

## 6.5 THE U.S. FEDERAL HIGHWAY ADMINISTRATION WINTER ROAD MAINTENANCE DECISION SUPPORT SYSTEM (MDSS) PROJECT: OVERVIEW AND RESULTS

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### 1.0 INTRODUCTION

Managing a winter maintenance program today is an increasingly complex endeavor. Just making sure that a plow blade is at the ready when the first flake falls is only a small part of the task. With tight budgets and the high expectation of the public for keeping roads clear of snow and ice, today's maintenance manager must be able to handle multiple tasks or risk falling behind the onslaught of winter weather. While good information leads to effective practices, all of the regulations concerning chemical applications, environmental impacts, and multiple, often contradictory weather forecasts can lead to information overload.

The U.S. Department of Transportation Federal Highway Administration (FHWA) recognized this potential problem in the late 1990's as part of its Road Weather Management (RWM) program. Weather forecasts were plentiful and a few companies issued road-specific forecasts, but there was a lack of linkage between the information available and the decisions made by winter maintenance managers. It was this gap between meteorology and surface transportation that became the genesis for the winter Maintenance Decision Support System (MDSS) (Mahoney, 2003).

Since 1999, the MDSS has matured into an operational prototype. During the winter of 2002–2003, the prototype was deployed at several maintenance garages in central Iowa for an initial field demonstration. A second, more comprehensive field demonstration was conducted during the winter of 2003–2004.

During the winter of 2004-2005, the prototype MDSS test bed will be operated in Colorado.

This paper describes the status of the MDSS project, results and lessons learned from the field demonstrations, targeted additional development efforts, and technology transfer process.

### 2.0 PROJECT ORGANIZATION

The MDSS is a research project that is funded and administered by the FHWA RWM program. A consortium of five national laboratories in coordination with State Departments of Transportation (DOTs), academia, and the private sector have also been participating in the development and implementation of the project, including:

- National Center for Atmospheric Research (NCAR), principal investigator
- Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL)
- Massachusetts Institute of Technology/Lincoln Laboratory (MIT/LL)
- National Oceanic and Atmospheric Administration (NOAA) Forecast Systems Laboratory (FSL)
- NOAA National Severe Storms Laboratory (NSSL)

The MDSS project integrates state-of-the-art weather forecasting and data fusion and optimization techniques with computerized winter road maintenance rules of practice (maintenance operations and procedures translated into computer logic). The result is guidance aimed at maintenance managers that provides a specific forecast of surface conditions and treatment recommendations customized for plow routes.

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The MDSS project has several goals:

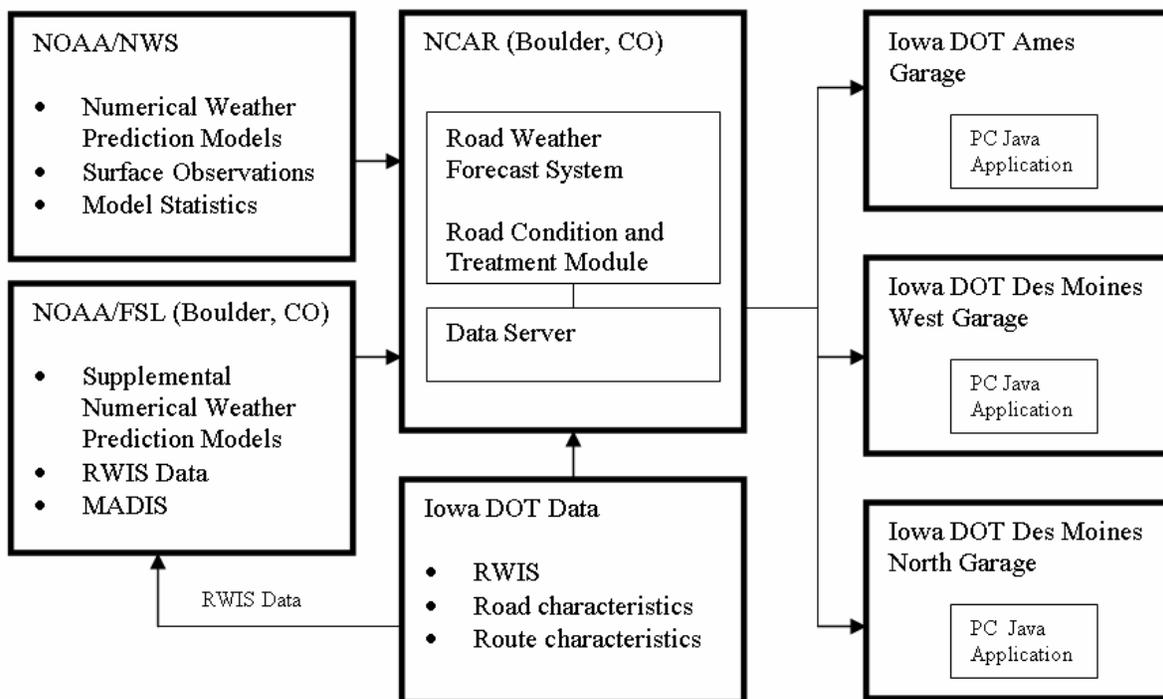
- Demonstrate to the State DOTs that new technologies are available to assist maintenance managers with maintaining safety and mobility on roadways and provide for more efficient use of chemicals, equipment, and staff.
- Show the private sector road weather providers that there is a market for these new technologies within the States. To aid this process, the FHWA is providing the core MDSS modules to any company or organization using an aggressive technology transfer process with the expectation that the MDSS technologies will be further improved and commercialized.

Success, as defined by the FHWA, will be reached when private sector companies integrate MDSS components or similar functions into their products, a process that has already begun. It is anticipated that State DOTs will purchase these new services. In the end, the project will serve to raise the bar on standards for services provided by the private road weather forecasting industry. This cycle has the potential to make State DOT operations more efficient and road conditions safer.

### 3.0 PROTOTYPE SYSTEM OVERVIEW

Each national laboratory brings unique capabilities and expertise to the project. CRREL has experience in creating models for predicting road surface temperature. MIT/LL concentrated on translating the road maintenance rules of practice into computer algorithms. FSL provided high resolution weather models called mesoscale models which generally cover a region or group of States. NSSL contributed algorithms for diagnosing precipitation type (e.g., rain, ice, snow) in weather models. NCAR was the lead laboratory providing the core data processing capability, the graphical user display, and the engineering to integrate all of the disparate parts into a complete, working prototype. To save time and money, many of the core modules were reused or reapplied from other projects.

Figure 1 shows a high-level flow diagram for the MDSS functional prototype that was used in the winter 2003–2004 demonstration. The top box in the left column represents data received from the U.S. National Weather Service (NWS) National Centers for Environmental Prediction (NCEP). These data include surface observations, statistical guidance products, daily



**FIGURE 1.** High-level flow diagram of the prototype Maintenance Decision Support System (MDSS) (as used during winter 2003–2004 demonstration).

weather summaries, and numerical weather prediction model output from national scale numerical weather prediction models called Eta (or the NAM, North American Mesoscale model) and the Global Forecast System (GFS).

