Maximizing the Use of Roadway Weather Information Systems: Final Report

Sponsored by the Project Development Division
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ABSTRACT

The object of this project was to make recommendations to the Iowa DOT (IaDOT) on more effective uses of Roadway Weather Information Systems (RWIS) data in winter highway maintenance decisions. We first recommend one site be placed on a paved surface that is not part of a traveled roadway to provide a test site for on-going research and demonstration on use of RWIS data.

From the results of the survey and discussions with supervisors, it is clear that graphical displays of data are needed to more effectively communicate information to end-users. The survey furthermore gave evidence that Automated Weather Observing Station (AWOS) data are being under-utilized, again in part because of lack of recognition of the value of these tabular data. Better visual displays of pavement temperature and weather information in general would facilitate decision-making by maintenance personnel. Also, the RWIS indicator that reports the presence of frost does not distinguish microscopic frost accumulations that are of no consequence to safety, from large accumulations that significantly reduce friction. Maintenance personnel therefore have no way of distinguishing the presence of significant frost. There is a need to have AWOS stations upgraded to include precipitation reports. Procedures need to be developed to effectively archive measurements for follow-on studies to further refine use of meteorological data.

Data and information from the National Weather Service (NWS) should be more directly incorporated into the IaDOT data stream, as should AWOS data. In particular, the current coding impediments to getting the NWS nowcasts on the Data Transmission Network (DTN) should be removed so that garages will have access to one of the most useful locally generated, publicly available short-term forecast products. Most importantly, all data should be blended as seemlessly as possible so users do not need some special code for accessing and displaying different types of data.

Survey results indicated that most supervisors are properly using meteorological data available to them during the 24 hours preceding a storm, and they find the DTN system to be especially helpful, probably because of its primarily graphical display of data. As an event begins, they appropriately rely heavily on radar data, but are not making optimum use of other types of data that would assist decision-making, such as AWOS and NWS warnings and special weather statements. Scenario-based training exercises should be used to improve the flow of weather data, information, and response actions during storm conditions. Also, because real-time reports of snowfall amount are sparse among traditional weather data sources, an internal system of measuring and relaying snowfall at garages should be established to assist in response and later forecast verification.

Educational and training programs are needed on use of AWOS data, use of pavement temperatures, and interpretation of radar. Videotapes are judged to be the most practical way at present to offer these programs, but interactive CD-ROM or Internet learning modules would be better in the longer term.

There are legal limitations on current pavement conditions that can be disseminated to the public. A limited amount of RWIS pavement temperature data now is available on the Internet. When the data dissemination system ultimately is migrated more fully to the Internet, data should be widely available to the general public.

The full spectrum of weather data, with recommended improvements, should be available to and their use strongly encouraged for cities and counties. Training programs and videos will be just as important at the city-county level as at the state level. Results of our intercomparison of RWIS pavement temperatures give examples of temperature variability from city-to-city and city-to-rural area. These can be used as a basis for estimating city/county pavement temperatures from measurements on state roadways. Data from RWIS and AWOS sites could be combined with agricultural and environmental measurements to provide a comprehensive resource for public safety, disaster preparedness, environmental management, and economic development.

INTRODUCTION AND OVERVIEW OF RESEARCH RESULTS

This project was proposed as Phase I of a 2-phase program to evaluate the present use of weather information by IaDOT maintenance personnel, recommend revised procedures, and then implement the resulting recommendations. Midway through Phase I (evaluation phase) the FORETELL project was funded. This project is a multi-state venture that engages the National Weather Service (NWS) and the Forecast Systems Laboratory of the National Oceanic and Atmospheric Administration and proposes to supplant the current weather information-generation and distribution system with an advanced system based on state-of-the-art technologies. The focus of the present project was therefore refined to consider use of weather data by IaDOT personnel, and the training programs needed to more effectively use these data. Results of the survey revealed that two major areas — training of personnel on use of data from whatever source and more precise information on frost formation — are not addressed in the FORETELL project. These aspects have been the focus of the present project.

SUMMARY OF SURVEY RESULTS

A survey was designed and distributed to IaDOT maintenance supervisors to assess the uses of weather information before and during winter events leading to snowfall or ice or frost accumulation. The survey and tabular summary of responses and conclusions are given in Appendix A. This survey formed the basis for much of the information relating to use of weather information and training needed to achieve more effective maintenance operations.

PAVEMENT TEMPERATURE ANALYSES AND SUMMARY OF CROSSROADS 2000 PAPER

Pavement temperatures are a critical factor in winter roadway conditions. Better understanding of pavement temperature changes offers opportunities for more effective strategies on snow, ice, and frost mitigation/removal activities. We provide here a summary of our investigation into behavior of pavement temperatures in various locations on bridges and roadways. More details are given in the paper prepared for delivery at the Crossroads 2000 conference, which is provided in Appendix B. The results given below go beyond the Crossroads 2000 paper to examine seasonal trends.

Nighttime pavement temperatures, pavement cooling rates, and the number of hours required for an urban location to cool to its rural counterpart (urban lag times) were analyzed for roadway approaches (RA), bridge decks over land (BL) and bridge decks over water (BW) for both Des Moines and Cedar Rapids downtown and southwest (rural) RWIS sites for different classifications of cloudiness during a four month period.

Pavement temperatures consistently differed between Des Moines urban and rural RWIS sites and also between the Cedar Rapids downtown and counterpart rural RWIS sites. An understanding of these consistent differences can provide maintenance supervisors valuable information for scheduling roadway treatment for frost or ice. For example, if an urban roadway temperature consistently lags a nearby rural roadway temperature by 3 hours under nighttime cooling, a 1 AM observed frost onset in the rural area would suggest a 4 AM frost onset in town, all other factors being equal.

In the following discussion, positive pavement temperature differences indicate that the urban site was warmer than its counterpart rural site. In addition, temperature difference ranges are expressed from the -1 to +1 standard deviations calculated from the average temperature differences.

Des Moines Pavement Temperatures

Analyses of Des Moines pavement temperature differences show that the urban site was consistently warmer than the rural site for all four months (October '96 (97), December '96, January '97, April '97) under different cloud classifications. For example, under clear/calm conditions, the average BL difference for October '96 was 2.9°F, for December '96 was 3.0°F, for January '97 was 3.0°F, and for April '97 was 1.3°F. Average temperature differences between urban and rural sites were greatest under clear/calm conditions, less for transitions in cloud cover, and least for completely overcast skies. For example, under clear/calm conditions, the average RA difference in December '96 was 3.0° F. When overcast skies became clear, the average value was 2.2°F. Transition from clear skies to overcast conditions led to an average magnitude of 2.0°F. For completely overcast conditions, the average difference was 1.9°F.

Seasonal trends for pavement temperature differences showed that January '97 had the greatest magnitudes under clear/calm conditions where the differences ranged from 2.2 - 5.6°F for RA, from 0.9-5.9°F for BL, and from 0.6-5.2°F for BW.

