Surface Sensor System

OBSERVATIONS AND FORECASTS OF ROAD, BRIDGE AND RUNWAY SURFACES

Joe R. Kelley (1)
David C. Trask (2)
Olga M. Hunt (3)

Surface Systems Inc.
St. Louis, MO 63144

ABSTRACT

This paper describes: a surface sensor system that provides real-time road, bridge and runway surface condition information to maintenance personnel and operational meteorologists; the computer software that interfaces with the sensor systems; the personal-computer graphic displays tailored for roadway and runway pavement interpretation and monitoring; the computer forecasting model that forecasts and projects pavement temperature and moisture; and the associated centralized and specialized forecasting center.

1. INTRODUCTION

An estimate of 3 billion dollars spent annually on ice and snow control in North America is probably conservative, and does not include damage and corrosion by salt and chemicals to automobiles, roads, bridges, runways, and other surfaces. To reduce this cost, one must be informed of when to and when not to apply sand, salt, or other chemicals and when to schedule maintenance crews to lessen the overtime and premium-hour pay. Can this be done without sacrificing the safety standards already established? The answer is yes; it can and has been done.

Forecasts for pavement conditions of roadways and motorways have been provided for the past few years in England with documented, cost-saving results. Not until the winter of 1986–87 was this type of service available to the United States and Canada. Now surface sensor systems that monitor and record the pavement temperature and the presence of water, frost, ice, and chemicals are installed and operational in over 70 airport runways and many highways, streets, and bridges in the United States, (Fig. 1), Canada and Europe.

The sensors observe the pavement temperature, the chemical factor, whether the pavement is wet or dry, and when there is ice, snow, or frost present on the pavement. Forecasters collect the pavement observations and produce a pavement condition forecast from a centralized forecast facility. The forecast includes: when precipitation will occur and what type of precipitation it will be; when the pavement will freeze and how long it will remain frozen; and when pavement temperatures will change and the degree of change. The forecast product is designed to make it easier for the decision maker to plan and prepare for a winter weather situation.

2. BACKGROUND ON ELECTRONIC PAVEMENT MONITORING AND ALTERING SYSTEMS

Commercial ice detectors in the 1960s and 1970s attempted to measure the electrical conductivity of water and ice across long metal probes set in the pavement. This method had several inherent shortcomings and the best accuracies observed were in the range of 50% to 60%.

In 1973–74 the Federal Highway Administration sponsored an evaluation of all the ice sensor systems available and field tested three of the systems. The purpose of the evaluation was to determine if sensor systems could be relied on to automatically activate warning signs to warn motorists when a bridge deck became icy. One system utilized the principal of conductivity, one the principal of detecting the latent heat of fusion, and the other was a sensor based on a capacitance/conductivity theory developed by Surface Systems, Inc. (*SSI) of St. Louis, Missouri. This sensor was thermally passive in that there was no melting or refreezing of the ice on its surface. It operated at pavement temperatures at all times since it was fabricated of materials with the same thermal characteristics as those of the pavement. This sensor used a flat capacitor beneath its surface to determine if the surface was wet or dry. This, along with a conductivity sampling and a very accurate temperature measurement, enabled the system logic to determine the surface condition.

After field testing of the three sensor systems, the Federal Highway Administration concluded that none of the systems evaluated were accurate enough to directly operate motorist-warning signs, but that the SSI capacitance system could be improved to that point. In 1975 SSI decided not to sell the system for the purpose of direct public warning. Instead it was determined that it could be sold to and utilized by agencies responsible for making decisions concerning public safety by preventing slippery surfaces. The sensor was improved, and since early 1987 the SSI *SCAN (Surface Condition ANalyzer) system has been operating successfully in nearly all kinds of highway and airport applications at over 200 locations in the United States, Canada, United Kingdom, and Europe.

3. THE SCAN SURFACE SENSOR SYSTEM

3.1 The Surface Sensor

The SCAN surface sensor (Fig. 2) is made of a special, tough epoxy with thermal properties similar to the road or runway surface. The sensor contains a capacitor whose two elements are mounted underneath the top of the sensor so that the effective capacitance depends on the dielectric constant of the water, ice, or snow on top of the surface. Because the dielectric constant of air differs from that of water, which

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*SCAN is patented and is a registered trademark of Surface Systems, Inc.

Fig. 1. Surface Condition ANalysis system installations in the United States.