The NWS models were supplemented by high resolution models run by NOAA FSL. These models were the NCAR/Penn State Mesoscale Model 5 (MM5) and the Weather and Research Forecasting (WRF) model. The models had a grid spacing of 12 km. A sample of the mesoscale output can be seen in Figure 2. In order to provide diversity into the data fusion module, FSL used the NWS Eta model to provide lateral boundary conditions to initialize each mesoscale model. For the 2004 field demonstration, the FSL mesoscale models were run hourly generating 15 hour forecasts.

Differing from the NWS models, the supplemental models used a new initialization routine to add realistic distributions of moisture and clouds to the model atmosphere. This method, called "hot-start," allows the mesoscale models to begin with a much better representation of clouds and precipitation (McGinley, 2000). The benefit of the hot start process is a more accurate prediction, particularly in the first six hours of the forecast cycle.

Forecast output from the models, plus surface observations from State DOT road weather information systems (RWIS) were forwarded to NCAR's data fusion engine called the Road Weather Forecast System (RWFS). The RWIS data were obtained from the Iowa DOT server and ingested into the NOAA/FSL Meteorological Assimilation Data Ingest System (MADIS) where it was quality controlled and disseminated. The RWFS module uses a fuzzy-logic ensembling scheme that has the ability to generate more accurate forecasts than any one individual model input by optimizing the blend of predictors based on recent skill (Myers, 2001 and Pisano, 2004).

Specialized algorithms such as the road temperature forecast module and the road condition and treatment module (RCTM) use the model outputs to generate temperature forecasts for the state and condition of the road surface as well as guidance for chemical concentration and dilution rates.

The final module in the system contains the rules of practice algorithms. The rules of practice are customized rules and techniques that are used at State DOT maintenance garages for maintaining mobility during winter conditions. These rules tend to be different for each State and in many cases are different for each garage. Hence, this module has the ability to customize many of its inputs so that it can be portable between maintenance facilities.

Output from the rules of practice module includes treatment recommendations for the DOT garage supervisor. Some of the guidance information contains the following:

- Recommended treatment plan, such as plow only, chemical use, and abrasives
- Recommended chemical amount (e.g., pounds per lane mile)
- Timing of initial and subsequent treatments

Figure 3 is an example from the MDSS prototype main display. The top left panel shows a summary table with color-coded bars illustrating forecast weather and road conditions for the next 48 hours. The panel at the left center provides access for displaying weather parameters or treatment routes. The bottom section controls the forecast time selection and animation. The main map (top right) can show either an entire state view or a zoomed-in route view (Figure 4).

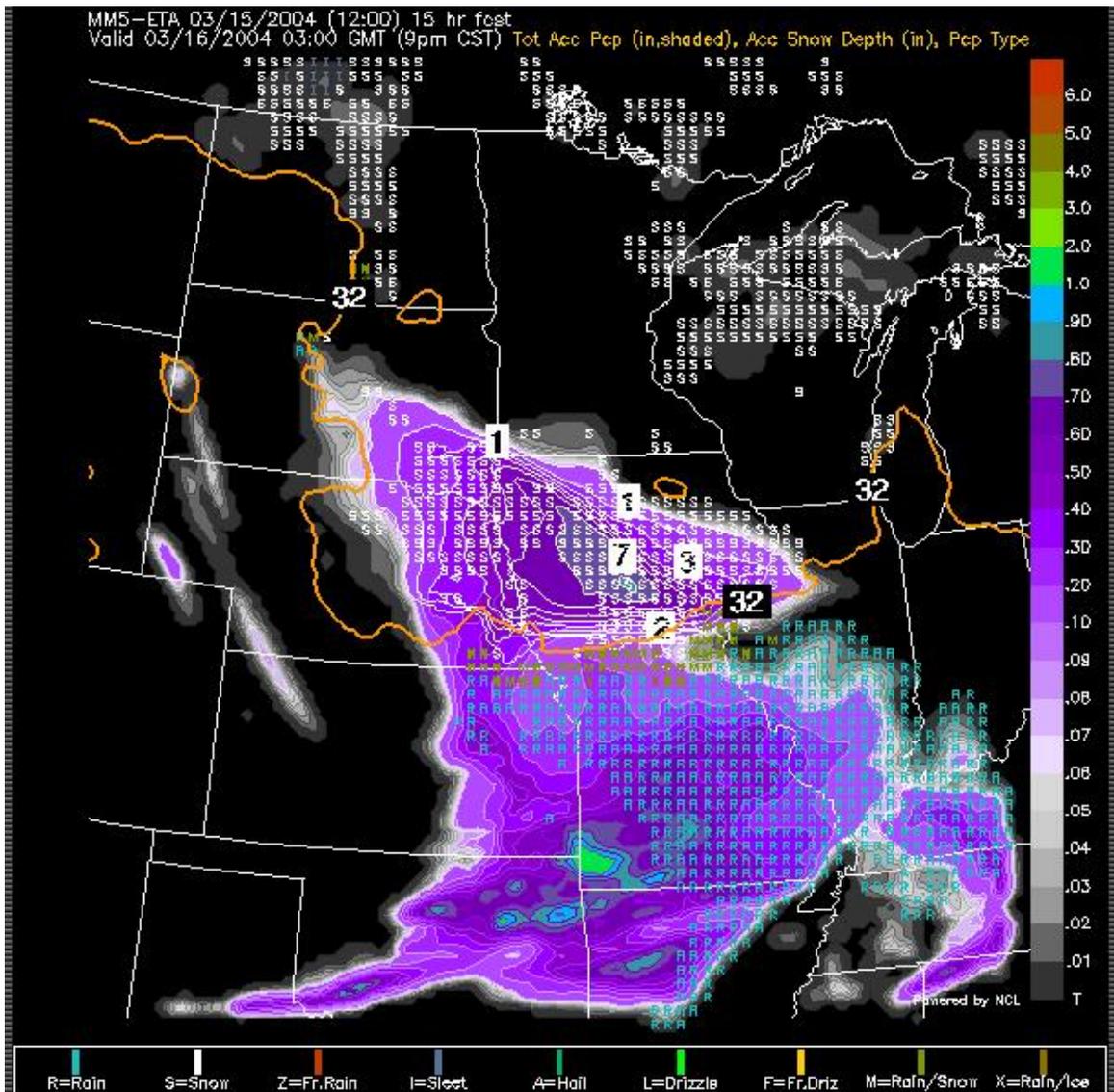
Forecasts are generated for locations that routinely provide observations (e.g., airports, NWS reporting sites, and road weather observations stations) and along each plow route using interpolation techniques. Moving a cursor over any point produces a dialog box with a time series graph of the selected forecast parameter plus additional site specific details.

The MDSS contains a "what-if" scenario treatment selector. This means that the operator is able to modify the recommended treatment times, chemical types or application rates, and see how the road condition predictions might change.

