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THE WINTER MAINTENANCE DECISION SUPPORT SYSTEM (MDSS): DEMONSTRATION RESULTS AND FUTURE PLANS

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1. 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 has to be able to handle multiple tasks or risk getting behind the onslaught of winter weather. All of the regulations about chemical applications, environmental impacts and multiple, often contradictory weather forecasts can lead to information overload.

The Federal Highway Administration (FHWA) recognized this potential problem in the late 1990's. Generally speaking, there were plenty of weather forecasts, along with a few companies that 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 weak link that became the genesis for the winter Maintenance Decision Support System (MDSS).

The MDSS has since matured into a functional prototype. During the winter of 2002-2003, the prototype was deployed at several maintenance garages in central Iowa for a field demonstration. This paper will document the implementation of the demonstration, a summary of lessons learned, verification statistics, and technology transfer activities. It will also describe plans for a longer, more comprehensive demonstration during the winter of 2003-2004.

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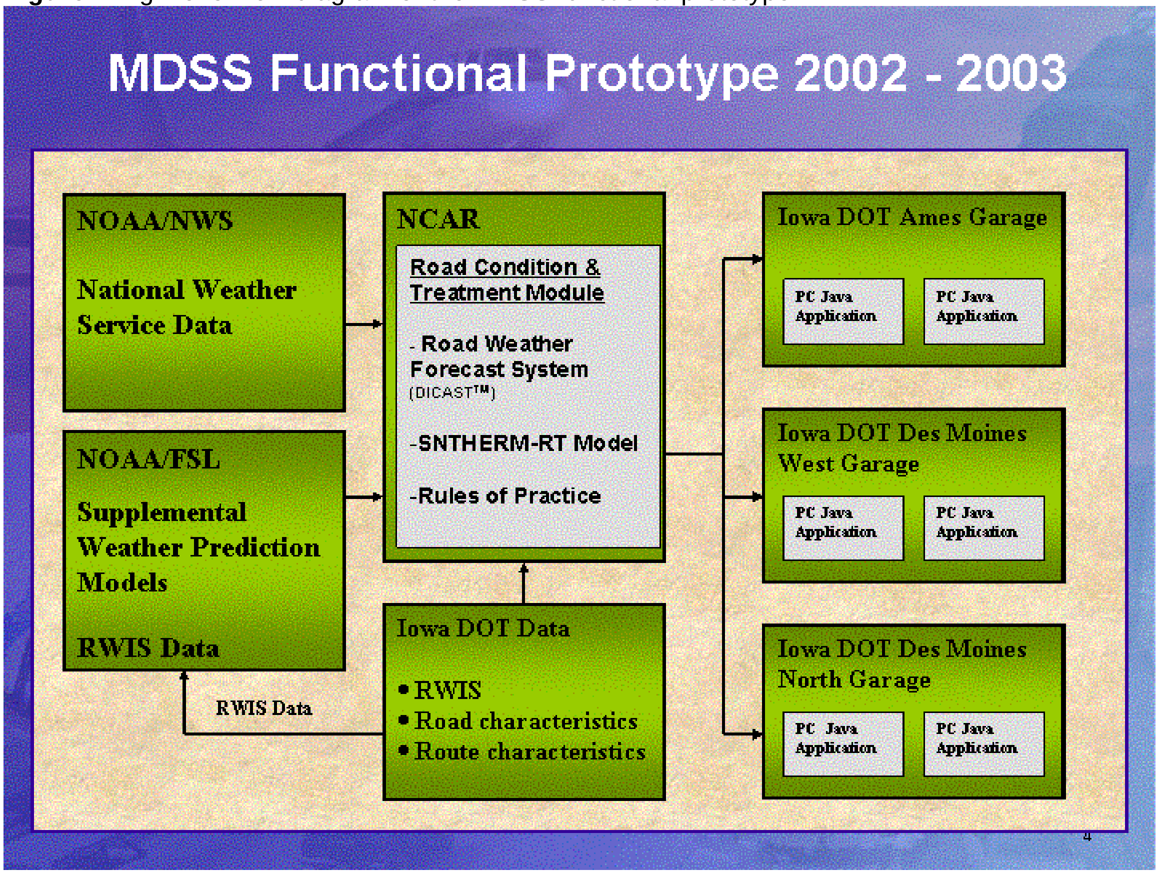
2. System Overview

The MDSS is a research project that is funded and administered by the FHWA Road Weather Management Program. Five national laboratories have been participating in the development and implementation of the project. Participating laboratories include:

- Army Cold Regions Research and Engineering Laboratory (CRREL)
- National Center for Atmospheric Research (NCAR)
- Massachusetts Institute of Technology – Lincoln Laboratory (MIT/LL)
- NOAA Forecast Systems Laboratory (FSL)
- NOAA National Severe Storms Laboratory (NSSL)

The MDSS project attempts to take state-of-the-art weather forecasting and data fusion techniques and merge them with computerized winter road maintenance rules of practice. The result is a set of guidance aimed at maintenance managers that provides a precise forecast of surface conditions and treatment recommendations customized for specific routes.