Des Moines rural cooling rates were greater than the urban rates. The only exception found was in October '96 when average urban rate was greater by 0.2°F/h than its counterpart rural rate under clear/calm conditions. Cooling rates were greatest under clear/calm conditions and least under overcast skies for all months. Trends showed that the transition from overcast to clear skies had greater magnitudes than the transition from clear to overcast conditions. It was common to see that the bridge decks had a larger magnitude by 0.2°F/h when compared to their counterpart roadways for all months and cloud classifications. April '97 values were greater than for other months for all cloud classifications. In general, spring values were 0.5-1.0°F/h greater than all other months, while December '96 values had the lowest cooling rates.

Overcast conditions allowed for the greatest urban lag times ranging from 0.3-9.5 h, otherwise no significant trends according to cloud classification were observable. In general, the bridge decks had smaller lag times than the roadways during all months and under the different cloud classifications. The April '97 calculations had the lowest lag values ranging from 0.3 h under overcast skies to 0.8 h under clear/calm conditions.

Cedar Rapids Pavement Temperatures

Positive average temperature differences indicated that the urban site was consistently warmer than its counterpart rural site under different cloud classifications for all four months examined. The average roadway values had the larger magnitudes when compared to their bridge deck values. Clear/calm skies allowed for the greatest temperature differences. April '97 values were the greatest under clear/calm conditions where the average magnitudes ranged from 1.5-2.2°F. October '97 values ranged from 2.0-2.4°F, January '97 values were 1.6-1.8°F, and December '96 values were 0.9-1.0°F. Not much consistency existed in pavement temperature differences under transitioning cloud coverage, but April '97 and October '97 had the greatest magnitudes (1.0-2.9°F). December '96 and January '97 values were the least (0.0-2.5°F), unlike Des Moines. Under overcast conditions, October '97 had the greatest values (1.4-1.9°F). Magnitudes for April '97 ranged from 1.1-1.4°F. December '96 and January '97 values were least ranging from 0.4-0.8°F, opposite of Des Moines where December and January had the largest values.

Downtown cooling rates were generally slightly greater or equal to the rural rates, opposite of Des Moines. So, in general, the urban rates were greater than the corresponding rural rates by 0.1-0.2°F/h. Rates at both locations were greater under clear/calm conditions, while under complete overcast skies the rates were the smallest. The exception was in December '96 when the highest rates occurred under overcast skies transitioning to clear conditions. In all months and under all cloud classifications the rural bridge deck cooling rates were equal to or slightly greater than the rural roadway rates by 0.2°F/h. In December '96 and January '97 urban bridge deck cooling rates were equal to or slightly greater than those for the urban roadway by 0.2°F/h, but for October '97 and April '97 values the reverse effect happened by the same magnitude for all cloud classifications. The spring and fall months had the greatest average cooling rates, while the winter months had the lowest values.

Similar to Des Moines, overcast conditions allowed for the greatest lag times ranging from 2.0-4.0 h, otherwise no significant trends were observed according to cloud classifications. In general, the bridge decks had smaller magnitudes ranging from 0.1- 0.2 h than the roadways except under overcast conditions where a degree or slightly more difference was common. Winter months had the largest lags while fall and spring months had the smallest lag times.

Conclusion

In summary, analyses of Des Moines and Cedar Rapids pavement temperatures revealed that the urban effect was greatest in winter months and least in fall and spring. Urban pavement temperatures tend to reach a threshold temperature (e.g., 32°F) after its comparable rural site. Secondly, a bridge deck tends to reach a threshold temperature before its comparable roadway. Clear/calm conditions allowed for the largest average temperature differences between urban and rural sites for both roadways and bridge decks, while overcast skies produced the lowest pavement temperature differences and largest urban lag times.

OVERVIEW OF TRAINING NEEDS

The survey revealed opportunities for better use of weather data. The research team, in close collaboration with the project monitor and associated Maintenance Division staff, has developed recommendations for training of maintenance personnel on how to better use weather data.

Educational and training programs are needed on use of AWOS data. AWOS data provide information at 1-minute intervals that can be used to monitor storm movement and evolution without waiting for hourly or less frequent measurements, or advisories issued from other sources. But these data are presented in coded tabular form, not easily interpreted by maintenance personnel who are at the time busy with many tasks. Better use of pavement temperatures and an understanding of pavement temperature behavior under various conditions of cloud cover at various times of the winter season will help supervisors anticipate imminent freezing and thawing conditions. Our research revealed that there are differences between urban and rural bridges and roadways in temperatures and cooling rates. Knowledge of these subtle characteristics will aid decision-makers in the timing of maintenance operations, particularly during morning and evening rush hours in urban areas. Instruction on interpretation of radar will aid supervisors in gaining an understanding of locations and types of precipitation as well as movement and evolution of precipitating regions.

Videotapes are judged to be the most practical way at present to offer training programs for maintenance personnel, but interactive Internet learning modules would be better in the longer term due to ease of updating and the use of real time information to enhance learning. Dialog is underway between video producers and members of the research team to produce video scenarios of evolving storm events and the appropriate use of data for these conditions.

OUTLINE OF FROST FORECAST NEEDS

Frost was identified in the survey as being one of the most troublesome elements of winter maintenance operations.

Because of the urgency expressed by some maintenance personnel of having better frost information, the research team has devoted effort to investigate alternative means of forecasting frost that goes beyond the frost occurrence information produced by Surface Systems Inc. (SSI). A preliminary frost accumulation model has been developed and is being tested. This model, with sufficient calibration, has the potential to distinguish between microscopic insignificant frost accumulations from accumulations that require treatment by maintenance personnel.

Some very preliminary tests were completed using the roadway pavement temperature, 2-meter air temperature, dew-point temperature, and road condition status from the rural (southwest) RWIS site in Des Moines over a period from December 30, 1996 through February 2, 1997. The Des Moines International Airport Automated Surface Observing System (ASOS) site weather data were used to determine sky conditions and precipitation events. SSI provided frost forecasts, and IaDOT maintenance personnel supplied visual roadway frost observations. For this preliminary analysis, eight separate cases were examined.

Case Studies

The frost accumulation model was tested by evaluating its predicted occurrence and magnitude of roadway frost against forecasts provided the IaDOT and against the automated observation of frost provided by the RWIS.

In Case Study I (12/31/96-01/01/97) under foggy skies and warm air advection, frost accumulation began by 21:24 (CST) and ended at 04:08 (CST) according to the model. A maximum depth, 0.000082 m (0.082 mm), was predicted to occur at 04:00 (CST) while sunrise was at 07:41 (CST). Sensor indicated "Frost". Frost was forecast by SSI, but winter maintenance personnel did not observe any frost on roadways or bridges.

