# REMOTE PAVEMENT WEATHER SENSING AND APPLICATIONS FOR THE TRANSPORTATION INDUSTRY

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ABSTRACT

This paper provides an overview of remote pavement weather sensing technology and applications for the transportation industry.

Components of remote pavement weather sensing systems and applied applications:

1. Surface sensors embedded in the pavement sense and record pavement temperature and pavement conditions (dry, wet, chemically wet [surface temperature $\leq 0°C$ with sufficient deicing chemical to prevent icing], ice/snow, dew and frost).

2. Atmospheric sensors that sense and record air temperature, relative humidity, wind speed and direction, precipitation (type [rain or snow] and intensities).

3. Data processing units, data handlers, color enhanced computer workstations, and system software that provide instant recognition of significant changes in pavement weather conditions.

4. A numerical weather forecasting computer model based on the heat balance equation, developed and refined to support the first centralized weather forecasting facility established solely to provide ice/snow control guidance.

5. Weather instruction and system education for ice and snow control managers.

Technology advances continue in weather instrumentation, remote pavement sensing, computer design and function, computer software, and communications. Although relatively new when compared to weather instrumentation installed by the National Weather Service (NWS) at commercial airports, remote road and runway weather stations for ice and snow control now number over six hundred installed throughout 44 of the United States.

Real-time pavement specific weather information provides meteorologists with required data for improved pavement temperature and pavement condition prediction that can reduce the estimated 2 billion dollars spent annually on ice/snow control in North America.

Key Words: Remote Roadway/Runway Weather Sensing System Technology

## INTRODUCTION

The purpose of this paper is to provide information about the rapid expansion of private sector roadway and runway remote weather sensing systems and applications for the transportation industry in North America.

In the United States, private sector commercial weather companies have provided all the funding for the research and development of road/runway weather information systems and numerical weather forecasting models for the provision of pavement weather data and for the preparation and issuance of ice and snow control management forecasts. This fits with the philosophical position taken by the United States Weather Service policy statement published by the U.S. National Weather Service, "The National Weather Service and the Private Weather Industry: A Public-Private Partnership. The U.S. NWS takes responsibility for general and severe weather forecasting, plus meteorological observations. Specialized forecasting and niche forecasting are allocated to the commercial weather companies."

This government-private sector relationship in the U.S. has allowed commercial weather companies to provide systems and services to agencies responsible for safe and cost effective management of roadways and runways.

## WHY REMOTE PAVEMENT WEATHER SENSING SYSTEMS ARE NEEDED

There are nearly 4 million miles of roads and streets in the United States on which more than 2 trillion vehicle miles of travel are logged each year.(*)

Our highways carry approximately 75 percent of the value of all goods and services produced by our economy, and more than 20 of all tons of freight hauled. Over 90 percent of all travel occurs on our highways. Even a temporary loss of mobility due to inclement weather will result in social and economic losses.(*)

The estimated annual maintenance cost for snow and ice control alone currently exceeds $1 billion dollars in the United States. In many states, snow and ice control is the single most costly maintenance activity.(*)

Over 10 million tons of winter chemicals and salt are applied to the nation's highways and bridges each year.(*)

In 1989, nearly 2 million (1,916,000) accidents occurred on wet, ice covered, or snow/slush covered pavements. This amounted to 29 percent of all accidents and includes approximately 7,500 accidents which resulted in fatalities. Statistics show that while inclement weather averages only about 3.5 percent of the time in the United States, 13 percent of the fatal accidents take place in bad weather. (*) Remote pavement weather sensing systems are a requirement for cost effective year around maintenance program. Making decisions that could save or waste many thousands of dollars, pounds, marks, etc. based on non-pavement weather information is no longer an acceptable maintenance practice.

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(*) Story, J., 1991. Road Weather Information System - Federal Perspective. In: Fifth Annual Winter Weather Workshop Presentation, St. Louis, MO.