Figure 1 High-level flow diagram of the MDSS functional prototype



Each laboratory brings unique capabilities and expertise to the project. Much of the software used in the core MDSS modules has been reused from other projects and tied together via inter-process communications.

Figure 1 shows a high-level flow diagram for the MDSS functional prototype that was used in the winter 2002-2003 demonstration. The top box in the left column represents data received from the National Weather Service (NWS). These data include both surface observations and numerical model output from both the ETA and GFS (Global Forecast System – formerly known as AVN) models.

The lower box in the left column represents supplemental mesoscale numerical weather prediction models that were provided and run by FSL. These models were the MM5 (Mesoscale Model 5), the RAMS (Regional Atmospheric Modeling System) and the WRF (Weather and Research Forecasting model).

In order to provide diversity into the data fusion module, FSL used the NWS models to provide lateral boundary conditions to initialize each mesoscale model. Hence, four times per day, FSL would generate six model solutions for the forecast domain (Figure 2).

Figure 2 Model domain for the MDSS demonstration. Area under the red star represents the approximate demo area.

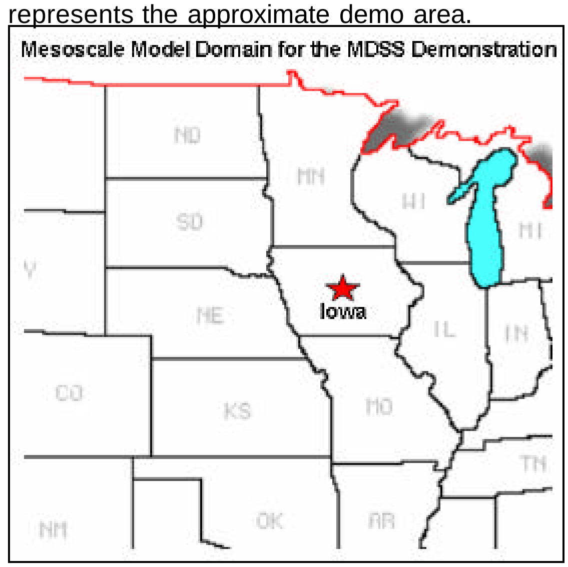
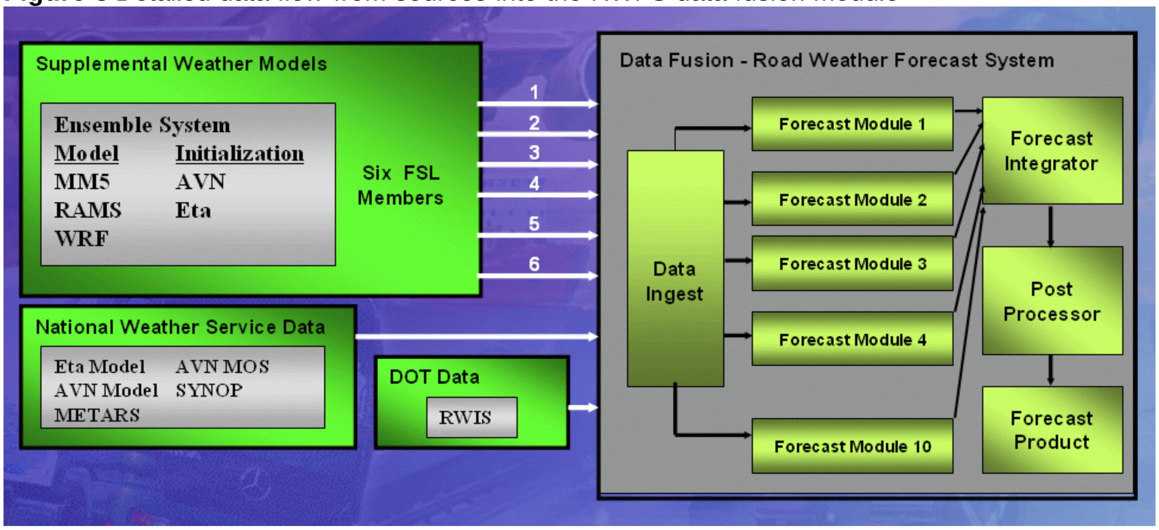


Figure 3 Detailed data flow from sources into the RWFS data fusion module



FSL model ensemble members included:

- ETA & MM5
- ETA & RAMS
- ETA & WRF
- GFS & MM5
- GFS & RAMS
- GFS & WRF

Different from the NWS models, the mesoscale models used a new initialization routine to add realistic distributions of moisture and clouds to the model atmosphere. This method, called "hot-start" (McGinley, 2000), allows the mesoscale models to have a more realistic and accurate set of forecast output sooner rather than having to wait the customary 6 (model) hours before the models begin to generate realistic moisture fields.