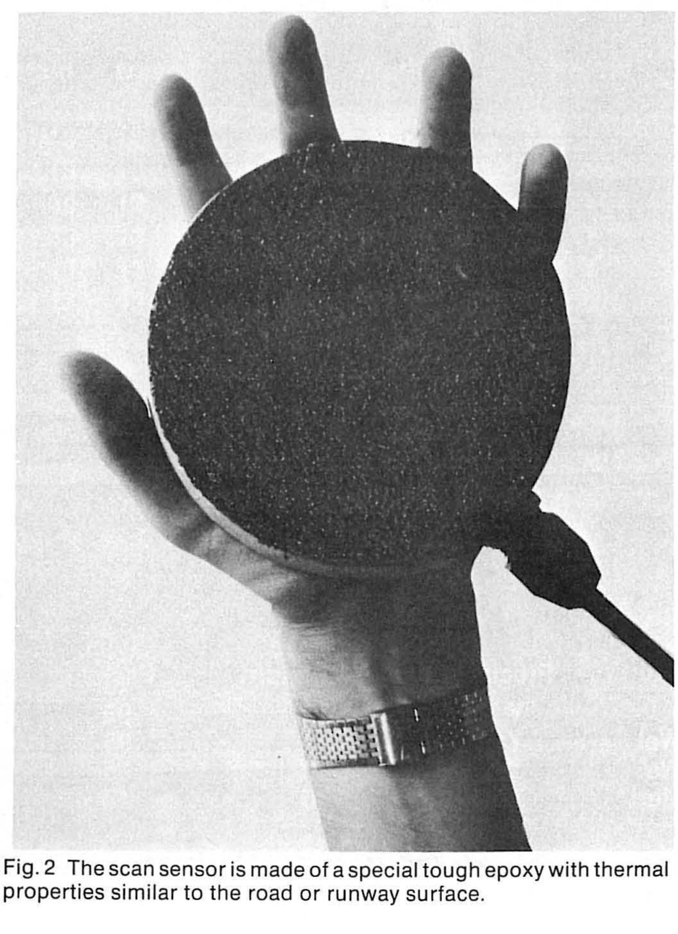

Fig. 2 The scan sensor is made of a special tough epoxy with thermal properties similar to the road or runway surface.

in turn differs from that of ice or snow, the sensor's output signal reflects the condition of its surface, which closely approximates that of the surrounding pavement surface. In simplistic summary, the sensor measures electric flow across the sensing unit to detect the presence of ice, snow or water, which exhibits varying degrees of electrical resistance. The sensor is installed flush into a 5½-inch hole (Fig. 3) and is color matched to the pavement surface so that it holds and releases heat at the same rate as the surrounding pavement composition.

The SCAN surface sensor can determine the temperature of the pavement if the pavement is "DRY," "WET," "CHEMICAL WET," "ABSORPTION" and "SNOW AND

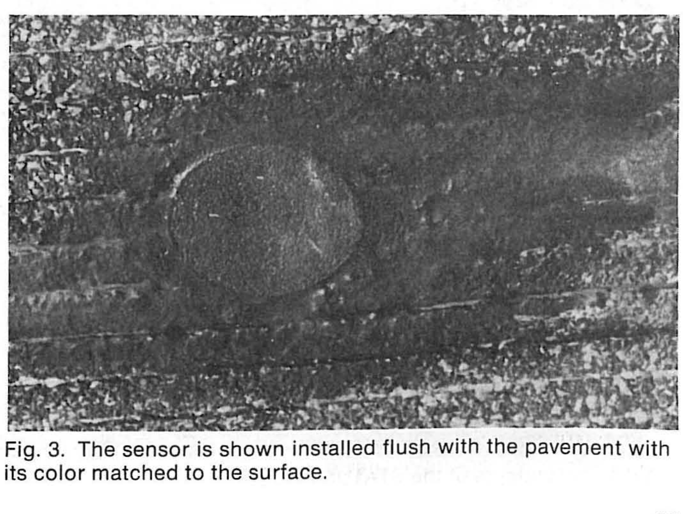

Fig. 3. The sensor is shown installed flush with the pavement with its color matched to the surface.

ICE ALERT." The SCAN sensor system measures a chemical factor which indicates the approximate amount of chemical concentrate on the pavement under wet conditions.