In Case Study II (01/03/97) under clear skies, accumulation was projected to begin at 00:00 and end at 08:48. A maximum depth, 0.000054 m (0.054 mm), was predicted to occur at 08:28 while sunrise was at 07:41. Sensor indicated "Frost". Frost was forecast, but none was found.

In Case Study III (01/18/97-01/19/97) under clear skies, accumulation was projected to begin at 23:18 and end at 10:03. A maximum depth, 0.00086 m (0.86 mm), was predicted to occur at 08:48 while sunrise was at 07:37. Sensor indicated "Frost". Frost was forecast and found.

In Case Study IV (01/19/97-01/20/97) under mostly clear skies, accumulation was estimated to start at 19:53 and end at 09:33. A maximum depth, 0.000058 m (0.058 mm), was predicted to occur at 09:28 while sunrise was at 07:36. Sensor indicated "Frost". Frost was forecast, but none was found.

In Case Study V (01/20/97-01/21/97) where transition from clear skies to partly cloudy conditions occurred, the model predicted accumulation to begin at 20:43 and end at 07:49. A maximum depth, 0.00072 m (0.72 mm), was estimated to occur at 07:05 while sunrise was at 07:36. Sensor indicated "Frost". Frost was forecast, but none was found.

In Case Study VI (01/24/97) under cloudy skies with snow falling, model frost accumulation began at 03:52 and ended at 07:58. A maximum depth, 0.0000052 m (0.005 mm), was predicted to occur at 05:19 while sunrise was at 07:34. Roadway condition status was different than "Frost" and stated "Chemically Wet". This showed that the sensor indicated that precipitation was occurring in liquid form even though the surface pavement temperature was at or below 32^0 F. Frost was not forecast and none was found.

In Case Study VII (01/30/97-01/31/97) under clear skies and NW winds blowing 5-20 mph, accumulation was predicted to begin at 20:56 and end at 03:04. A maximum depth, 0.000027 m (0.027 mm), was predicted to occur at 01:40 while sunrise was at 07:28. Sensor indicated "Frost". Frost was not forecast, and none was found.

In Case Study VIII (01/31/97-02/01/97) under transition from clear skies to cloudy conditions, model frost accumulation began at 20:12 and ended at 08:27. A maximum depth, 0.000083 m (0.083 mm), was projected to exist at 07:52 while sunrise was at 07:27. Sensor indicated "Frost". Frost was forecast, but none was found.

Conclusion

The RWIS roadway sensor condition status reports "Frost" whenever the pavement temperature falls to or below the dew-point temperature. However, this in itself does not necessarily mean that the roads are slippery or that the maintenance personnel will visually observe frost. The model uses the same criterion to begin accumulating frost but goes beyond the SSI yes/no report to provide an estimated accumulation depth.

Roadways that are subject to frequent chemical treatment are likely to frost later or not at all under conditions that would produce frost on clean pavement. Several of the case studies where frost was forecast likely would have produced frost on roadways had no residual chemical been present. The current agreement of IaDOT with the weather forecasting service calls for an alert if there is 30% or greater chance of frost. From this we also will expect differences between forecasts and observations.

There is a need to standardize frost observations made by IaDOT. For instance, observations made before sunrise may give different results than observations after sunrise for light frost due to illumination differences. Also a standardized criterion (e.g., visible tracks, actual collection of ice crystals as observed from 3 feet above the roadway surface) will help reduce uncertainty in marginal situations.

Although many more case studies must be undertaken to provide accurate calibration, the case studies herein reported suggest that a model-defined depth must be more than 0.72 mm to be observed on a roadway. A further complication to calibrating the model arises due to the possible effects of residual frost/ice suppression chemicals on the roadway that might preclude frost formation. In some cases the model and the SSI sensor report frost that forms and disappears before the normal observing time, in which case no human observations would be available for verification. However, these preliminary results give encouragement that software can be developed to provide maintenance personnel with enhanced information on frost occurrence.

RECOMMENDATIONS

As a result of the foregoing survey, investigations, and other activities we have the following recommendations with respect to use of weather data by IaDOT maintenance personnel, some suggestions for use by cities and counties, and some suggestions on development of a state-of-the-art measurement network.

Specific Recommendations

1. Deployment modifications (including possible extension of the sensor network) of RWIS equipment

Since the proposal was written, the RWIS network has been expanded from 22 sites to 31 and now is in the process of being extended to 50. Criteria for placement have changed from primarily an equal-spaced grid approach to one that recognizes traffic counts and specifics of the interstate system. The research team has discussed micrometeorological considerations where flexibility in siting is possible. One recommendation is that one site be placed on a paved surface that is not a part of a traveled roadway to provide a test site for on-going research and demonstration on use of RWIS data.

2. Acquiring supporting software (off-shelf or to be developed)

From the results of the survey and discussions with supervisors, it is clear that graphical displays of data are needed to more effectively communicate information to end-users. The survey furthermore gave evidence that AWOS data are being under-utilized, again in part because of lack of recognition of the value of these tabular data. Better visual displays of pavement temperature and weather information in general would be helpful. Also, the RWIS indicator that reports the presence of frost does not distinguish microscopic frost accumulations, which are of no consequence to safety, from large accumulations that significantly reduce friction. Maintenance personnel therefore have no way of distinguishing the presence of significant frost. There is a need to have AWOS stations upgraded to include precipitation reports. Procedures need to be developed to effectively archive weather information for follow-on studies that will help further refine the use of meteorological data.

3. Acquiring and using of weather information outside the RWIS network (NWS, AWOS).

Data and information from the NWS should be more directly incorporated into the IaDOT data stream, as should AWOS data. In particular, the current coding impediments to getting the National Weather Service nowcasts on the DTN should be removed so that garages will have access to one of the most useful locally generated, publicly available short-term forecast products. Most importantly, all data should be blended as seemlessly as possible so that users do not need some special code for accessing and displaying one kind and another for a second type of data. Discrepancies in identifying data (IWOS vs AWOS) need to be resolved.

4. Development of the most effective flow of weather data, information, and response actions during storm conditions

Survey results indicated that most supervisors are properly using meteorological data available to them during the 24 hours preceding a forecasted storm, and they find the DTN system to be especially helpful, probably because of its primarily graphical display of data. As an event begins, they appropriately rely heavily on radar data, but are not making optimum use of other types of data which would assist in the decision-making process, such as AWOS and National Weather Service warnings and special weather statements. Scenario-based training exercises should be used to improve the flow of weather data, information, and response actions during storm conditions. In addition, because real-time reports of snowfall amount are sparse among traditional weather data sources, an internal system of measuring snowfall at the garages and relaying the information should be established to assist in response actions and later verification of forecasts.

5. Educational and training programs for implementation of revised procedures

Educational and training programs are needed on use of AWOS data, use of pavement temperatures, and interpretation of radar. Videotapes are judged to be the most practical way at present to offer these programs, but interactive CD-ROM or Internet learning modules would offer a better learning environment and more timely updates in the longer term.