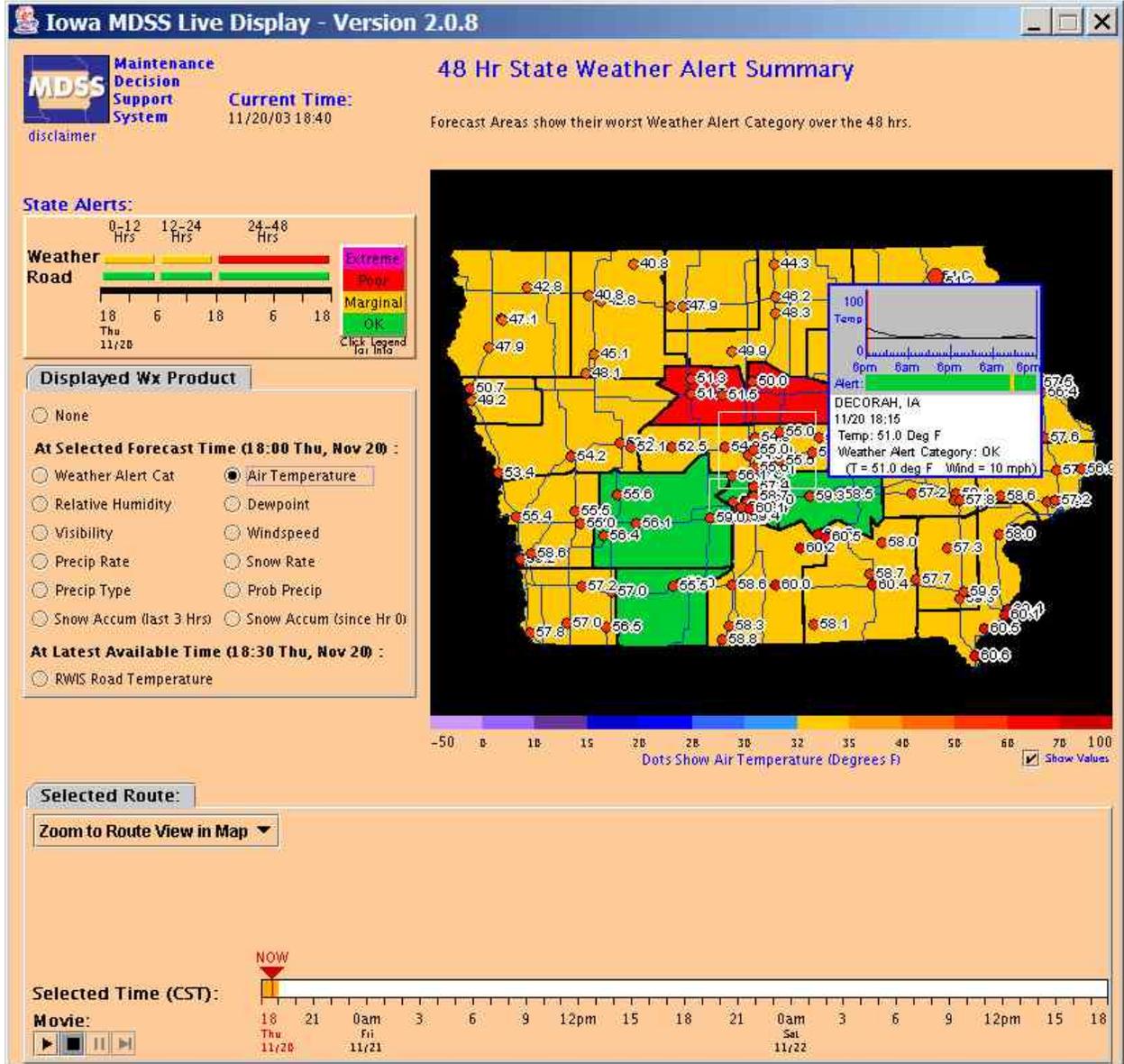
An example of the MDSS treatment selector for U.S. route 30 in Iowa on 2 February 2004 is shown in Figure 5. This provides the user with an indication of the mobility, snow depth on the road, road surface temperature and chemical

concentration for various treatment scenarios (e.g., no treatment, recommended treatment, and current treatment plan). The lower part of the screen shows the recommended treatment

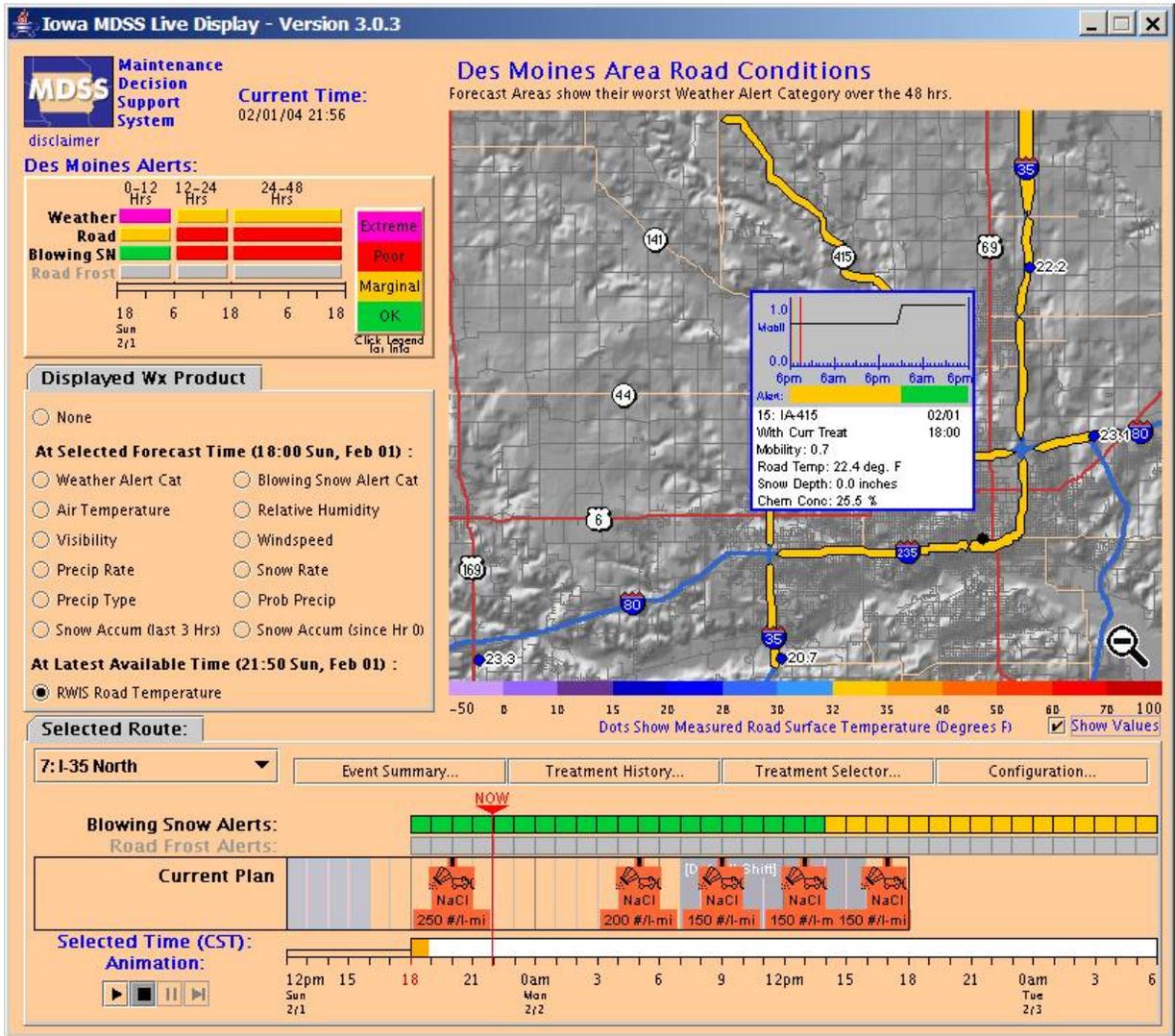
plan and the current plan chosen by the Ames, Iowa garage supervisor. In this example, the recommended and current plan includes a plowing treatment followed by applications of salt (NaCl).