3.2 Atmospheric Sensors

The SCAN system measures the air temperature and relative humidity at a Remote Processing Unit (RPU). The dewpoint temperature is calculated from the air temperature and the relative humidity of the air at the RPU.

3.3 Data Processing Units

All data collected by the sensors are transmitted to Remote Processing Units (RPU). Each RPU receives data from up to four pavement sensors, as well as atmospheric sensors, in the form of a DC analog signal. The RPU processes the analog signal into a digital format which is then relayed to the Central Processor Unit (CPU). The CPU analyzes, stores and formats the data it receives from the RPUs and displays it on microcomputer terminals. The terminals display RPU and sensor locations, air and surface temperatures, dewpoint temperature, relative humidity, wind direction and speed, and the current date and time. The system updates the data on the terminal screen every 15 seconds. The system information can be displayed with custom color graphics, tailored to the customer's specification. All information displayed can be printed in various formats, depending on the information desired.

3.4 Displays of Observations from the Scan Surface System

The data collected from the SCAN system surface and atmospheric sensors are displayed on the terminal of the system in specific formats called pages. Pages include:

a. "STATUS PAGE" which provides: a title Section, Atmospheric Conditions, and Surface Conditions. The status titles listed below describe the surface condition at the surface sensor location. See Fig. 4.

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

WET: Precipitation/moisture present in liquid form on the surface, and surface temperatures above 32°F (0°C).

DEW: Moisture present on the surface, the dewpoint has been reached and surface temperature is above 32°F (0°C).

FROST: Frost present on surface, the dewpoint has been reached and surface temperature is below 32°F (0°C).

FROST AND DEWPOINT: Frost conditions have been reached and the surface temperature is no longer at or below dewpoint temperature of the air.

ABSORPTION: Residual chemical pulling moisture from the air; pavement may appear dry.

CHEMICAL WET: Precipitation/moisture present in liquid form on the surface and surface temperature is at or below 32°F (0°C).

SNOW/ICE ALERT:

a) Precipitation/moisture in liquid form on the surface starting to freeze.

b) Precipitation/moisture on the surface, which has frozen.

b. The "SUMMARY PAGE" (Fig. 5) presents the current data of all the surface sensors connected to the system. It allows the operator to see "at a glance," much more of the data from the entire system for a quicker analysis. The CHEMICAL FACTOR displayed on the SUMMARY page is a feature that will assist in following the trend of surface conditions. CHEMICAL FACTOR is a relative indicator of chemical present in the moisture on the surface.

c. The "HISTORY PAGE" (Fig. 6) presents historic data from any surface sensor connected to the System. The last 15 significant changes which have occurred at this surface sensor are displayed. Progression of time is from the bottom to the top of the page. The parameter that caused the significant change is indicated with an asterisk.

d. The "GRAPH AIR PAGE" (Fig. 7) presents a graph of the previous hour's air temperature at the remote processing unit (RPU).

e. The "GRAPH SURFACE PAGE" (Fig. 8) displays a graph of the previous hour's surface temperature of any surface sensor.