6. Data to be made available to the public

There are legal limitations on current pavement conditions that can be disseminated to the public. A limited amount of RWIS pavement temperature data now is available on the Internet. When the data dissemination system ultimately is migrated more fully to the Internet, data should be widely available to the general public.

Applications for Cities and Counties

The full spectrum of weather data, with improvements recommended above, should be available to and their use strongly encouraged for cities and counties. Training programs and videos will be just as important at the city-county level as at the state level. Results of our intercomparison of RWIS pavement temperatures give examples of temperature variability from city to city and city to rural area. These can be used as a basis for estimating city/county pavement temperatures from measurements on state roadways.

A Multi-agency Environmental Measurement Network

The IaDOT has an opportunity to partner with ISU and other state agencies to create a state-of-the-art environmental measurement network. Data from 50 RWIS sites and 32 AWOS sites could be combined with agricultural and environmental measurements to provide a comprehensive resource for public safety, disaster preparedness, environmental management, and economic development.

APPENDIX A. FROST SURVEY RESULTS SUMMARY

Use of Weather Information
in
Roadway Maintenance Decisions

Results of a Survey

July 1997

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INTRODUCTION

The Iowa Department of Transportation, in partnership with the Federal Highway Administration, approved a project to investigate the use of meteorological information in making winter maintenance decisions by state highway maintenance personnel. One part of that study was the conducting of a survey of personnel at regional transportation centers across the state of Iowa during May 1997.

The survey was designed to gather the following information from the regional transportation centers for winter maintenance operations: (1) sources and types of weather data, (2) sources and timing of weather forecasts, (3) characteristics of observed bridge and roadway frost, (4) personnel computer skills, and (5) comments on opportunities for improvement of weather information provided to the local garages. A sample questionnaire is given in Appendix 1 with the tabulated responses provided for each question.

Eighty-nine surveys were sent to maintenance supervisors throughout the state, and seventy-three surveys were returned as itemized in Table S1. Results were analyzed and compared with a similar (but not identical) survey conducted in the fall of 1987 (Takle, 1987). The following sections provide an analysis of these data and intercomparison between the two surveys.

TABLE S1 Return of survey sent to IaDOT maintenance supervisors in IaDOT Transportation Centers (ITCs)

ITC	Surveys Sent	Surveys Returned	Percent Returned
Northwest	14	12	86
Northeast	15	12	80
East Central	14	12	86
Southeast	14	8	57
Central	17	11	65
Southwest	15	15	100
Unidentified		3	
Totals	89	73	82

Weather Information and Forecasts Received Electronically by Garages

The first question asked respondents to classify the importance they put on several types of weather forecast information received electronically at the garage in their preparation for an imminent storm. Precipitation type, storm start time, and wind speed were judged most important and dew-point temperature and wind chill were viewed as least important. Also very notable was the fact that 6 respondents did not recognize pavement-temperature information.

The second question requested how much reliance was put on various types of weather information after the storm was in progress. Respondents overwhelmingly are most likely to rely on radar, satellite, and TV or radio forecasts and were least likely to use AWOS through the IaDOT mainframe and NWS statements; city forecasts and NWS hourly roundups were more evenly divided. SSI forecast information and current RWIS data also were not widely used during the storm event.

SSI issues a weather and frost forecast at 1:00 PM with an update, if needed, at 4:00 AM. Respondents were asked to give the best time for an updated forecast. Responses slightly favored the present (4 AM) update over an earlier (10 PM) time of alert. When asked whether they would be willing to use a cellular phone to report and receive current weather, 73% answered yes.

From this series of questions, we conclude that there exists an urgent need to develop training programs to better use available data. Pavement temperature and dew-point temperature information is available both in forecast and observed form, but its usefulness is not recognized by operations personnel. Cloud-cover forecast information, which might be useful in post-storm road treatment is not used, apparently because of low level of forecast accuracy.

Meteorologists consider AWOS measurements reported at 1-minute intervals to be extremely valuable in following storm evolution. However, AWOS data scored extremely low, presumably because the supervisors do not find the AWOS data available through the IaDOT mainframe to be very user friendly and are unsure of how to interpret the data. A graphical representation of AWOS data would be most helpful for maintenance operations during storm events.

FROST INFORMATION

Table S2 gives a summary of responses to the question of whether one particular bridge is the first to accumulate frost during a frost event. There seems to be little agreement among transportation centers on this issue, with the NW center reporting yes and the others reporting no. The majority of 57% indicated no. These results are quite different from results of the same question on the 1987 survey that revealed that 64% of respondents observed one particular bridge to frost first.

TABLE S2 Is there one particular bridge in your area that is likely to be the first one (maybe the only one) to frost in the early morning in your area?

	1997			1987		
ITC	Yes	No	No Response	Yes	No	No Response
C	4	7		16	3	
NE	5	7		14	6	
NW	9	3		14	11	
SW	6	9		13	9	
SE	3	5		11	10	
EC	3	9		11	6	
Total	30	40		79	45	1

A similar question on roadway frost also generated mixed responses as is shown in Table S3. Again, only the NW ITC reports a particular stretch of roadway to frost first. It perhaps is notable that there are at least some in each region that agree with the statement, even though 71% reported that no particular stretch was first to frost. In the previous survey, 51% responded affirmatively to this question, but the division of answers within each region was much more even. In fact, the majority response was negative in all regions except the NW and NE.

TABLE S3 When roadways frost, is there a particular stretch of road that seems likely to frost first?

	1997			1987		
ITC	Yes	No	No Response	Yes	No	No Response
C	2	9		9	10	
NE	4	8		13	8	
NW	8	4		16	9	
SW	1	14		10	12	
SE	1	7		8	13	
EC	4	8		7	8	
Total	20	50		63	60	1

Visual evidence suggests that the timing of chemical application is quite important in maximizing effectiveness due to fugitive loss resulting from vehicular traffic. A related question is whether residual ice-suppression chemical may be retained on the roadway in sufficient amounts to be a factor of consideration for subsequent treatments. Respondents to the 1997 survey, by a slight majority of 37 to 33, observed a residual effect of roadway chemical treatment that extended over one day (Table S4). The SW and EC regions were the only regions disagreeing with the majority. In the 1987 survey, all regions had a majority responding negatively, with the totals favoring no by a margin of 76 to 43.

TABLE S4 Is a treated roadway less likely to frost the following morning?

	1997			1987		
ITC	Yes	No	No Response	Yes	No	No Response
C	8	3		8	9	
NE	8	4		8	12	
NW	7	5		10	14	
SW	6	9		5	16	
SE	5	3		8	13	
EC	3	9		4	12	
Total	37	33		43	76	6

The question summarized in Table S5 asked whether volume of traffic affects the formation of frost. Respondents in 1997 submitted a majority opinion of no, in agreement with the 1987 respondents, although the majority in 1997 was much less dominant. Only the SE and EC regions reported a majority of responses as yes in 1997 and none did so in 1987.