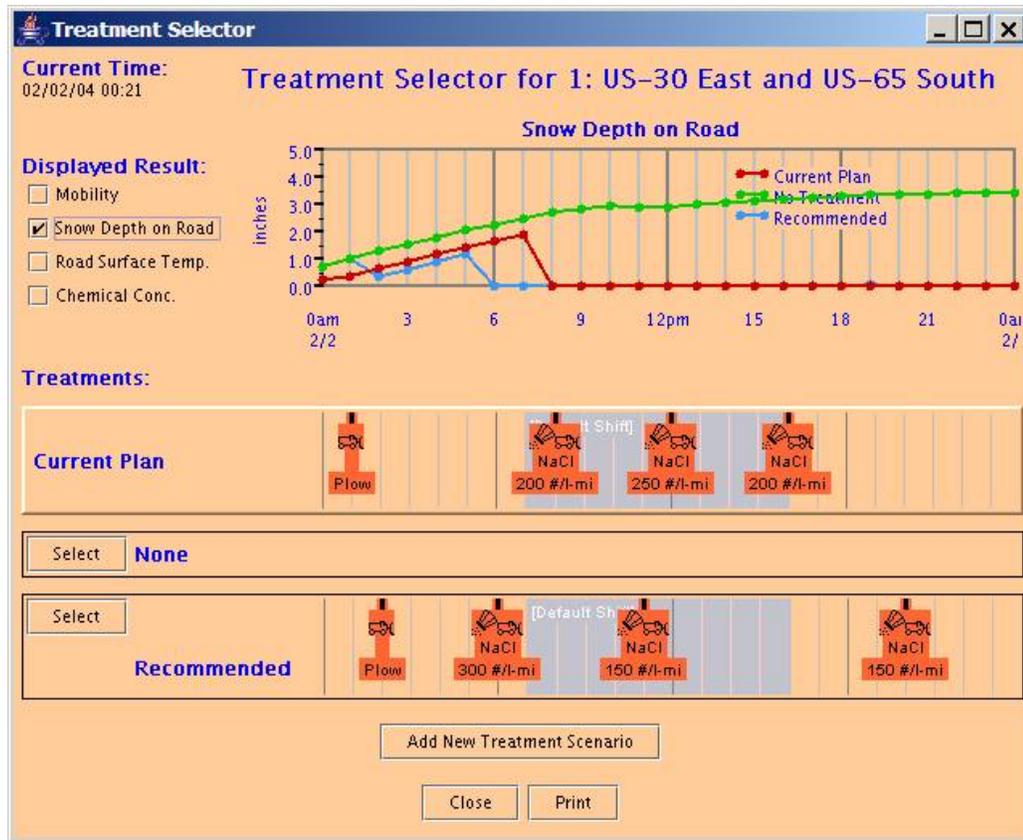
**FIGURE 2.** MM5 model output showing a forecast of more than a half foot of snow (represented by the letter S) over the winter demonstration area. Areas of rain are represented by the letter R. The white contours represent snow accumulation in inches. Images such as these were available on the Web during the demonstration periods.



**FIGURE 3.** MDSS prototype main user screen. Weather and road condition alerts for each DOT zone are provided. In addition, the user can mouse-over forecast points to view weather prediction information.



**FIGURE 4.** Des Moines area MDSS plow routes and forecast points. Users can view the weather and road condition alerts and information for each route as well as the current treatment plan. In addition, users can select to view the recommended treatments and treatment history.



**FIGURE 5.** Sample of the MDSS treatment selector screen. The traces (top window) shows the predicted snow depth on the road for various treatment scenarios (e.g., no treatment, recommended treatment, and current treatment plan). The lower part of the screen shows the recommended treatment plan and the current plan chosen by the Ames, Iowa garage supervisor.

#### 4.0 FIELD DEMONSTRATION I

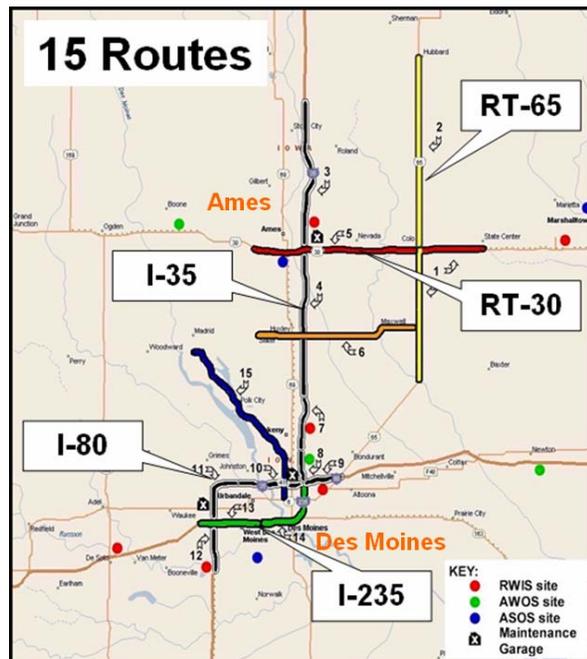
During the summer of 2002, six states competed to win the opportunity to host the MDSS project. While there were several very good candidates, Iowa DOT was selected. Determining factors included their progressive maintenance programs, the availability of high-speed communications and computers at maintenance garages and a willingness of DOT personnel to participate in training and verification activities. Iowa was also surrounded by a dense network of surface observations and did not have complex terrain.

In all, 15 plow routes and three maintenance garages around Des Moines and Ames, Iowa, were selected to participate in the demonstration (Figure 6). The colored dots along the roadways

represent automated surface observing stations that were either operated by the NWS, the state, or the Federal Aviation Administration (FAA). These stations served as ground truth for forecast initialization and verification.