Figure 1 illustrates the potential waste in manpower and materials that might occur when timely surface (pavement) specific information is not available for making a critical ice and snow control maintenance decision. Without site specific pavement temperature and pavement condition information available for the storm scenario illustrated in Figure 1, there would have been a high probability that decisions would have resulted in taking unnecessary actions, resulting in considerable waste of taxpayers money. The following exemplifies improved decisions based on remote pavement weather sensing systems.

Premium Pay

Without pavement specific information, crews could have been alerted and called out as early as 0700 hours based on the air temperature and the forecast for snow. Based on real-time pavement temperature and pavement condition information with an accurate pavement specific forecast, this agency reduced the number of crews on standby and delayed calling out crews until 1600 hours.

Anti-Icing/De-icing Chemical Application

Snow began falling at 1000 hours with an air temperature of 0°C. Without knowledge that the pavement temperature at that time was 7°C, tons of chemical (salt) would have been applied unnecessarily and 7 to 8 hours before actually needed. Applying chemical too early or too late is both wasteful and damaging. An application too early usually results in loss from blowing off the roadway or runway. An application too late allows the ice to bond to the pavement.

## THE ROAD/RUNWAY WEATHER INFORMATION SYSTEM (See Figure 2)

Surface (Pavement) Sensors

Pavement temperatures are obtained from solid-state electronic devices installed in the roadway or runway. The *passive* surface sensors are usually constructed of materials with thermal characteristics similar to those of common pavement materials. The surface sensor is approximately 13 centimeters in diameter, installed in a 14 centimeter hole flush with the pavement surface, and color matched to the surrounding pavement so the sensor absorbs and releases light energy at the same rate. Surface sensor systems use both thermally active and passive sensors. However, the passive type has had much greater acceptance with well over 2000 in the U.S., Canada, the UK, Europe, and Iceland. The passive sensor contains a capacitor with two elements mounted underneath which measure the dielectric effect of moisture, both water and solid-state forms. Because the dielectric constant of air differs from that of water, which in turn differs from that of ice and snow, the sensor's output signal reflects the condition on top of the sensor, which closely approximates conditions on the surrounding pavement surface. Pavement condition statuses are DRY, WET (above 0°C), WET (not frozen at or below 0°C), SNOW/ICE ALERT (at or below 0°C), DEW, FROST and ABSORPTION. Other measurements from this sensor include a chemical concentration factor (a relative indicator of the deicing or anti-icing chemical present in the moisture on the surface sensor. Performance of the sensor is not degraded by climatic conditions, traffic, or ice-control chemicals. The thermally passive sensor has a stable operating range from -30°C to +50°C.

Subsurface Temperature Sensors

Probes are installed directly below the surface sensor at a depth of near 40 cm and provide heat flux information primarily for computer models designed to predict pavement temperatures. Frost depth information is also used by highway agencies to regulate truck routing on the basis of the frost level beneath the road surface. The accuracy range is -30°C to +50°C.

Atmospheric Sensors

*Air Temperature* is measured over a range from -62°C to +70°C.

*Relative Humidity* measurements range from 10 to 100 percent.

*Hydrometeors* (including precipitation) are detected in the air by sensing interruptions in an infrared optical beam.

*Wind Direction and Speed* sensors have an operating range of 360 degrees and record speeds up to 215 km/hr.

Data Processing Units

All data collected by the sensors are transmitted to a remote processing unit (RPU), which in turn converts the analog signal into a digital format and then relays the information to the central processing unit (CPU). The RPU receives data from up to four surface sensors, four subsurface sensors, and the atmospheric sensors. Measurements from the atmospheric sensors are used in the system logic processed by the RPU. The CPU analyzes, stores, and arranges the data it receives from the RPUs for information display on the workstation. The workstation displays the RPU and surface sensor locations and statuses, the atmospheric sensor information, and the current date and time. The system updates the information on the workstation as frequently as every 15 seconds.