TABLE S5 Does the volume of traffic affect the formation of frost?

	1997			1987		
ITC	Yes	No	No Response	Yes	No	No Response
C	5	6		6	12	
NE	6	6		5	16	
NW	4	8		9	16	
SW	6	9		7	15	
SE	5	3		5	15	
EC	7	5		4	12	
Total	33	37		36	86	3

Table S6 summarizes observations on frosting of asphalt vs concrete road surfaces. The 1987 respondents clearly observed concrete to frost more quickly in the northern part of the state and asphalt to frost faster in the south. This polarization of surface behavior is clear in the 1997 data as well.

TABLE S6 Road surface which frosts most frequently

	1997			1987		
ITC	Asphalt	Concrete	No Diff.	Asphalt	Concrete	No Diff
C	4	4	3	7	8	4
NE	5	7	0	3	15	3
NW	3	6	3	3	17	5
SW	11	3	1	10	0	11
SE	1	2	4	15	2	4
EC	5	4	4	5	6	3
Total	29	26	15	43	48	30

A final frost question asked whether age of a roadway might influence its propensity to frost over in the winter. The same overwhelming majority in both years said no.

TABLE S7 Does the age of the roadway affect frost formation?

	1997			1987		
ITC	No	Yes, Older	Yes, Newer	No	Yes, Older	Yes, Newer
C	11	0	0	18	0	1
NE	9	2	1	17	3	1
NW	10	0	2	23	1	1
SW	10	2	3	20	2	0
SE	7	0	1	20	1	0
EC	10	1	1	13	2	1
Total	57	5	8	111	9	4

USE OF COMPUTERS BY IOWA DOT MAINTENANCE PERSONNEL

A series of questions sought information on familiarity of personnel with electronic media (computers and DTN). Ninety five percent of respondents use computers 3 or more times per week, with most (97%) of employees using computers at work and (52%) also using them at home. Computers mostly are used for access to the mainframe (97%), although other uses, in order, are remote-access DTN (67%), word processing (59%), and obtaining current RWIS data (53%). Sixty two percent of respondents were "very comfortable" or "comfortable" with computers, the rest being "not comfortable" or "somewhat comfortable". Ninety three percent indicated they would be willing to learn more about using computers. In contrast, 92% of those completing the survey were comfortable with the DTN, and 95% were willing to learn more about it. A final computer-related question asked whether a graphical or text format was preferred for weather information. Seventy three percent favored graphical display, 10% favored text, and 17% wanted both.

SUMMARY OF SURVEY GENERAL COMMENTS

Question 23 of the survey dealt specifically with improvements in weather information, and as might be expected with weather forecasting, the largest number of similar comments were about improving the accuracy of the forecasts. This type of comment was mentioned in 21 of the 45 responses. Many of the comments were directed at improving forecasts of storm start time. However, just about all other weather parameters were mentioned at least once, including glazing, wind speeds, wind direction, air temperatures, precipitation type, road temperatures, frost, storm stop time, and time of freezing of roads.

A somewhat more easily addressed problem was the next most popular, with 12 comments, and concerned more frequent weather updates. For the most part, more frequent forecasts (short-term forecasts of just a few hours) were mentioned, but a few people also wanted to see more rapid updates of current weather information. Fifteen-minute updates were mentioned, since 15 minutes is also the update time of the DTN radar images. These ideas could be implemented fairly easily and would also help to improve the perceived accuracy mentioned by so many supervisors.

Several comments (8) desired more RWIS sites closer to the garages. Most of these comments concerned the NE and SW parts of the state, although some concern was also mentioned by supervisors in the east-central and the western part of the central region. The northeastern region seems to have the biggest need.

Otherwise, no specific concern was mentioned by more than one or two surveys. It appears some areas don't have easy access to current RWIS information and would like it. Precipitation measurements of snow or ice would be helpful. Video cameras on towers were mentioned. It was also mentioned to include the time of sensor readings on the maps since there was concern that some readings looked old. Perhaps if a 15-minute (or other uniform) update time was used, this wouldn't be needed. Finally, a few people wanted to see highways or other roads overlaid on the radar maps and possibly other maps.

In summary, more accuracy is needed, especially for storm start time. Some improvements in accuracy or at least in user satisfaction would occur with much more frequent weather forecast updates. Better communication between SSI and the garages would help everyone involved to know when weather conditions are changing rapidly, or unexpectedly. Up-to-the minute data is desired, and at least some maintenance decisions are being made based on current conditions that could better be determined with more frequent and reliable updates of data, along with better map overlays.

Question 24 allowed general comments to be added and these were lengthier. Again, 15 of 33 (the largest number) were complaints about accuracy. Several people wanted to skip the 4 AM frost forecast since it didn't seem to be accurate in their view. Next in popularity were 6 praises for DTN, which some users feel is the best tool they have. About 4 comments again wanted more RWIS information, or more frequent RWIS updates on the current temperature maps. Finally, 3 again mentioned more frequent updates of the forecasts. Some concern was expressed about getting too much information and about difficulties with several different forecasts floating around. In light of the fact that many comments requested more information (more RWIS sensors, more frequent data), and receiving more frequent updated weather forecasts, it seems that most personnel see the need for timely information and are willing to alter SSI forecasts based current conditions.

APPENDIX B

May 1997 Winter Weather Survey
Compilation of Responses

1. Suppose a winter storm is being predicted to occur in your area within 24 hours. When preparing for the predicted storm, how important are the following portions of a forecast to you? (Circle the number that best describes the importance level of each portion. If you don't recognize or have access to some of the portions below, don't circle anything for those portions.)

		Very Important 4	3	2	Not at all Important 1	Did not recognize/ have access
A.	Pavement Temperature	52	12	3	0	6
B.	Air Temperature	54	17	1	0	1
C.	Probability of Precipitation	44	26	2	0	1
D.	Cloud Cover Percentage	14	31	21	6	1
E.	Wind Speed	59	11	2	0	1
F.	Wind Direction	44	23	6	0	0
G.	Wind Chill	7	15	32	15	4
H.	Dew Point	10	17	30	12	4
I.	Visibility	32	25	14	1	1
J.	Precipitation Type	66	6	0	0	1
K.	Snow Amount	46	23	3	0	1
L.	Storm Start Time	64	8	1	0	0
M.	Storm End Time	53	17	3	0	0

2. How much do you use the following types of weather information once a winter storm has begun (i.e. precipitation has begun, or will very shortly? (Circle the number that best describes how much you use each type of weather information. If you don't recognize or have access to some of the weather information below, don't circle anything for those.)