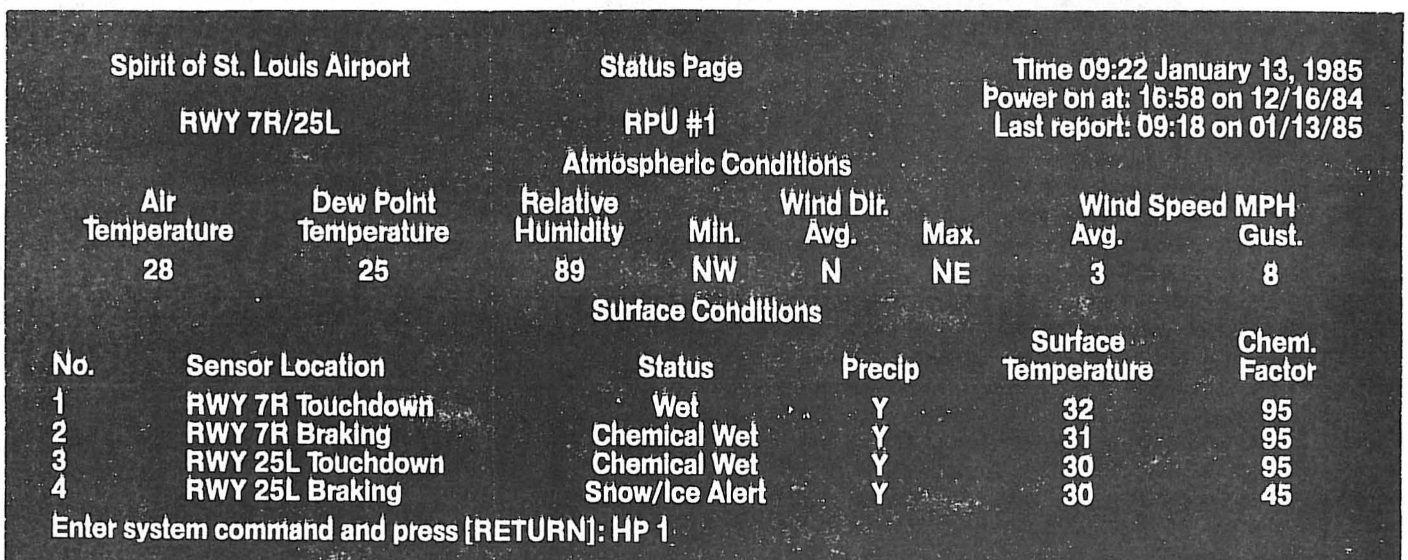

Fig. 4. An example of the STATUS PAGE.

CITY OF ST. LOUIS STREETS DEPT. Summary Page Time 08:16 February 10, 1987
Power on at: 13:40 on 01/05/87

Sensor No.	Sensor location	Status	Precip		Temperatures Surf		Air	Dew pt	CF
1	Rvr DsP S/B Dr. App.	Dry	N	^	34	^	33	23.0	
2	Rvr DsP N/B Pa. App.	Dry	N	^	37	^	33	23.0	
3	Rvr DsP N/B Dr. Deck	Dry	N	^	30	^	33	23.0	
4	Rvr DsP S/B Pa. Deck	Dry	N	^	30	^	33	23.0	
5	Rvrvw S/B Pa. App.	Dry	N	^	35	^	36	14.8	
6	Rvrvw S/B Dr. Deck	Dry	N	^	34	^	36	14.8	
7	Rvrvw N/B Dr. App.	Dry	N	^	35	^	36	14.8	
8	Rvrvw N/B Dr. Deck	Dry	N	^	32	^	36	14.8	
9	Gravois W/B Pa. App.	Dry	N	^	38	^	34	20.9	
10	Gravois W/B Dr. Deck	Dry	N	^	35	^	34	20.9	
11	Gravois E/B Pa. App.	Dry	N	v	34	^	34	20.9	
12	Gravois E/B Pa. Deck	Dry	N	^	34	^	34	20.9	
13	Lindell E/B Pa. Deck	Dry	N	^	34	^	39	22.1	
14	Union S/B Pa. Deck	Dry	N	^	35	^	39	22.1	
15	Union N/B Pa. App.	Dry	N	^	36	^	39	22.1	
16	Lindell W/B Dr. Deck	Dry	N	^	34	^	39	22.1	

Enter system command and press <RETURN> :

Fig. 5. An example of the SUMMARY PAGE.

I.D.O.T. Peoria District Four Time 09:23 March 13, 1984
Power on at: 16:58 on 03/06/84
Sensor # 1 History Page McClug Br App W/B pl

Time	Day	Status	Precip	Rel. Hum.	Chem. Factor	Temperatures Surf.	Air	Dew pt.	Wind Dir/Vel
09:15	13	Wet	Y	88	95	33	* 28	24	246/ 2
09:13	13 *	Wet	Y	90	95	* 33	27	24	248/ 2
09:00	13	Chemical Wet	Y	90	95	* 31	27	24	240/ 3
08:53	13	Chemical Wet	Y	92	95	* 30	26	24	242/ 3
08:40	13	Chemical Wet	* Y	92	95	* 29	26	24	250/ 2
08:17	13	Chemical Wet	N	92	95	28	* 26	24	241/ 3
07:57	13	Chemical Wet	N	92	95	* 27	25	23	240/ 3
06:44	13	Chemical Wet	N	93	95	* 25	24	22	245/ 2
01:26	13	Chemical Wet	* Y	92	95	24	24	* 22	245/ 3
22:25	12	Chemical Wet	N	91	95	22	23	20	241/ 3
22:12	12	Chemical Wet	* N	91	95	* 23	23	20	238/ 5
22:00	12 *	Chemical Wet	Y	91	85	25	23	20	230/ 4
19:19	12	Ice/Snow Alert	Y	93	45	25	23	21	225/ 8
19:11	12	Ice/Snow Alert	Y	92	45	* 27	23	21	225/ 8
19:01	12	Ice/Snow Alert	Y	92	45	* 29	24	21	229/10

Enter system comand and press [RETURN]

Fig. 6. An example of the HISTORY PAGE.