Forecast output from these six models, plus surface observations from state departments of transportation (DOT) road weather information systems (RWIS) were forwarded to NCAR's data fusion engine (Figure 1 – top center box, or Figure 3) called the road weather forecast system (RWFS).

The RWFS module used a fuzzy logic ensembling scheme that has the ability to generate more accurate forecasts than any individual model input. Section 3.1.2 later in this document provides verification information on this capability.

Once forecasts have been generated by the RWFS, a number of algorithms are queued for execution. These include the road temperature forecast module and the road condition and treatment (RCTM) module. The former generates temperature forecasts for the state and condition of the road surface. This is used as input into the RCTM which contains algorithms such as for chemical concentration and dilution.

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 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 garages.

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

- Timing information for the start and duration of precipitation
- Precipitation type and accumulation
- Optimized treatment times
- Recommended chemical types and dispersion rate

Figure 4 MDSS functional prototype main user screen (from the 2002-2003 demonstration)

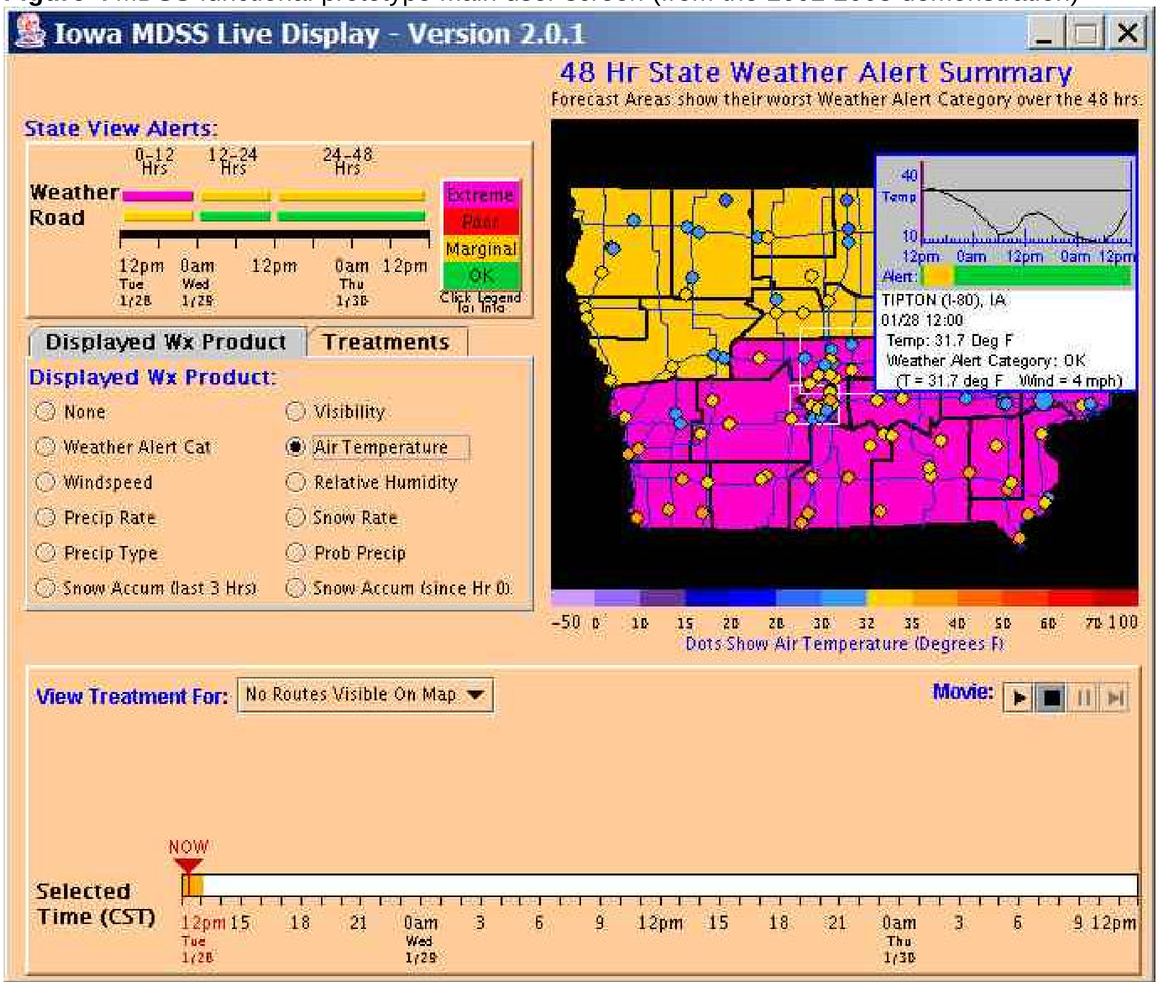


Figure 4 is an example from the MDSS prototype main display. The top left panel shows a summary table with color coded bars showing forecast weather and road conditions for the next 48 hours. The panel at the left center provides access for displaying weather parameters or treatment routes. The bottom 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 5).