Note: NWS is National Weather Service

	Use a Lot 4	3	2	Never Use 1	Do not recognize/ Do not have access
A. SSI Forecast	32	24	10	0	7
B. Current RWIS Data	29	20	10	3	11
C. Weather Radar	66	6	1	0	0
D. Weather Satellite	44	18	6	0	5
E. TV or Radio Forecast	48	22	3	0	0
F. AWOS (IaDOT Mainframe; IDMS10)	6	12	18	19	18
G. Current Road Temps (on the DTN)	30	27	13	1	2
H. City Forecasts (DTN)	23	21	17	4	8
I. NWS Zone Forecast (Detailed Forecasts-NWS Iowa Zone Forecasts on the DTN)	26	18	19	3	7
J. NWS Hrly State Roundup from Current Conditions-IOWA on the DTN)	21	25	19	1	7
K. NWS Statements (NOAA Warnings & Alerts: NOAA Wire on the DTN)	14	18	20	7	14

3. Currently, SSI issues a weather and frost forecast at 1:00 p.m. If necessary, the frost forecast will be updated around 4 a.m. For you, what would be the best time for the updated frost forecast? (Circle one)

(31) A. 10 p.m.
(1) B. 11 p.m.
(0) C. Midnight
(0) D 1 a.m.
(41) E. As is (around 4 a.m.) ***If no answer was given, the default was 'E'***

4. Would you be willing to use a cellular phone to report and receive current weather information from around the state? You would use a cellular phone during major storm events and type in numbers (using a cellular phone) to report and receive current conditions.

(53) A. Yes, I am willing to use a cellular phone to report and receive current weather

(20) B. No, I am not willing to use a cellular phone to report and receive current weather.

5. Is there one particular bridge that is likely to be the first one (maybe even the only one) to frost in the early morning in your area?

(32) A. Yes

(41) B. No

6. Compared to other bridges, is there anything unique to this bridge that in your experience leads to more frequent frost formation? (***Note: This question was answered only if letter A was circled on the previous question***)

(20) A. Yes

(12) B. No

7. When roadways frost, is there a particular stretch of roadway that seems to frost first?

(21) A Yes

(52) B. No

8. Compared to other stretches of roadway, is there anything unique to-this stretch of roadway that in your experience leads to more frequent frost formation (e.g., sheltered area)? (*Note: This question was answered only if letter A was circled on the previous question*)

(21) A. Yes

(0) B. No

9. If a bridge or stretch of roadway is treated for frost one morning, does that make it less likely to frost the following morning, even if frost has been forecast to occur?

(39) A. Yes

(34) B. No

10. Does the volume of traffic on a bridge or roadway affect the formation of frost?

(35) A. Yes

(38) B. No

11. Which type of road surface seems to frost more frequently? (Circle one)

(29) A. Concrete

(29) B. Asphalt

(15) C. No difference

12. Does the age of the roadway affect whether it frosts more frequently? (Circle One)

(5) A. Old roadways frost more frequently

(9) B. New roadways frost more frequently

(59) C. There is no difference in frost frequency between new and old roadways

13. Which type of road surface seems to frost more heavily? (Circle one)
(23) A. Concrete
(34) B. Asphalt
(16) C. No difference

14. Does the age of the roadway affect whether it frosts more heavily? (Circle One)
(6) A. Old roadways frost more heavily
(10) B. New roadways frost more heavily
(57) C. There is no difference in the 'heaviness' of frost between new and old roadways

15. How often do you use a computer (not including the garage DTN)? (Circle one)
(69) A. 3 or more times a week
(2) B. 1 to 2 times a week
(2) C. 1 to 3 times a month
(2) D. Less than 1 time a month

16. Where do you use the computer (not including the garage DTN)? (You may circle more than one).
(38) A. At home
(71) B. At work
(3) C. Other

17. What do you use the computer for; whether you're at home, at work, or someplace else (not including the garage DTN)? (You may circle more than one).
(71) A. IaDOT Mainframe (Office Vision, IDMS 10, etc.
(43) B. Word Processing or Spreadsheet Applications
(39) C. Access current RWIS data
(49) D. Remote-Access DTN through laptop or home computer
(7) E. Internet or other On-Line Service
(20) F. Computer Games
(5) G. Other

18. How comfortable do you feel using a computer (not including the garage DTN? (Circle one)
(16) A. Very Comfortable
(29) B. Comfortable
(24) C. Somewhat Comfortable
(4) D. Not Comfortable

19. Regardless of your computer skills (not including the garage DTN), would you be willing to learn more about using computers?
(68) A. Yes
(5) B. No

20. How comfortable do you feel when you are using the garage DTN? (Circle one)
(47) A. Very Comfortable
(20) B. Comfortable
(6) C. Somewhat Comfortable
(0) D. Not Comfortable

21. Regardless of your garage DTN computer skills, would you be willing to attend a DTN training session if it were offered?
(69) A. Yes
(4) B. No

22. When you are using a computer or the garage DTN, do you prefer to view graphical weather information, or text weather information?
(53) A. I prefer to view graphical weather information.
(7) B. I prefer to view text weather information.
Note: 13 people circled both A and B

23. What one improvement in weather information available to you would allow you to make more effective decisions on winter road maintenance? (See summary page 16)

24. Please add any comments or suggestions you have. (See summary page 17)

APPENDIX C:

CROSSROADS 2000 PAPER

Use of Pavement Temperature Measurements for Winter Maintenance Decisions

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ABSTRACT

Formation of ice and frost on roadways and bridges presents a significant potential impediment to safe winter travel in Iowa. Roadway surface temperatures are not measured routinely by the National Weather Service and are not part of public forecasts of winter conditions, but highway maintenance personnel must make frost suppression and anti-icing decisions based on expectations of future roadway temperatures. Pavement temperatures are now measured at numerous locations in the state of Iowa and reported in real time to maintenance offices. One difficulty in use of such data is the question of how representative measurements made at one location are for other roadways in the vicinity.

We have analyzed January pavement temperature data from urban/rural sites for both bridges and roadways in/near Cedar Rapids and Des Moines to evaluate nighttime trends and differences of temperatures at different locations and under different weather conditions. Preliminary results show that urban roadway pavement temperatures near both Des Moines and Cedar Rapids are 2 to 5 °F higher than rural roadway pavement temperatures under clear sky conditions but only 1 to 2 or 1 to 3 °F higher under cloudy conditions or when cloud cover is changing.

INTRODUCTION

Literature Review

Northern latitudes of North America and western Europe experience frequent snow, sleet, ice, and frost events from late autumn to early spring. Impacts of these conditions on highway safety have stimulated numerous studies of road surface temperatures (*1*, *2*, *3*). Topography is a key factor controlling the variation of road surface temperature (RST). Winter nighttime RSTs can vary more than 25.4 ^{0}F (10 ^{0}C) across a road network depending on factors such as exposure, altitude, traffic and changes in the road-surface characteristics. Such variable pavement temperatures can create significant variations in surface traction when moisture is present on the surface and the range of pavement temperatures span the freezing point of water. Numerous studies (*4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14*) have led to development of road-surface models to predict the occurrence of frost, wet, dry, and icy conditions on the roadways.