The Des Moines West garage is located to the west of I-80 and is responsible for portions of I-80 and I-235. The Des Moines North garage is located near the intersection of I-80, I-35, and I-235. This garage is responsible for the expressways through and north of downtown, including secondary roads to the north of the city. The Ames garage is located about 40 miles north of Des Moines near the intersection of I-35 and U.S. 30. The Ames garage is responsible for longer but less traveled routes through the rural areas of central Iowa.

The demonstration period began on Monday, February 3, 2003 and concluded on Monday, April 7, 2003. During that time, five light snow events (3 inches or less accumulation), three heavy snow events (accumulations of greater than 3 inches), and one mixed rain/snow/ice event occurred.



**FIGURE 6.** The 2002–2003 MDSS winter demonstration route map consisting of 15 Routes around metropolitan Des Moines and Ames, Iowa

#### 4.1 Demonstration I—Lessons Learned

The first MDSS demonstration was quite valuable as it gave the development team first hand observations of winter maintenance operations. While the demonstration was a success because the prototype was deployed and utilized by several State DOT maintenance personnel, a long list of lessons learned was compiled (NCAR, 2003). Some of the more important lessons included:

- 1) The MDSS requires highly specific forecasts of precipitation type, amount, start time, and duration. These parameters translate into more accurate treatment guidance. However, there were numerous occurrences of light precipitation that were not captured by

the numerical models. It was found that the numerous, short-lived, light precipitation events could produce significant problems on roads because drivers and maintenance crews alike were often caught off guard. It was confirmed that such accurate prediction of small-scale precipitation events is pushing the current limits of predictability.

- 2) The rules of practice module needed additional development to handle a wider variety of weather and road condition scenarios and treatment responses. Even though the development team met with each of the garage supervisors prior to the demonstration period, it was found that the actual operational practices of maintenance supervisors were different and not necessarily what was described in their operations plans.
- 3) The availability and quality of observed real-time precipitation rate and accumulation data were very poor for snow and ice. It was known that State DOT RWIS sites did not have heated precipitation gages making them useless for freezing and frozen precipitation. However, it became readily apparent that the NWS Automated Surface Observing Systems (ASOS) either greatly underreported wintry precipitation or failed to report accumulations and liquid equivalents altogether. This lack of accurate precipitation ground truth data prevented the use of the dynamic weighting schemes and forward correcting algorithms in the Road Weather Forecast System and hindered the MDSS verification process.
- 4) The road condition and treatment module needed more development to cover additional weather and road condition scenarios. The model needed development of algorithms to account for the impact of vehicle speed and volume on chemicals and the complex problem of blowing and drifting snow on the roadway.
- 5) Because weather will not soon be predicted perfectly at road scales, probabilistic products should be developed. For decades, the typical delivery of forecast probabilities was

depicted in a deterministic mode. The user was not provided with any level of confidence that an event would occur. Using a probabilistic approach, the user could, for example, be given information on the probabilities of rain, snow, and ice so that there would be a better understanding of the actual chances of each precipitation type.

- 6) The State DOT maintenance personnel who were involved with the demonstration complained that the verification forms became too burdensome to complete during some of the more significant precipitation events. A better verification scheme had to be developed for subsequent demonstrations.

## 5.0 FIELD DEMONSTRATION II

One of the reasons why the list of lessons learned from the first demonstration was so long was because there was almost no precipitation for approximately three months prior to the start of the first demonstration. This eliminated the system testing and shakedown period, which resulted in a series of system enhancements being implemented during the course of the demonstration period.

The FHWA recognized this limitation and provided funding to address many of the issues raised during the first demonstration. Based on lessons learned from the first demonstration, a number of enhancements were made for the second demonstration. These included:

- RCTM Enhancements – The rules of practice module was significantly improved by learning from archived case data from the first demonstration. New logic was implemented to recognize the overall storm scenario rather than only looking at specific forecast hours. A blowing snow alert algorithm was also created for evaluation by maintenance managers.
- RWFS Enhancements – For the second demonstration, the mesoscale models and RWFS were modified to generate output hourly for the first 15 hours of the forecast period. The remaining time (forecast hours 16 through 48) still used 3-hourly NWS model data, but at a

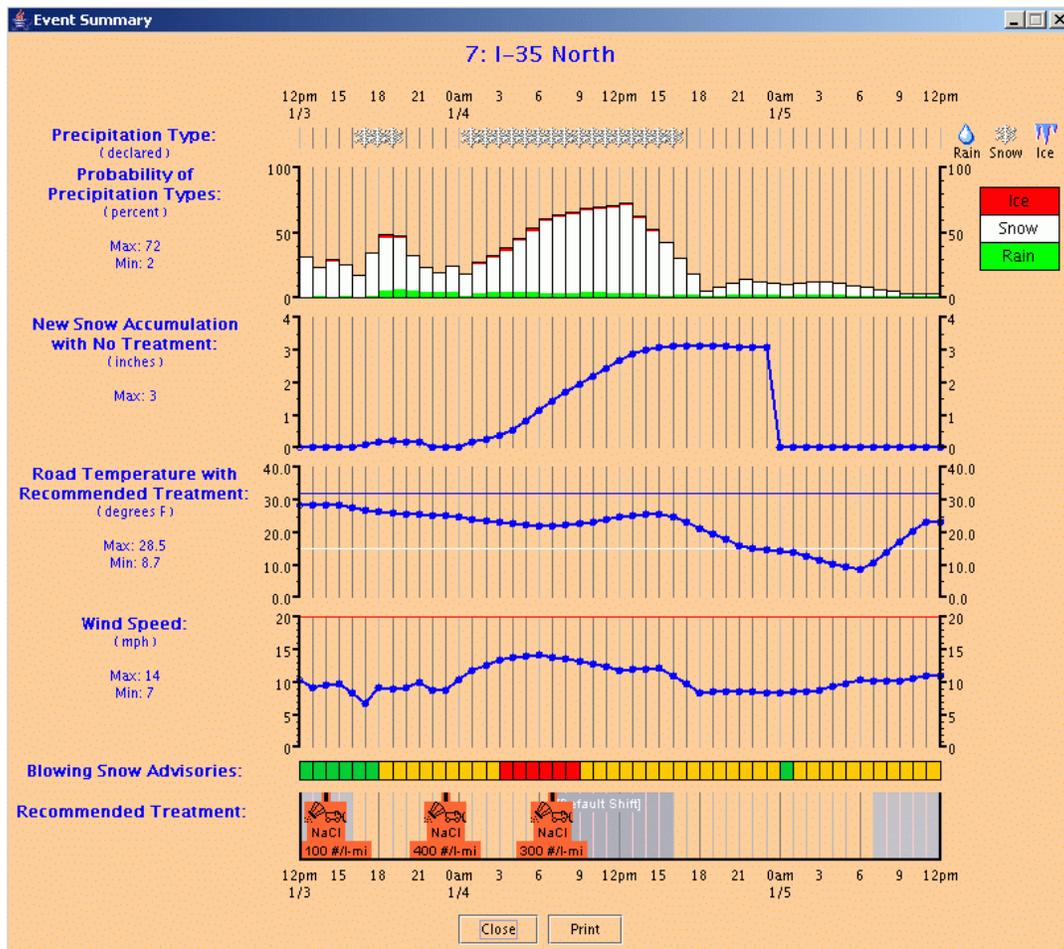
lower grid resolution. Other improvements to RWFS included adding probabilistic forecast information for selected fields, such as precipitation type as shown in Figure 7, forward error correction to adjust predictions to better match observations when the forecast time is the current time, and the ability to predict weather and road conditions for a bridge segment.