Each dot on the main map represents a forecast point. Moving a cursor over any point brings up a trace of the selected forecast parameter plus additional site specific details.

Figure 5 Des Moines area MDSS routes and forecast points

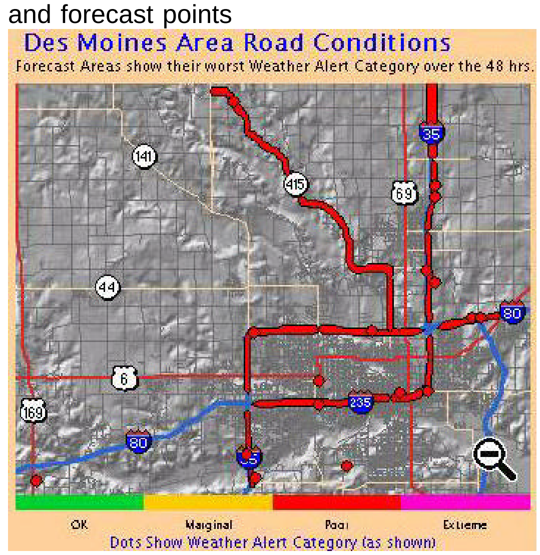
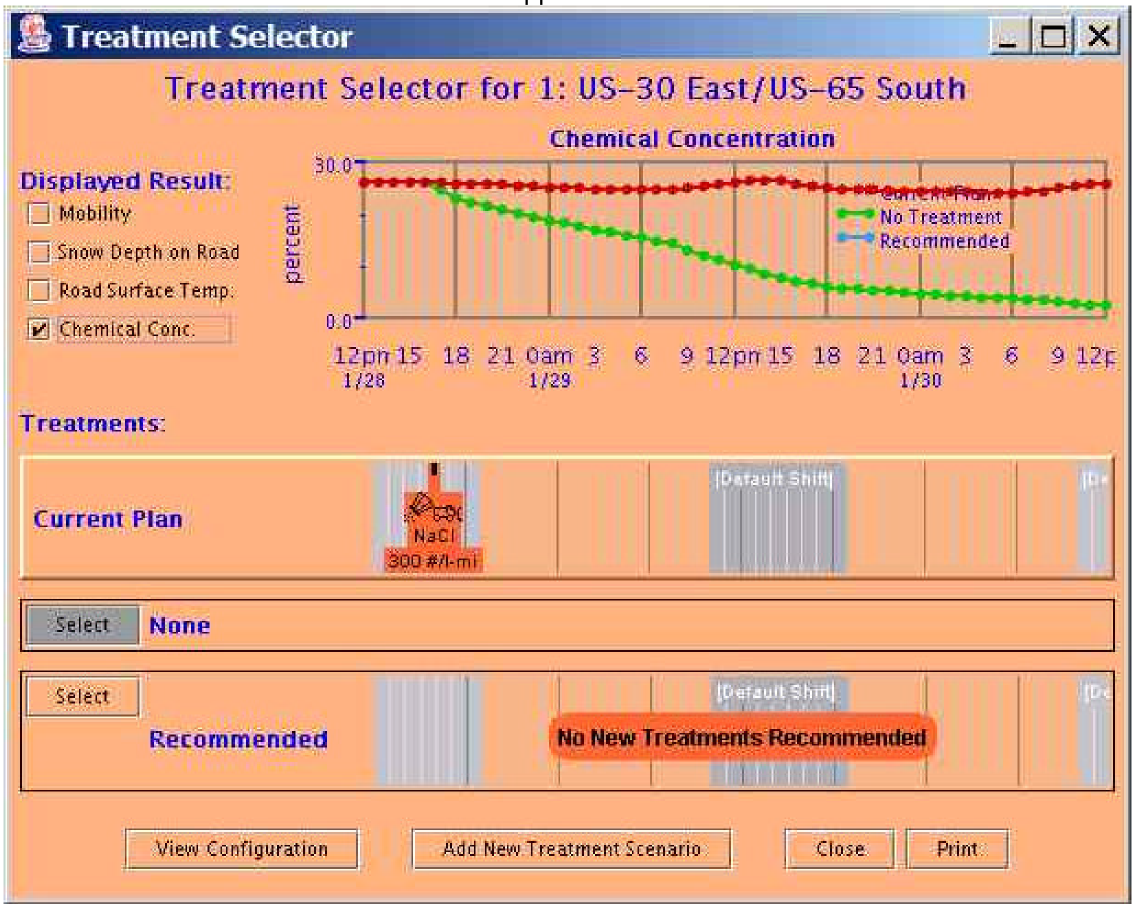


Figure 6 MDSS treatment selector screen. The red trace (top window) shows the predicted chemical concentration if the treatment application is followed. The green trace shows the chemical dilution rate if no chemicals were applied.