3.5 Tailored Computer Graphics for Monitoring and Interpretation

The SCAN Color Graphics Terminal is an SSI software package that allows the SCAN System user to view in an enhanced form the pavement and atmospheric data from the system. Pavement statuses are displayed in colors selected by the user and thus can provide instant recognition of potentially hazardous situations. Sensor data histories may be viewed graphically, also utilizing color to assist interpretation of the information. A map option, available for each of the

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BOSTON LOGAN AIRPORT              Graph Page    Time  08:43   February 10, 1987
                                                Power on at: 07:40 on  02/08/87

Air temperature               0        RPU # 3         Intxn. 9-4R
  25  +
  24  +
  23  +
  22  +
  21  +
  20  +
  19  +
  18  +                                                          **
  17  +                                                        **
  16  +
  15  +**                                                 *****
  14  +  ********
  13  +          *****************************************
  12  +
  11  +
  10  +
   9  +
   8  +
   7  +
   6  +
      +         +    .    +    .    +    .    +    .    +         +
      6         5         4         3         2         1         0
Enter system command and press <RETURN> :RS 6
```

Fig. 7. The GRAPH AIR page displays the previous hour's air temperature at the remote processing site.

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BOSTON LOGAN AIRPORT              Graph Page    Time  08:39   February 10, 1987
                                                Power on at: 07:40 on  02/08/87

Surface temperature                 Sensor # 6         Runway 9/4R
  27  +
  26  +
  25  +
  24  +
  23  +
  22  +
  21  +***
  20  +
  19  +   ********
  18  +           *************
  17  +                        **********
  16  +
  15  +                                  *****************        *
  14  +                                                   ********
  13  +
  12  +
  11  +
  10  +
   9  +
   8  +
      +         +    .    +         +         +    .    +         +
      6         5         4         3         2         1         0
Enter system command and press <RETURN> :
```

Fig. 8. The GRAPH SURFACE page displays the previous hour's temperature at the ground surface.

systems, displays the information from the entire system in color map format.

4. FORECASTING FOR ROAD, BRIDGE, AND RUNWAY SURFACES

It takes 5 to 10 times more chemical to remove ice than to prevent it. Therefore, the procedure of anti-icing (as opposed to de-icing) is much more cost effective in snow and ice control. One of the most important factors in anti-icing is timing, knowing, "when" to apply chemicals. Putting on too much too soon is wasteful. Applying too little too late is also wasteful and will allow ice formation to continue.

A very important factor in anti-icing is the pavement temperature. Knowing the current pavement temperature is important in determining what kind of chemical to use and to some degree the application rate. To properly plan for anti-icing situations, it is also necessary to have an accurate forecast of pavement temperature for the next 6 to 24 hrs. An accurate forecast of pavement temperature is much more important than the air temperature forecast because it is the pavement temperature that affects ice formation on the pavement surface. Temperature differences between air and pavement can be as much as 30° to 40°F.

An accurate forecast of when the pavement conditions are going to change (dry/wet and unfrozen/frozen) is equally important in the anti-icing procedure.

4.1 The SSI Forecast *(SCAN*CAST) Center

Surface Systems, Inc. (SSI), headquartered in St. Louis, MO., in early 1986 to establish a forecasting facility that concentrated on "pavement" forecasting (See Fig. 9). This is a forecasting service not offered by government agencies or other private weather forecasting sources. The SSI pavement forecast is called SCAN*CAST, SCAN for Surface Condition ANalyzer, and CAST as in foreCAST. The products and services provided by this specialized forecast center are primarily designed for agencies responsible for the maintenance of pavements (roads, bridges and runways), and for those responsible for safe and timely traffic operations (motor carrier dispatchers, airline flight controllers, and airport flow-control specialists).

The SCAN*CAST Center is staffed with professional, experienced meteorologists. In addition to accurate and continuous SCAN System pavement observations, the Center utilizes observations, forecasts, advisories, warnings and graphical maps from the National Weather Service and the Federal Aviation Administration.