- Mesoscale Model Enhancements - Rather than running six different combinations of models every three hours, a time-lagged ensemble technique was used. This method had the mesoscale models running with new data every hour. Then, every three hours the RWFS would accept forecast data from the current hour, the previous hour, and the hour before that as input from the mesoscale model ensemble. This method was also selected to reduce forecast inconsistencies that would sometimes occur, as the models would alternate from one solution to another.
- Graphical User Interface (GUI) Enhancements – From suggestions from State DOT personnel, the MDSS GUI received several modifications. These included adding digital values to state and route view graphics, adding a real-time display of State DOT RWIS data, providing a historical window to review guidance from previous forecast cycles, and a display summary page as shown in Figure 7. The display summary page was a “quick-look” summary of weather and road variables for each forecast period and for each plow route. The summary page included maximum and minimum predicted air and road temperatures, total new snow accumulation, and an indication of the conditional probability of precipitation type, which is the probability of a certain precipitation type (e.g., rain, snow or ice) should any precipitation occur.

Finally, there were numerous changes made to the demonstration verification system. With the lack of credible automated weather observations, the huge expanse of the 15 verification routes selected for the first demonstration, and the incomplete paper records from the maintenance garages, it was

apparent that a better verification methodology had to be created for this project. The plan for the second demonstration included:

- Reducing the number of routes where verification data were collected from 15 to 3 to concentrate personnel resources in a coordinated data gathering effort.
- Installing Global Positioning System/Automated Vehicle Location (GPS/AVL) instruments onto eight plows. Each GPS/AVL system had the ability to record the vehicle location, speed, and direction every 10 seconds. The system interfaced directly into the plow's controls and sensors providing detailed information on the main plow position, the chemical application rate, and the air and road temperature.
- Copies of shift logs were collected and collated, GPS/AVL data were used to supplement these forms and lab, DOT headquarters and Iowa State University's Center for Transportation Research and Education (CTRE) personnel were utilized to collect ground truth conditions and process the GPS/AVL data.
- A suite of weather sensors was installed at the Ames, Iowa maintenance garage. The sensors included a heated precipitation gauge and typical temperature, humidity, and wind instruments. It also included a pyranometer to measure the amount of incoming short wave solar radiation and an ultrasonic snow depth sensor.



**FIGURE 7.** Sample image of the MDSS event summary page. Graphical probabilistic forecasts were introduced (top set of graphics) for precipitation type. Each bar in the time line contains the model derived probability of rain (green), ice (red) or snow (white).

## 5.1 Demonstration II—Results and Recommendations

The second field demonstration began on December 29, 2003. The GPS/AVL units were loaded onto the plows during late December and early January 2004. By the time the 88-day demonstration concluded (on 24 March, 2004), there were 15 weather event days ranging from mixed rain and snow events to freezing rain and record heavy snows (NCAR, 2004).

Enhancements made to all aspects of the prototype based on the results of the 2003 demonstration made a significant difference in the quality of the forecasts and treatment guidance and the subsequent confidence shown by the users. The primary results and recommendations are described below.

- 1) Road Weather Forecast System: The data fusion methods and statistical techniques used in the RWFS improved the overall weather prediction skill for parameters that are measured and available in real-time (e.g., air temperature, wind, humidity, etc.). The use of multiple inputs also makes the system more robust as it is not prone to down time with the loss of individual forecast modules. The RWFS forecasts had significantly better skill in the first six hours because of its forward error correcting capability.
- 2) Winter Precipitation Measurements: The poor quality of winter precipitation measurements did not provide the same automatic forward correcting benefit for the prediction of precipitation amount. If a data fusion system that self-adjusts based on observations similar to the RWFS is utilized, care must be taken to ensure that the weights given to individual prediction modules are appropriate. If only low quality verification data are available, the weights should be fixed based on experience and/or expert opinion.
- 3) Short Wave Solar Radiation: The ability of models to predict insolation varies greatly between models, particularly in partly cloudy conditions. Care must be taken to ensure that model values compare well with measured values. Changes to both research and operational models may impact

insolation calculations so routine comparisons should be made. Because insolation measurements are critical for road temperature prediction, it is recommended that insolation measurements be added to surface observing stations and be provided in real-time to weather service providers. Real-time access to insolation data would provide an opportunity for systems like the RWFS to utilize the data and optimize predictions.

- 4) Mesoscale Modeling: The high resolution mesoscale models did not add value above standard NWS models for forecast parameters such as wind, temperature and humidity. However the mesoscale models did provide more skill at predicting precipitation type, rate and timing. The use of mesoscale models is recommended for MDSS applications. It should be noted that the high resolution models should be run out to at least 24 hours as user decisions are generally made the day before events begin.
- 5) Probabilistic Products: Winter maintenance supervisors are in the business of risk management. Because weather and road conditions will never be perfectly predicted on the scale of plow routes, probabilistic prediction products should be provided. The MDSS conditional probability of precipitation type product was well received by the end users.
- 6) Road Temperature Prediction: Road temperature prediction skill varied greatly between day and night and between cloudy and clear conditions. When solar radiation values were low, the road temperature prediction accuracy was quite good (within 1 to 2 degrees C). The analysis suggests that an improvement in the prediction of insolation may provide a major improvement in road temperature skill. Methods and techniques aimed at improving insolation prediction should be investigated.
- 7) Rules of Practice: Significant improvements to the rules of practice module in 2004 resulted in treatment recommendations that better matched DOT operations. In some cases, the treatment recommendations were implemented without modification with

excellent results. The rules of practice code (as provided in MDSS Release-3.0), although not perfect, provides a solid starting point for further development and tailoring to specific road operating authorities by the private sector.

- 8) Forecast Services: Because the national laboratories are research-oriented and do not provide operational weather forecasting services, the prototype MDSS was designed to be a fully automatic system. The users indicated that an operational MDSS should include meteorological consulting services so that the users have the ability to seek clarification on predicted weather and road conditions.
- 9) User Benefits: There was a consensus among the maintenance supervisors that there was noticeable improvement to the system in the second demonstration and their confidence in using the system was growing. While there were still some features the supervisors would like to see implemented, there was a general agreement that the system showed significant promise and had proven itself to be a valuable tool both for operations and training. Iowa DOT estimated that an operational MDSS has the potential of saving the DOT between 10% and 15% of their annual maintenance costs (materials and manpower), which equates to approximately \$3.5M per year.