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 submit other values to see how the road condition predictions might change.

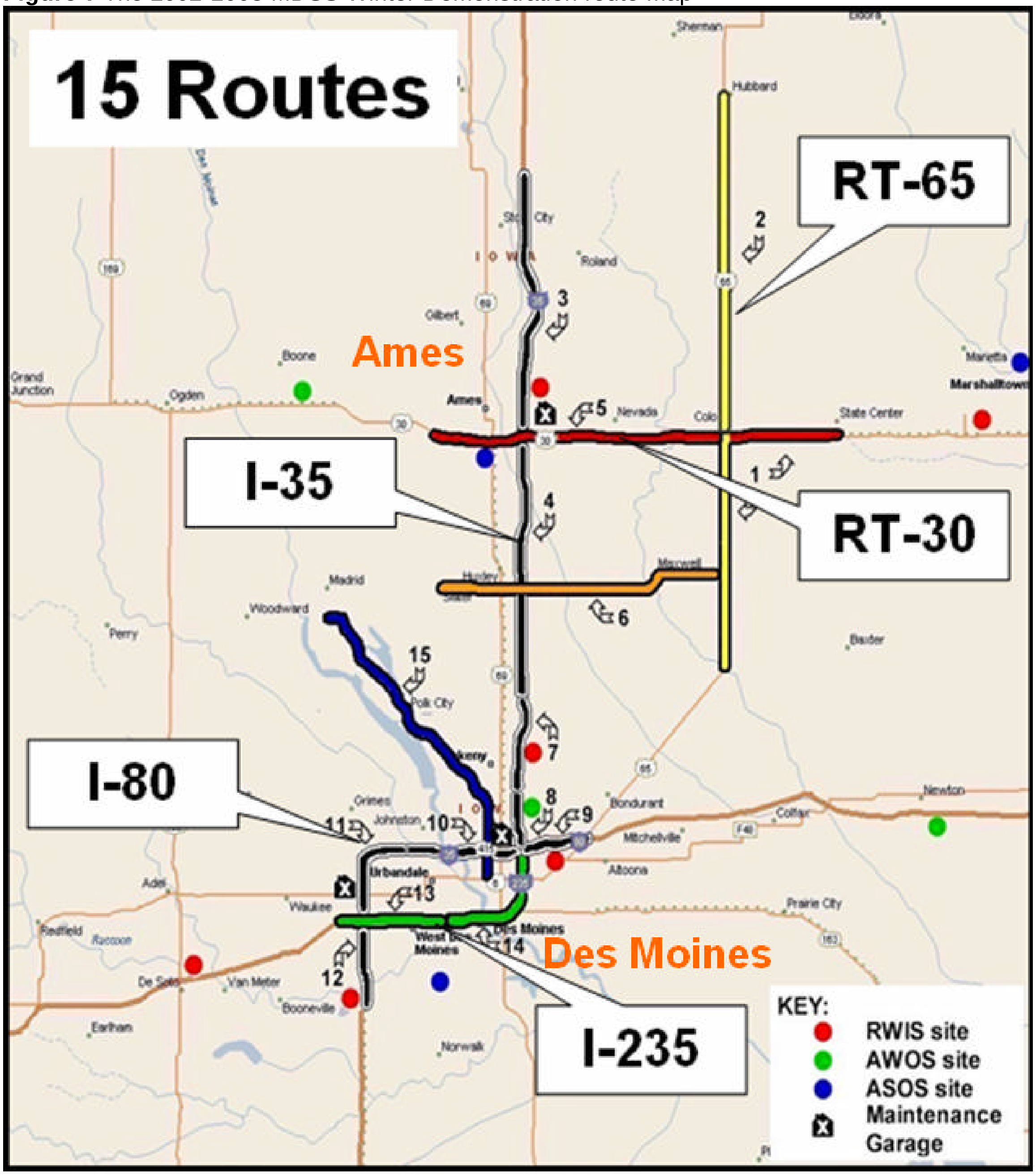
In Figure 6, a chemical concentration display shows the results of two scenarios. The green trace shows the dilution rate of sodium chloride on the road surface if no additional treatments of chemicals are applied. In this case, given the forecast weather conditions, the chemical concentration on the road surface would fall to 10 percent or less within 24 hours. With one application of sodium chloride (at a rate of 300 pounds per lane mile), the red trace indicates that the chemical concentration would stay about constant through the 48 hour forecast period.

3. Field Demonstration 2003

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

In all, 15 routes and three maintenance garages around Des Moines and Ames Iowa were selected to participate in the demonstration (Figure 7).