Communications

Several telemetry options are available for system configuration, including dial-up and leased telephone lines, radio, microwave, fiber optics, satellite, and value added networks.

Workstation Formats and Displays

In addition to displaying the information in tabulated text formats, the system provides customer specified individualized color graphics. An example of a graphics format is illustrated in Figure 3. Critical pavement temperatures are color coded to provide instant recognition of situations that may require pro-active decisions.

## TAILORED VALUE ADDED WEATHER INFORMATION

Pavement Specific Weather Forecasting

The single most important element in making PROactive ice and snow control decisions is the current and projected (for the next 12-24 hours) pavement SURFACE temperature. The model output graphic prepared for ice and snow control maintenance managers is illustrated in Figure 3.

Ice prevention requires between 30 to 75 percent less chemicals than deicing operations (*). Therefore, anti-icing (as opposed to deicing) is much more cost-effective in snow and ice control. Knowing the current and forecast pavement temperature and the amount of chemical concentration on the pavement allows for improved chemical application timing. The difference between air temperature and pavement temperature can easily exceed 7°C.

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(*) FAA Advisory Circular 150/5220-13A, 1983: Runway Surface Condition Sensor Specification Guide.

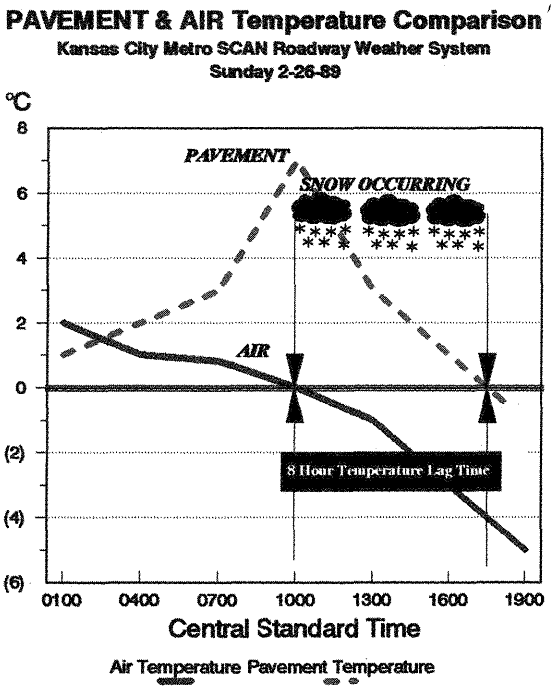


Figure 1

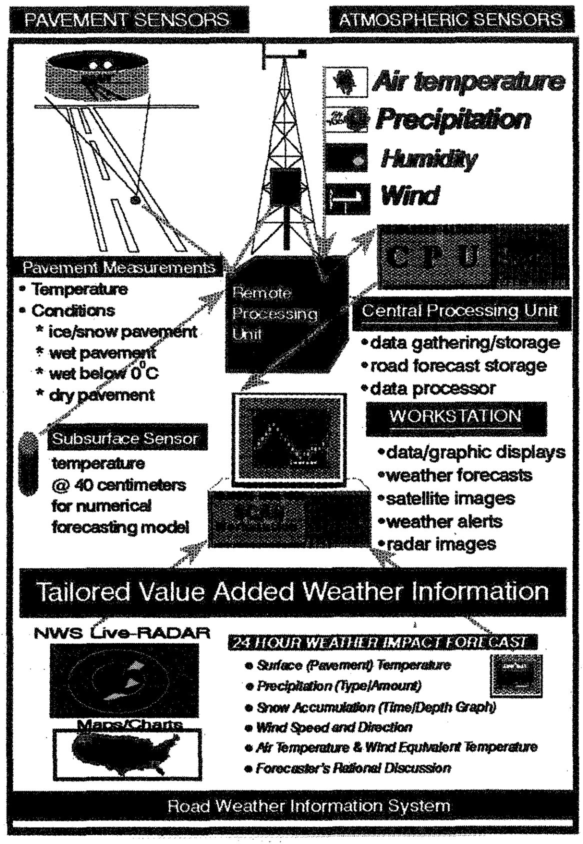


Figure 2

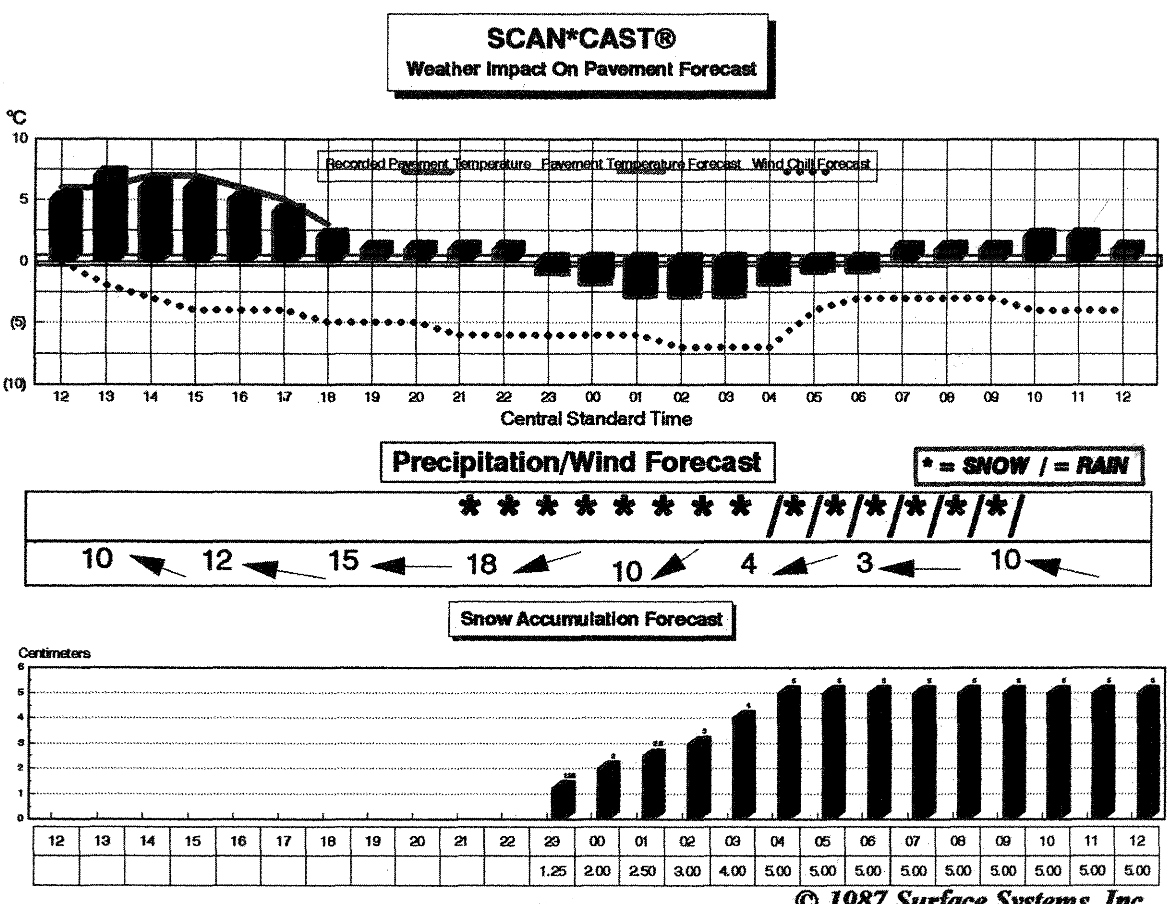


Figure 3

The pavement temperature at any given time is a balance between the heat added by meteorological parameters and heat lost by weather processes. To accurately project pavement temperature requires an accurate forecast of weather parameters, a stable numerical energy balance model, and the initial surface (pavement) temperature and subsurface temperature about 40 centimeters below the pavement surface. Pavement prediction models require site specific surface and subsurface data for initialization. The heat balance equation is expressed as:

0 = heat in - heat out
= (sun's heat + air's Heat + cloud's heat + heat of condensation + turbulent heat + ground heat) - heat loss from the pavement

or

$$RN + H + S + LE = 0$$

where

RN = net radiation
H = heat exchange with the air
S = heat exchange with the pavement structure, and
LE = latent heat exchange.