## 6.0 FUTURE ACTIVITIES

With the conclusion of the 2003-2004 winter demonstration, the major thrust of project development was completed. All Release 3.0 documentation, software and presentations have been made available on the NCAR web site:

[http://www.rap.ucar.edu/projects/rdw\\_x\\_mdss/index.html](http://www.rap.ucar.edu/projects/rdw_x_mdss/index.html)

While the pace of funding and development has slowed, very important work continues on this project. During the winter of 2005 there will be targeted research on surface transportation issues such as weather forecasting in complex terrain and the problem of forecasting road and

bridge frost deposition. In addition, the FHWA RWM program and the national laboratories will continue the technology transfer activities by providing support to organizations that are implementing MDSS capabilities.

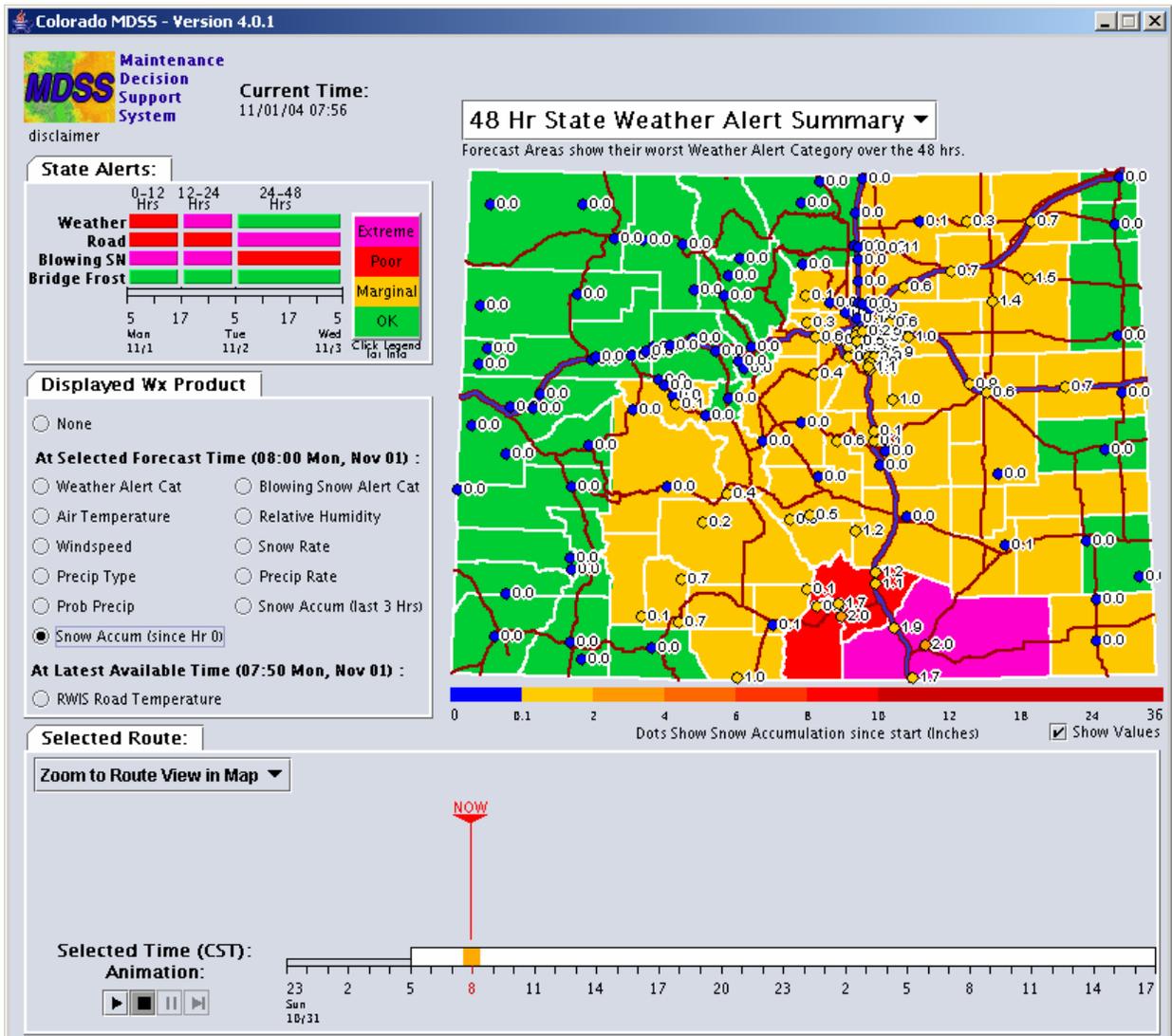
### 6.1 Targeted Research, Winter 2005

The field demonstrations that were conducted in the central Great Plains do not fully reflect all weather and road conditions and treatment strategies where winter maintenance managers have to make decisions. For example, the ability to provide treatment guidance in complex terrain (such as mountainous areas) where the weather, road conditions, and treatment plans can vary greatly over a single plow route requires additional study.