Figure 7 The 2002-2003 MDSS Winter Demonstration route map



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

The colored dots along the roadways represent automated surface observing stations that were either operated by the NWS, the state or the DOT. These stations served as ground truth for forecast initialization and verification.

The demonstration period began on Monday, 3 February 2003 and concluded on Monday, 7 April 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.

3.1 Verification

3.1.1 Establishing Data Quality

A study was performed to determine the quality of the NWS Automated Surface Observation System (ASOS), the state DOT operated Automated Weather Observing System (AWOS) and RWIS within the demonstration domain. Both ASOS and AWOS instrumentation are located at airports which typically have no obstructions. RWIS, on the other hand, are generally located along roads or near bridges and often have terrain or obstruction issues. All three systems are maintained and calibrated, however each is of a different quality and capability.

Table 1 shows overall results of comparisons between the automated airport observations and the roadside observations. For air temperature, most observations were within 2.5C (4.5F). However, compared with ASOS the Ames RWIS tended to be 1-2C (2-4F) too warm and the Ankeny AWOS (I-35 north of Des Moines) tended to be about 1C (2F) too cool.

Table 1 Comparisons between automated airport and roadside observations

Parameter	**Comparison**
Air Temperature	Most within 2.5C (4.5F)
Relative Humidity	Most within 10%
Wind Speed	Most within 4 knots
Cloud Cover	Not Available
Precipitation	Not Available
Road Temperature	Cloudy <2C (<4F) Sunny 4-5C (7-9F)

Most relative humidity readings were within 10 percent. However, some differences were noted because ASOS reports dew points in whole degrees C while RWIS uses tenths of a degree C. A possible calibration problem was also noted at the Ankeny AWOS as it consistently reported relative humidity 10-15 percent too high when the RWIS reported humidity of less than 50 percent.

In general, wind speeds were within 4 knots of each other. Probably due to better exposures in airports, ASOS reported higher winds than RWIS especially at speeds less than 12 knots. The only exception was found at the Ankeny AWOS where the RWIS reported higher winds.

No comparison was possible for cloud cover since RWIS has no cloud sensing capability and ASOS only approximates coverage. RWIS also does not have a heated precipitation gauge which means that winter precipitation cannot be measured by the IADOT RWIS network.

Interestingly, the NWS ASOS system also had major problems reporting winter precipitation (especially liquid equivalent), even though it employs a heated tipping bucket type gauge. During the evaluation period, most of the snow accumulations from ASOS were underreported when compared to human observed ground truth. In seven of the 11 significant periods of ice or snow, a value of zero liquid equivalent was reported for the entire event. The biggest snowstorm of the demonstration period produced 13 inches of snow at Des Moines airport. ASOS reported zero liquid equivalent for the entire storm.

This very poor ability to measure and disseminate winter precipitation can have a deleterious effect on systems such as the MDSS. One of the advantages of the MDSS logic is that it has the ability to forward correct its forecasts based on observations that are supposed to be ground truth. These grossly underreported precipitation observations produced a marked dry bias in the forecast. Hence, some of the precipitation observations (both ASOS and RWIS) were removed from the forward correcting scheme to overcome this deficiency.

Table 2 Verification statistics for the MDSS mesoscale models (2002-2003 Demonstration)

	Temperature (Deg C)		Wind Speed (m/s)		Dew point (Deg C)	
	RMS	**Bias**	**RMS**	**Bias**	**RMS**	**Bias**
MM5-GFS	3.1	-0.7	2.5	+0.8	5.6	+1.5
MM5-ETA	3.0	-0.5	2.5	+0.8	5.5	+1.6
RAMS-GFS	5.8	-1.1	2.6	+1.6	6.5	-0.9
RAMS-ETA	5.9	-1.1	2.6	+1.7	6.9	-1.0
WRF-GFS	3.1	-0.4	2.4	+1.1	5.7	+1.4
WRF-ETA	3.1	-0.4	2.4	+1.0	5.7	+1.3

3.1.2 Model Verification

The mesoscale models were run four times per day, providing output in three-hourly increments. The initial requirements when the ensemble scheme was constructed was to focus on the "planning" or 12-24 hour time span as being the most critical for maintenance managers. However, as the demonstration progressed, it became evident that more "tactical" (2 – 12 hour) forecasts were also very important.

Table 2 provides some statistics on the performance of each mesoscale model. Both the root mean square (RMS) error and the statistical bias are provided.

Temperature forecasts had an error of about 2.5C (4.5F) during the first 24 hours with RMS errors increasing to around 3C (5F) for both the WRF and MM5 models for the entire 48 hour forecast period. As shown in section 3.1.1, this error was close to the quality of the ground truth observations. Errors for the RAMS model were much higher. Also, all of the models showed a cool bias, forecasting temperatures colder than what was observed.