Present Study

This study focuses on analysis of pavement temperatures in Iowa. We have examined differences between urban and rural patterns of temperature and temperature changes under different types of weather conditions. The cooling part of the temperature-change cycle is most critical for maintenance decisions, so we focus on pavement temperature behavior from late afternoon to early morning.

Data from roadway weather information systems (RWIS), maintained and disseminated under the auspices of the Iowa Department of Transportation (IaDOT), provide a valuable resource for numerous winter maintenance decisions. We analyzed nighttime pavement temperatures as reported by RWIS sensors located in and near Des Moines and Cedar Rapids under different conditions of cloud cover. Temperatures reported in this study are given in US customer units because maintenance personnel are most likely to use these units in operation.

METHODOLOGY

Data

Des Moines and Cedar Rapids each have two RWIS sites, one located generally southwest of the highly populated urban area and the other positioned in a downtown location. The downtown Cedar Rapids site has four pavement sensors located on I-380 in the vicinity of the Cedar River. Its rural (southwest) site is located on US Highway 30 near a railroad overpass, and it also has four pavement sensors. The downtown Des Moines site has three sensors located in the vicinity of the Des Moines River on I-235. Its rural (southwest) site has four pavement sensors located on I-35 over the Raccoon River and Highway 5. Sensors at all urban and rural sites are placed on roadway approaches, bridge decks over land, and bridge decks over water (Des Moines rural site has one sensor in each of two bridges over water, BW1 and BW2). Cloud cover for Des Moines and Cedar Rapids was obtained from the January 1997 Local Climatological Data (LCD) records maintained by the National Climatic Data Center.

Procedure

RWIS pavement temperature data recorded at irregular intervals for the period 1-31 January 1997 were extracted from IaDOT archives and linearly interpolated to produce an hourly temperature dataset. This dataset served as the basis for computing temperature differences, cooling rates, and lag times between urban and rural sites. Average values were stratified according to conditions of cloud cover and cloud-cover change such as clear sky/calm wind, transition from overcast to clear skies (30-50% cloud cover), transition from clear to overcast skies (75% cloud cover), and complete overcast conditions. For both cities, in general, 3-6 cases were used for each cloud-cover category.

ANALYSIS AND SUMMARY

We excluded from our analyses periods when no major changes in large-scale weather systems were the dominant influence on changes in pavement temperature.

Des Moines Pavement Temperatures

We analyzed and compared nighttime pavement temperatures for roadway approaches (RA), and bridge decks over land (BL) and water (BW) between downtown and rural Des Moines RWIS sites under different classifications of cloud cover. Figure 1 shows an example of diurnal variations in pavement temperatures for a calm/clear case.

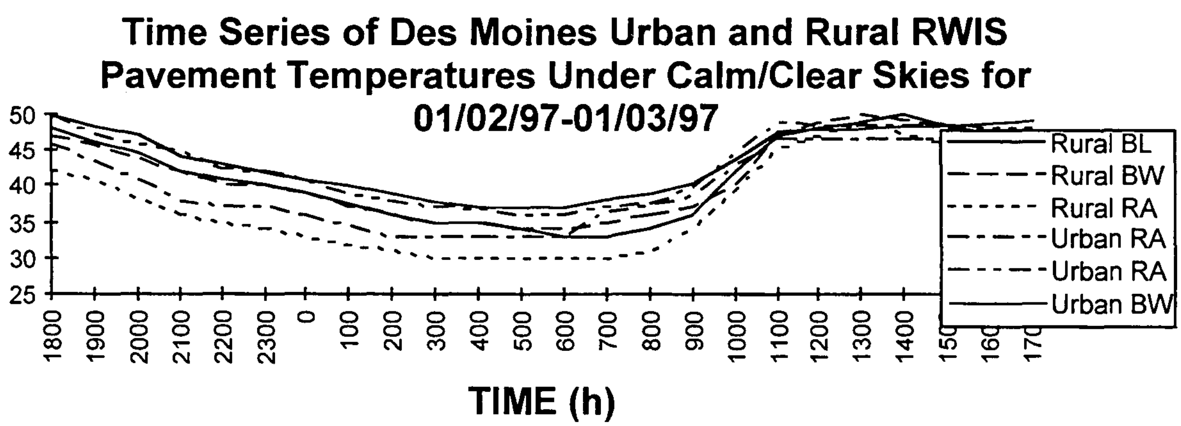

FIGURE 1 Time Series of Des Moines Urban and Rural RWIS Pavement Temperatures

Monotonic decrease in temperature from mid afternoon to early morning as shown in Figure 1 is a typical pattern of observed pavement temperatures, with clear skies giving the most extreme rate of temperature decrease. Under clear sky conditions, the downtown roadway approach pavement temperature exceeded the southwest site temperature by 3.9^0 F, the bridge deck over land downtown was warmer by 3.4 ^{0}F, and the bridge deck over water downtown was warmer by 2.9^0 F. With complete overcast conditions, the roadway approach temperature downtown was warmer than its counterpart rural site by 1.6^0 F, the bridge deck over land downtown was warmer by 1.4^0 F and the bridge deck over water downtown was warmer by 1.2^0 F.

When complete overcast conditions gave way to clear skies (30-50% cover), the downtown roadway approach and bridge deck over land pavement temperatures were warmer than the southwest site by 2.0^0 F and 2.6^0 F respectively, and the downtown bridge deck over water pavement temperatures were 1.4^0 F warmer than its counterpart rural site. When skies became 75% cloud covered, the roadway approach downtown was 2.6^0 F and the urban bridge deck over land was 1.2^0 F warmer than the comparable rural site. The downtown bridge deck over water was warmer (1.4^0 F) than the rural bridge deck over water.

For Des Moines, a pavement temperature anomaly was observed to occur immediately proceeding sunrise (0600-0730 LST). Under all classifications of cloudiness, the urban roadway approach and bridge decks downtown were warmer than the rural west site by 5-10^0 F. The cause for this pavement temperature anomaly is unknown and requires further study.

The rate at which the pavement cools is a significant factor in forecasting when wet surfaces might freeze. Under clear skies, cooling rates in Des Moines ranged from 0.8-1.1^0 F h^{-1} for approaches, 1.0-1.3^0 F h^{-1} for bridge decks over land, and 1.1-1.2^0 F h^{-1} for bridge decks over water. Transition to partly cloudy conditions produced cooling rates of 0.8-0.9^0 F h^{-1} for approaches, 0.8-1.0^0 F h^{-1} for bridge decks over land, and 0.9-1.0^0 F h^{-1} for bridge decks over water. The transition to mostly cloudy skies produced cooling rates of 0.9^0 F h^{-1}, 0.9-1.0^0 F h^{-1}, and 0.9^0 F h^{-1}, respectively. When skies were overcast the cooling rates were only 0.2-0.3^0 F h^{-1}, 0.2^0 F h^{-1}, and 0.2^0 F h^{-1}, respectively. As a general rule, clear skies allowed fastest cooling, while completely cloudy skies suppressed the nighttime cooling rate. In addition, the approaches had the smallest cooling rates, while the bridge decks over water had the greatest cooling rates.