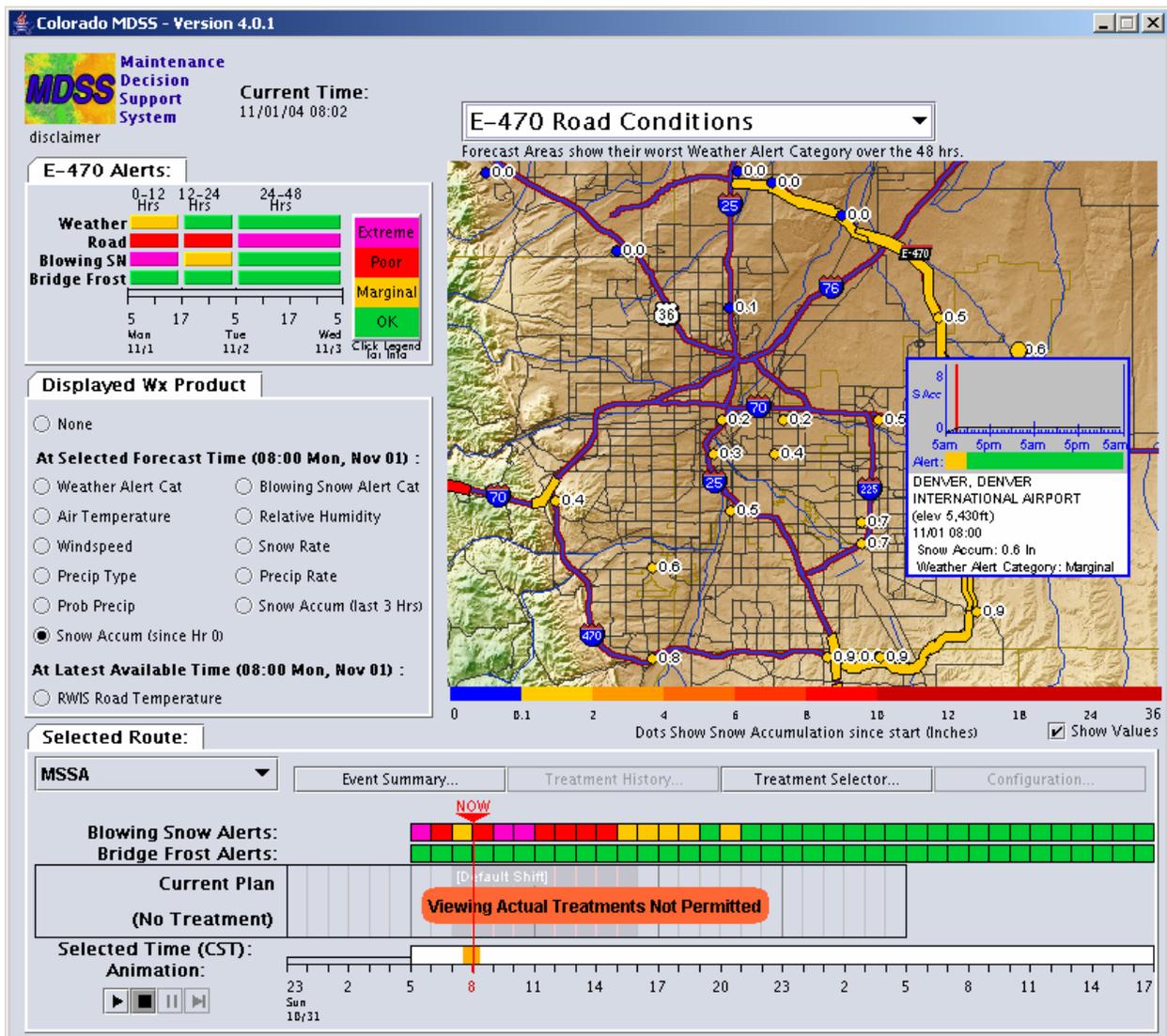
During the winter of 2004-2005, the national labs will relocate the MDSS test domain from central Iowa to central Colorado (Figure 8). In coordination with the Colorado DOT and the E-470 Public Highway Authority (Figure 9), targeted research will be conducted to:

- Expand the rules of practice to include the road treatment recommendations in complex (mountainous) terrain.
- Enhance algorithms for predicting and treating black ice.
- Add the ability to handle multiple simultaneous treatments (from multiple vehicles or tandem trailers following plows).
- Continue development and testing rules that incorporate output of the blowing snow alert algorithm.
- Implement and evaluate a robust road and bridge frost prediction algorithm by leveraging work already performed by Iowa State University.

This work will be done as a partnership between FHWA and NOAA, with NCAR and LL actively engaged in the effort. All 2005 research materials and evaluations will be made available on the NCAR MDSS Web site during the fall of 2005. (The Web address is included in Section 6.0).



**Figure 8.** For the winter of 2004-2005 the MDSS test bed will be relocated from Iowa to Colorado. The image shows the main MDSS display with the Colorado main map (top right) and the implementation of the blowing snow and bridge frost algorithms (top left).



**Figure 9.** The winter 2004-2005 MDSS display zoomed in to show features around metropolitan Denver, CO. The E-70 Public Highway Authority operates the perimeter road that extends around the eastern perimeter of Denver. Forecast snowfall information for Denver International Airport is shown in the small dialog box.

## **6.2 Technology Transfer Activities**

The main thrust of development and evaluation was completed with the successful development and demonstration of the prototype. Starting in FY2005, the project will transition from mainly development to a combination of focused research and development and technology transfer activities.

Throughout the life of the MDSS project, all briefing materials, technical reports, evaluations, and software have been made available to any interested party. Each year, the FHWA sponsored a stakeholder meeting where personnel from State DOTs, research laboratories, academia, and the private sector providers could all be briefed on project progress. During the summer of 2004, the sixth MDSS stakeholder meeting took place. Approximately 115 persons attended the meeting. A technology transfer workshop was also conducted to allow software engineers to learn about the details of the MDSS components from the scientists that worked on the project.

During fiscal year 2005, the national labs will provide the following technology transfer services:

- Create a technology transfer focal point within the laboratory structure so that State DOT or private sector representatives can easily make contact with an expert when they have specific implementation questions.
- Provide direct technology transfer support (per FHWA approval) by making one or two targeted visits to locations where commercial MDSS systems are being implemented to assist the commercial development efforts.
- Maintain the NCAR MDSS Web site with the latest project information and presentations (see the address in section 6.0).
- Continue to promote MDSS technologies through outreach and presentations at relevant conferences.
- Provide a short paper that describes current and near future observing and forecasting capabilities for surface transportation (both MDSS-related and in general) to educate State DOT administrators on the state-of-the-art in observing and forecasting services. It is

hoped that this paper will allow State DOT personnel to be better consumers of weather products.

- Provide a set of questions that State DOT personnel can use when interviewing prospective commercial firms about purchasing services based on MDSS technologies.
- Provide a short paper for State DOT personnel to enable them to procure and evaluate the best MDSS technologies for themselves. This document will include an example specification to aid in ordering these services from private sector firms.

The FHWA is fully committed to assisting the states in understanding the results and implications of the MDSS project. Similarly, the FHWA will continue to reach out to the private sector and continue to push for better services and support technologies.

## **7.0 SUMMARY**

The FHWA has been funding and directing a team of national laboratories to create and refine a decision support system for the winter road maintenance community. A demonstration of the MDSS prototype was conducted in central Iowa during the winters of 2003 and 2004. The system showed consistent improvement as the demonstration progressed and a list of lessons learned has been presented. A second demonstration provided many enhancements resulting in much improved forecasts and treatment guidance. Comments from Iowa DOT personnel found the system to be of growing value and showed increasing confidence in its use. They also stated that an operational system could save millions of dollars per year in winter maintenance costs.

As described above, success is achieved when private sector companies integrate MDSS components or similar functions into their products for State DOTs. And success has been achieved in multiple cases, such as in the upper Midwest and in Florida, where independent efforts among the private sector and State DOTs are taking place. In parallel with these activities, and to meet the need to continue improving decision support for the whole surface transportation community, additional work in the form of targeted research and technology transfer activities will continue.

## 8.0 ACKNOWLEDGEMENTS

The FHWA's Office of Transportation Operations, RWM program, acknowledges the technical expertise and dedication of the national laboratories on this project. In addition, more than twenty State DOTs have been active participants throughout the life of the project and their feedback has been critical.

The development of the MDSS concepts and functional prototype is a team effort involving several U.S. national laboratories, several State DOTs, Iowa State University's Center for Transportation Research and Education (CTRE), and Professor Wilf Nixon of the University of Iowa. The MDSS Iowa demonstration could not have been conducted without the hard work of staff from the Iowa DOT. We want to give special thanks to Dennis Burkheimer, Paul Durham, Edward Mahoney, Richard Hedlund and Jim Dowd.

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