4.2 SCAN*CAST Center Products and Services

All products and services provided by the SCAN*CAST Center are based on observations from the SCAN Systems.

The SCAN*CAST Bulletin was designed to assist decision makers, those individuals responsible for ice and snow control. The SCAN*CAST provides a forecast of pavement temperature and pavement condition. Parameters are projected graphically as shown in Fig. 10. Both the pavement temper-

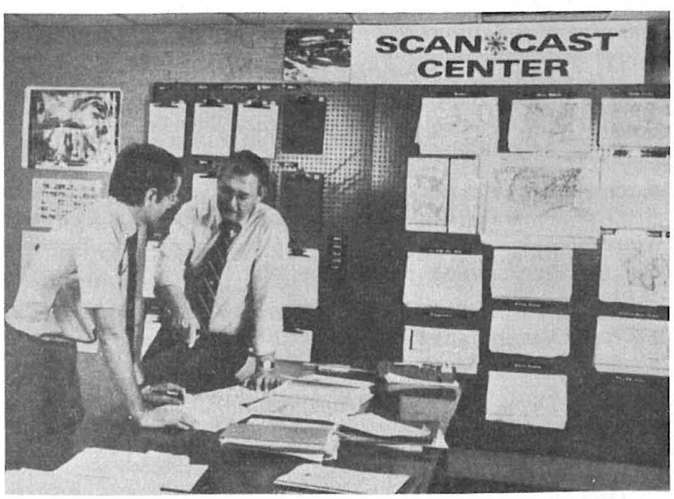

Fig. 9. At the SCAN*CAST center, Joe Kelley discusses a forecast with a staff member.

*SCAN*CAST is a registered trade mark of Surface Systems, Inc.

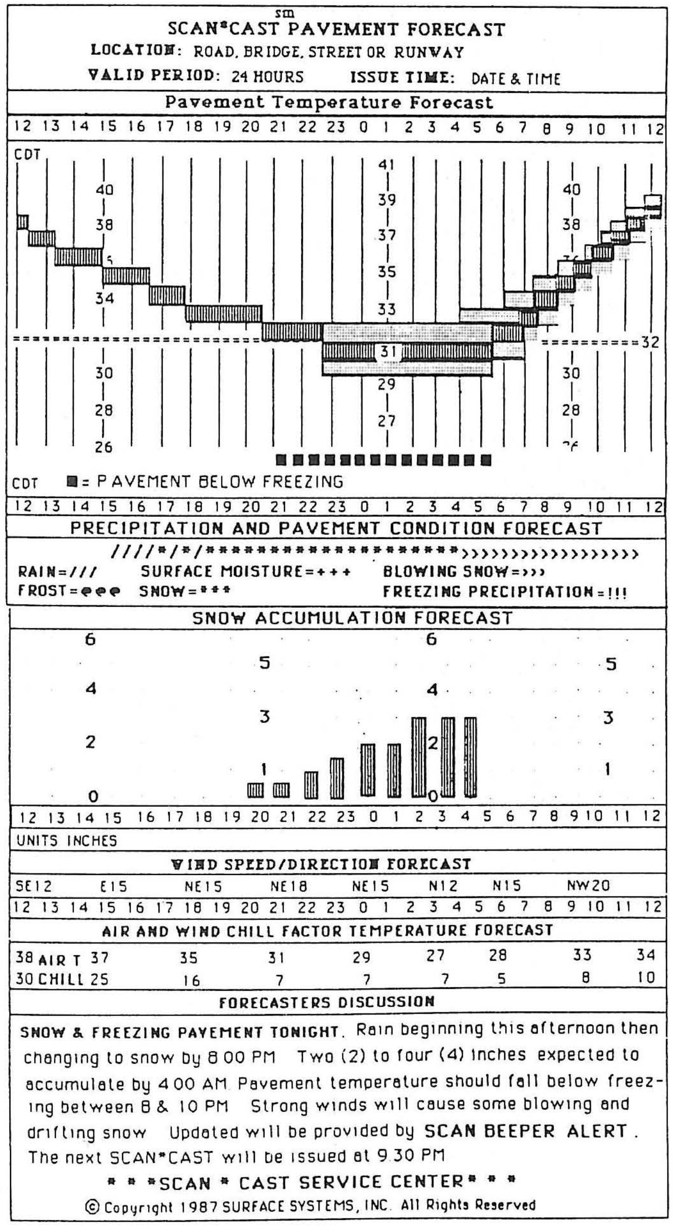

Fig. 10. A graphical SCAN-CAST print-out of the various parameters.