Maintenance personnel may be able to take advantage of the urban/rural pavement temperature difference in refining the timing of urban roadway treatments. For instance, if the time of ice formation due to pavement cooling at the rural site is noted, the urban pavement temperature and cooling rate can be used to predict time of freezing at urban sites. By dividing the urban/rural temperature difference by the urban cooling rate, we obtain an estimated lag time for the urban location to cool to the temperature of its rural counterpart. Table 1 shows the mean and standard deviation of temperature differences, cooling rates, and urban lag times for the roadways (RA), bridge decks over land (BL), and bridge decks over water (BW) for the different classifications of cloud cover.

TABLE 1 Average Pavement Conditions Between the Des Moines Urban and Rural RWIS Sites for Different Classifications of Cloud Cover, January 1997

	Clear and Calm Skies			Overcast to Partly Cloudy Skies(30-50% cover)			Clear to Mostly Cloudy Skies (75% cover)			Complete Overcast Skies		
	RA	BL	BW	RA	BL	BW	RA	BL	BW	RA	BL	BW
Temp. Difference (^{0}F)	3.9±1.7	3.4±2.5	2.9±2.3	2.0±1.1	2.6±1.4	1.4±1.5	2.6±1.9	1.2±0.8	1.4±1.4	1.6±1.6	1.4±1.1	1.2±1.2
Cooling Rates R: (^{0}Fh^{-1}) U:	1.1±1.0 0.8±1.2	1.3±0.9 1.0±1.0	1.2±1.0 1.1±1.0	0.9±1.3 0.8±1.1	1.0±1.3 0.8±1.1	1.0±1.1 0.9±1.2	0.9±1.3 0.9±1.3	1.0±1.4 0.9±1.1	0.9±2.6 0.9±1.2	0.3±1.0 0.2±0.9	0.2±1.0 0.2±0.8	0.2±0.8 0.2±0.8
Mean Urban Lag Time (h)	4.9	3.4	2.6	2.5	3.3	1.6	2.9	1.3	1.6	8.0	7.0	6.0

R: Rural cooling rate
U: Urban cooling rate

In summary, analyses of the Des Moines January 1997 data show that the downtown pavement temperatures were consistently warmer than the rural-site temperatures, usually by 2.5^0 F and as much as 3-5^0 F under clear skies. Under clear skies, the urban time lag was largest for approaches, and least for bridge decks over water. With 30-50% cloud cover, the lag was largest for bridge decks over land, and least for bridge decks over water. When cloudiness increased to 75%, the lags were highest for roadways, and lowest for bridge decks over land. For overcast conditions, the lags were very large for all sensor locations.

Cedar Rapids Pavement Temperatures

We evaluated and compared nighttime pavement temperatures for roadway approaches, bridge decks over land, and bridge decks over water for Cedar Rapids downtown and southwest (rural) RWIS sites for different classifications of cloudiness for the same period covered by the Des Moines analysis.

Data available for Cedar Rapids, although fewer than Des Moines, offer an independent comparison of urban/rural temperature differences and cooling rates. Under clear skies, the roadway approach temperature downtown typically was warmer than the southwest site by 1.6^0 F although differences as large as 3^0 F were recorded. The downtown bridge deck over land was approximately 1.8^0 F warmer than the rural site. For overcast conditions the downtown roadway approach pavement temperature exceeded the rural site temperature by 0.4^0 F, and the bridge deck over land was warmer by 0.7^0 F. For partly cloudy skies with 30-50% cloud cover, downtown pavement temperatures for both roadway approach and bridge deck over land were modestly warmer (0.4^0 F for approaches and 0.8^0 F for decks over land). When skies became about 75% cloud covered, the downtown roadway approach was consistently 1.5^0 F warmer than the comparable location outside the city. The urban bridge deck over land also was warmer (2.5^0 F) than the rural deck over land.

Downtown Cedar Rapids cooling rates generally were greater than rural-site rates. Under clear skies cooling rates ranged from 0.8-0.9^0 F h^{-1} for approaches and were 1.0^0 F h^{-1} for bridge decks over land. When skies were overcast cooling rates were only 0.2^0 F h^{-1} for approaches and bridge decks. Transition to partly cloudy conditions (30-50% cloud cover) and transition to mostly cloudy conditions (75% cloud cover) produced cooling rates of 0.4-0.6^0 F h^{-1} for approaches and 0.6-0.7^0 F h^{-1} for bridge decks. As a general rule, clear skies allowed fastest cooling, while completely cloudy skies suppressed the nighttime cooling rate.

In summary, the Cedar Rapids data show that urban pavement temperatures can be expected to exceed rural pavement temperatures, with a difference of 1.6^0 F being typical under clear conditions. Urban temperature lags typically were 1.8-2.0 h for clear skies, 1.0 h for roadways and 1.3 h for bridge decks under partly cloudy skies, and 3.0 h for roadways and 4.2 h for bridge decks under mostly cloudy conditions. For overcast conditions, the lags were 2.0 h and 3.5 h for roadways and bridge decks, respectively.

CONCLUSION AND DISCUSSION

In conclusion, we have seen that RWIS pavement temperatures can differ significantly between urban and rural locations and that cloud cover can have a significant influence on cooling rates at all locations.

Data for Des Moines show that downtown pavement temperatures were consistently warmer than the rural-site temperatures, usually by 2.5^0 F for cloudy conditions and as much as 3-5^0 F under clear skies and calm conditions. Cedar Rapids data confirmed the urban heat island effect although the magnitude of the difference was consistently less. Des Moines area cooling rates were the greatest with clear skies during the nighttime hours and the rates for bridge decks over land (1.0-1.3^0 F h^{-1}) exceeded its rates for approaches and bridge decks over water. Cedar Rapids cooling rates were of comparable magnitude. For clear sky conditions, the urban time lags ranged from 2.6-4.9 h in Des Moines where the approaches had the greatest values and bridge decks over water had the lowest values. Cedar Rapids lag times were about half as large. When skies were overcast the cooling rates were greatest (0.2-0.3^0 F h^{-1}) for approaches at both cities. For complete overcast conditions, the urban lags ranged from 6.0-8.0 h in Des Moines and about half as much in Cedar Rapids.

We emphasize that these results are preliminary since they cover only January and not other winter months which may experience different patterns of temperature cooling. Also, other January months may give patterns that depart from the limited period studied herein. Despite these limitations, we conclude that pavement temperatures offer roadway maintenance personnel guidance for treating roadways for frost, snow, and ice conditions.

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