the Chemical Factor will be displayed as a numerical value at temperatures below 50 degrees Fahrenheit (10 degrees Celsius) and will be blank above 50 degrees Fahrenheit (10 degrees Celsius). A decreasing chemical factor corresponds to a decrease of chemicals or contaminants, or an increase in the amount of moisture, on the surface sensor.

Studies have shown that the Chemical Factor will respond negligibly to moisture that contains Urea.

Figure A3. Surface condition status titles

The new version of software also had improved graphics formats for viewing the data.

Over the two winters operation, Surface Systems provided use of two of their weather forecast services. The first winter, access was provided to the National Weather Service radar in Oklahoma City. During the latter part of the second winter's operation, a trial use was offered of a new weather forecast service which included deck surface temperature projections.

System Cost

No cost figures are available for the equipment provided by SSI for ODOT's trial installation. Equipment provided is itemized as follows:

1 - Remote Processor Unit (RPU) including:

- Weatherproof Cabinet
- Air Temperature Sensor
- Relative Humidity Sensor
- Precipitation Sensor

1 - Wind Speed Sensor/Wind Direction Sensor

4 - Roadway Surface Sensor (2 ea. at deck measuring location)

1 - Central Processor Unit (CPU) including:

- Cabinet
- Dual Tape Drive
- Radio Transceiver and Antenna
- Two Modems

1 - IBM Personal computer (PC)

- Two Modems

1 - Portable data Terminal

1 - Printer

Costs for the installation were:

1 - 120 volt electrical service line at the RPU

2 - Dial telephone line (1 ea. at CPU and PC)

Equipment Reliability

During the evaluation period, the equipment worked well overall with a limited amount of down time. Two major problems experienced were:

1. The data storage tape cassettes were found to be twisted on two occasions, causing the CPU to become inoperable.
2. A CPU power supply failure.

The most serious problem experienced, which caused the system to be inoperable at critical times, was with the radio telemetry. An exceptionally high number of "Communication Failures" were experienced. A specific cause was not determined.

The original humidity sensor was found to be faulty and replaced. During the second winter of operations, the replacement was noted to be somewhat erratic in operation.

Towards the end of the second winter of operations, one of the deck probes was noted not detecting icing conditions accurately. In some instances its response lagged the response of the second probe. It was found that the deck temperature sensor was 5° to 10° high, depending on surface moisture conditions and amount of sunlight.

System Evaluation

The basic sensor responses and deck surface status information were evaluated by comparison to visual observations. The air temperature and humidity were compared to National Weather Service data as an aid in spotting any gross errors in the sensor response.

The system was monitored during normal office working hours. In the event of icing conditions during the night and on week-ends, the printer was used to record the history data for later analysis.

With well defined icing conditions, the equipment provided accurate and reliable data that was in general agreement with visual observations. Typical situations were:

1. Wet snow in measurable amounts sticking and/or freezing to the deck surface.
2. Measurable rain or freezing rain on a supercooled deck or with rapidly declining temperatures.
3. A hard heavy area wide frost with temperatures well below freezing.

The sensors were not reliable in detecting light frost. This was also the case in other types of thin "slush like" situations experienced. These missed events were more evident when deck temperatures were hovering around freezing.

It is apparent that operator intervention is a necessity to effectively use the data provided by the system. This conclusion was more evident when looking at early warning capabilities. As an example; the precipitation sensors could not detect reliably dry blowing snow. During one such snow storm, the first indication of what was occurring at the deck was a sudden ICE ALERT status. The user of the system would need considerable experience to interpret the data provided by the system in order to effectively react.

Conclusion

The SCAN equipment appears to be a workable system. Overall, it demonstrated a usefulness as a decision making support tool in snow and ice control operations.