ature and the condition projection are computer generated with inputs from the SCAN Sensor System and from the SSI forecasting staff. The temperature forecasting model is based on the heat balance of the pavement surface, using the heat balance equation:

$$RN + H + S + LE = O$$

where
RN = NET RADIATION
H = HEAT EXCHANGE WITH THE AIR
S = HEAT EXCHANGE WITH THE ROAD STRUCTURE
LE = LATENT HEAT EXCHANGE

The computer forecasting model is called SHARP, an acronym for *S*CAN *H*ighway *A*nd *R*unway *P*rojection.

The forecasting model is initialized from SCAN System information.

a. The actual pavement temperature at the SCAN site.
b. The actual subsurface temperature at the SCAN site (unless the forecast site is a bridge or elevated pavement).

The forecast values input into the model by the meteorologists are:

a. Air temperature
b. Dewpoint temperature
c. Cloud amount
d. Cloud type
e. Precipitation—pavement wetness
f. Wind speed averages

The following variables can be changed or modified for each individual SCAN*CAST site:

a. The thermal properties of the road stucture
b. The latitude
c. The shadow ratio relating to the road or runway topography

4.3 SCAN*CAST Accuracy

The 1986–87 winter season verification statistics have been completed for six locations covering the geographic areas from New England to the Rockies (Massachusetts to Colorado).

Freezing Pavement—The forecast to alert maintenance officials of frozen pavement conditions during the forecast period was correct 90% of the time.

Freeze Time Error—The average error in forecasting the time when the pavement would reach 32° F or 0° C was 1 hour and 59 minutes. The minimum error for the 6 locations was 52 minutes and the maximum was 2 hours and 15 minutes.

Precipitation (start time, duration, and snow amount)—The combined accuracy of these three forecast components was 74.5% correct.

4.4 SCAN*CAST Service Not Limited to the Winter Season

The SSI Forecast Center will provide the SCAN*CAST service throughout the year. Airlines have expressed interest in using the temperature model projection for high-altitude airports. Construction companies and airports have also expressed interest in the SCAN*CAST for peak temperature forecasts.

5. SUMMARY

Accurate observations of pavement temperatures and conditions (DRY, WET, CHEMICAL WET, and SNOW AND ICE), and reliable data processing and data storage units that interact with computer terminals can now provide decision makers (responsible for ice and snow control) with valuable, real-time pavement data.

New computer technology has and will continue to improve forecasting skills in many meteorological areas. The SCAN * CAST service product is an example of focus and concentration on a specific forecasting problem that has the potential to save large amounts of monies for those responsible for ice and snow control. Consider a large city street department that spends $5,000 per hour for crew overtime. If a correct pavement weather forecast can save one hour in overtime cost per storm, and the city averages 10 storms per year, the annual saving amounts to $50,000 just in overtime costs.

The SCAN pavement network can provide valuable meteorological data not available from other sources, and with continued growth could greatly improve the accuracy of numerical computer models for all types of weather prediction.

ACKNOWLEDGMENTS

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NOTES AND BIBLIOGRAPHY

1. Mr. Joe R. Kelley has over 30 years in the field of meteorology, including eight years as a General Manager of Global Weather Dynamics, Inc. of Monterey, California. He is presently Vice President, Meteorological Services with Surface Systems, Inc. of St. Louis, Missouri. Mr. Kelley was instrumental in the start-up of two commercial weather forecasting centers, one to support airlines and aviation; the other, a first of its kind in North America, provides roadway and runway pavement weather prediction for ice and snow control.

2. Mr. David Trask received the B.S. and M.S. in Meteorology from the University of Utah, Salt Lake City, Utah. He is presently Manager, Weather Forecasting Services with Surface Systems, Inc. of St. Louis, Missouri. Mr. Trask has 14 years experience in providing weather support to highway departments and airport operations responsible for ice and snow control.

*3. Ms. Olga Hunt received the B.S. in Meteorology from Parks College of St. Louis University, Cahokia, Illinois. She is currently a staff meteorologist with Surface Systems and assigned to the SCAN*CAST Center.*

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