Wind speed forecasts had an error of around 2.5 m/s (5 knots) and all models displayed a high bias. This means that wind speeds were forecast to be somewhat stronger than what was observed. Forecasts of dew point had larger errors. For the 48 hour period the average RMS error was 6C (almost 11F). This resulted in relative humidity forecasts being off by +/- 20 percent. This type of error could pose problems for fog or frost deposition forecasting.

Cloud cover forecasts (not shown in Table 2) were generally one category off observed conditions. The forecast showed an overall bias toward more cloudy conditions. This type of error can produce problems with road temperature forecasts since the forecast energy fluxes would contain errors.

The models generated conditional probabilities of snow (CPOS), rain (CPOR) and ice (CPOI). Table 3 highlights some of the results.

The CPOS was most successful when values reached 70 percent. The same level of success was reached by CPOR when it reached 80 percent. However middle range

Table 3 Conditional probability of snow (CPOS), rain (CPOR) and ice (CPOI)

CPOS	CPOS>0.7 snow occurred 95%	0.2<CPOS<0.7 snow occurred 15-60% of the time. Remainder was a variety of precipitation	CPOS<0.1 rain occurred 95% of the time
CPOR	CPOR>0.8 rain occurred 95% of the time	0.3<CPOR<0.8 rain occurred 20-30% of the time. The remainder was snow.	CPOR<0.3 rain rarely occurred. Snow dominated
CPOI	CPOI>0.3 rain fell 85% of the time	0.2<CPOI<0.3 rain, snow and unknown precipitation occurred with equal frequency	CPOI<0.2 snow dominated

forecasts (20-80%) showed much more of a variety of forecast precipitation types.

Very few cases of ice were reported during the demonstration period and the probability value never exceeded 0.4. Table 3 shows that the ice forecasting skill was relatively low.

Average RMS errors for road temperature forecasts were about 2.5C (4.5F) with a slight cool bias regardless of temperature range. Errors were maximized during the daytime under clear skies. Under these conditions forecasts were too low by 5-10C (9-18F). Hand held radiometer tests showed the biggest discrepancies with the pavement sensors under these conditions (~5C or 9F). Hence, there may also be some pavement sensor error involved.

Forecasts under cloudy and precipitating conditions were much more accurate. The majority of road temperature forecasts were within 2C (3.6F) when precipitation was falling, especially snow.

3.1.3 Rules of Practice

The treatment recommendations that are provided by the MDSS are generated by the rules of practice module. During the demonstration period, both garage supervisors and plow operators were asked to fill out storm evaluation forms so that verification of the recommendations and a comparison to what treatments were actually performed could be tabulated.

Overall, it was found that given the forecasts from the RWFS, the recommendations were reasonable. The following section provides some insight to the rules of practice verification.

Case 3-4 February 2003 – Ames

This event was a short lived 5-7 hour event that deposited about one inch of snow (0.1 liquid equivalent) over both the Ames and Des Moines routes. The MDSS recommended a pretreatment of liquid brine followed by two successive treatments of sodium chloride with an application rate of 150 pounds/lane-mile.

The actual IADOT treatments consisted of one treatment of 300 pounds/lane-mile. However due to a rapid drop in air and road temperatures before the melted snow could dry, IADOT had to provide several more applications to keep the roads from refreezing.

It was determined that the MDSS recommendations were reasonable. However, the strong winds (> 18 knots) prior to the storm caused IADOT to not pretreat the roads. The initial treatments of the roads were similar. However, the lateness of the day and the blowing snow kept the road surface wet as temperatures dropped. The MDSS did not recommend additional treatments because the snow had stopped and it was believed that the applied chemicals were enough to last until the roads were dry.

Case 14-15 February 2003 – Des Moines

This event provided the heaviest snowstorm of the demonstration with nearly a foot of snow deposited over the region. In Des Moines, the event started as rain then changed to snow which lasted almost 20 hours.

The MDSS recommended a pretreatment of liquid brine several hours before the onset of precipitation. The Des Moines West garage did not perform a pretreatment since they recognized that the initial period of rain would have reduced the effectiveness of the brine.

The MDSS then recommended 12 chemical treatments ranging from 100 to 350 pounds/lane-mile. The overall treatment recommendation was about twice the tonnage that was actually applied by the Des Moines West garage. However, they did supplement their treatments with 'plow only' operations (something not currently supported by the MDSS).

As a result of the case studies, many algorithms within the rules of practice module will be updated with information collected during the winter 2003 demonstration. A more complete set of rules of practice verification examples can be found in NCAR, 2003 and Wolff, 2004.