## WEATHER INSTRUCTION AND SYSTEM EDUCATION

Without proper training and educational programs, the return on investment in remote weather stations cannot be fully realized. Through training and education, users of remote weather systems will understand how to properly maintain and use the information from remote weather information stations. An investment must be made not only in the system, but also for initial and on-going training. Making the correct ice and snow decision involves understanding meteorological processes as they affect pavements. When will the precipitation start? Will it be rain, snow, mixed; or will rain freeze as it strikes the pavement? How much will there be and how long will it last? How cold will the pavement get? What chemicals will be effective? Specialized workshops and seminars can improve the use of pavement weather information and weather impact forecasts for ice and snow control on roadways, bridges, and runways.

## SYSTEM UTILIZATION AND BENEFITS

The RWIS is not the total solution for cost effective and highly efficient ice and snow control maintenance programs, but certainly has proven very successful in reducing standby/availability pay as well as increase savings in materials due to preventive rather than reactive treatment of pavements.

Documented and published savings from pro-active decisions based on road weather information systems:

1. Indianapolis Department of Transportation (*)
   - $23,050 (one storm) saved because a correct decision was made to not call out crews, based on the observed and forecast pavement temperature.
   - $486,375 (two seasons) saved in manpower, equipment and chemicals (*).

2. Wisconsin Department of Transportation (**)
   - $75,000 saved per storm
   - 2,500 tons of salt saved per storm

3. New Jersey Department of Transportation (***)
   - 3 hours delay in spreading chemicals
   - $54,170 saved for each statewide spread saved

## SUMMARY

Technological advances continue in weather instrumentation, remote pavement sensing, computer design and function, computer software, and communications. Although they are relatively new, roadway and runway remote weather stations with pavement-specific data provide improved information on which to base ice and snow control management decisions.

Pavement weather events directly affect all pavement maintenance decisions. Therefore, pavement weather data and pavement-specific forecasts should be considered by agencies which are responsible for ice and snow control. Pavement-specific weather reports and forecasts allow ice and snow control officials to be proactive instead of reactive. This can reduce the billions of dollars spent each year on ice and snow control in North America.

## ACKNOWLEDGMENT

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## REFERENCES

Balgowan, R., 1988. Evaluation of the Accuracy, Reliability, Effectiveness, Expansibility, and Potential Benefits of the SCAN EF Moisture, Frost and Early Warning System. Report FHWA/NJ-88-003, U.S. Department of Transportation.

Kelley, J., 1990. Solutions to Improve Ice And Snow Control Management on Road, Bridge, and Runway Surfaces. Transportation Research RECORD No.1276 - Maintenance, Transportation Research Board, National Research Council, Washington D.C.

Story, J., 1991. Road Weather Information Systems - Federal Perspective. Prepared for presentation at the Fifth Annual SCAN Winter Weather Workshop, St. Louis, MO

Wisconsin's Winter Weather System, 1990. TR News 147, TRB, National Research Council, Washington, D.C., pp. 22-23.

Yamin, H., 1991. Analysis of the Integrated Weather Monitoring System in Indianapolis, Indiana. Prepared for presentation at the North American APWA Snow Conference, Montreal, Canada.

(*) Analysis of the Integrated Weather Monitoring System in Indianapolis, Indiana.
(**) TR News 147, Wisconsin's Winter Weather Workshop.
(***) Evaluation of the Accuracy, Reliability, Effectiveness, Expansibility, and Potential Benefits of the SCAN EF Moisture, Frost and Early Warning System.