3.2 Summary of Lessons Learned

The following list contains lessons learned or confirmed from the 2002-2003 MDSS field demonstration:

- The MDSS requires highly specific forecasts of precipitation, which is pushing the limits of predictability.
- The rules of practice module needs additional development to handle a wider variety of weather and road condition scenarios and treatment responses.
- The availability and quantity of real-time precipitation rate data are very poor.
- During a winter storm, the DOT operators often do not have the time to enter actual treatments for each route. Therefore, the MDSS can lose track of actual road conditions.
- Light snow events and intermittent events are critical to DOT operations and are particularly hard to predict.
- The road temperature prediction model did a good job given adequate weather inputs and road characteristic data. However, more work is needed to account for the impact of travel, chemicals, compact snow and blowing snow.
- The users have a strong desire for tactical (0-2 hour) decision support.
- Because weather will not soon be predicted perfectly at road scales, probabilistic products should be developed.
- Just varying the lateral bounds models (Eta, GFS) has little effect on adding dispersion to the ensemble.

In addition to lessons learned, several shortcomings in the system were noted:

- The MDSS prototype is not designed to provide treatment recommendations for blowing snow conditions.
- The MDSS does not contain explicit algorithms that identify road segments that may need treatments due to frost.
- Users indicate that a measure of forecast confidence would be beneficial.

3.3 Testimonials

Since the beginning of the MDSS concept, a large group of interested individuals has participated in the shaping and refinement of the project. Members of the road maintenance community, private sector vendors and academia have comprised a stakeholder group. Each year, the stakeholders gather to review past progress and to discuss and shape the future plans of the project.

Results from the 2002-2003 winter demonstration were presented at the 2003 annual stakeholder meeting. After the summary of lessons learned was discussed, a panel of participants was asked if the overall concept of the MDSS makes sense for the future. The following are some responses:

- “Absolutely. At first, some of the operators were really apprehensive that this tool was going to take away jobs. Then, it became like a video game and a discovery tool. Just don’t take the ultimate decision away from the end user.”
- “Very valuable – even if it wasn’t totally accurate – getting people down to the surface and away from aviation weather was very important.”
- “There will be a drastic reduction in guard rail repairs and this will save lives. This is very good for the Iowa DOT. It provides an opportunity to try new things. We constantly have to do more with less.”

The members of the stakeholder group were pleased with progress made by the MDSS project and were looking forward to further refinements in 2004.

4.0 Plans for Demo II – Winter 2004

After evaluating the performance of the MDSS during the first demonstration, it was determined that the system was not yet mature enough to survive on its own in the private sector. Hence, the FHWA decided to fund one more complete field demonstration. It will again take place in central Iowa and extend from 29 December 2003 until 19 March 2004.

Numerous enhancements will be engineered and implemented prior to the start of the demonstration. These include:

- Continuing to develop, refine and tune the road temperature forecasting module
- Adding a 'plow only' treatment option. Investigating adding a 'pre-treat with brine' option
- Adding the ability of the users to reset the road conditions to zero for both road snow depth and chemical concentration on a route or network basis
- Creating a treatment recommendation to alert when blowing snow conditions are likely (in the absence of an actual blowing snow model)
- Continuing to expand, refine and test the coded rules of practice to better reflect actual treatment plans
- Modifying treatment recommendations to utilize estimates of road drying time
- Continuing to work with Iowa State University on adding frost deposition forecast support
- Deploying real-time snow gauges to obtain better liquid equivalent information for demonstration verification
- Revising the RWFS to accept, process and output hourly forecast data (rather than 3 hourly data) to at least 24 hours in the forecast period
- Generating probabilistic information for selected data fields (such as precipitation occurrence, precipitation type and air temperature)
- Reconfiguring the ensemble modeling system to remove the under-performing RAMS model. Since the parallel ensemble scheme did not provide enough diversity to optimize the forecasts, run the MM5 and WRF models every hour and use a "time-lagged" ensemble technique to provide diversification of solutions to the RWFS data fusion engine. Using this technique may reduce the amount of cycle-to-cycle shock that can sometimes be generated by updating model cycles.
- Updating the main display to replace the color dots with digital values
- Adding the ability to view current RWIS observational data
- Designing a way to view recent history on the display (within 6 hours) so that more than just the latest 48 hours is viewable

Even after all of these changes are implemented, there will still be many challenges to overcome to create a truly comprehensive MDSS. However, the spirit of cooperation between the public and private sectors will move the entire industry closer to this goal.

5.0 Technology Transfer

Once the second field demonstration is complete, the laboratories will begin to compile new verification statistics and evaluation reports. The FHWA will also begin to work with different champions to see how this technology can be transferred to the private sector. One such champion is the AASHTO (American Association of State Highway and Transportation Officials) Technical Implementation Group. The MDSS project will be submitted as a new and promising technology during the spring of 2004. It is hoped that components of the MDSS will be integrated into the product lines of private companies so that the technology can be used to raise the level of service for all state DOTs.

A meeting of the MDSS stakeholder group will be held in July 2004 in Boulder, CO. At this meeting, the laboratories will be holding a workshop to provide a detailed engineering overview and exchange to any company that is interested in utilizing the MDSS technology.

Finally, CDs with all of the software and documentation associated with the winter 2004 demonstration will be distributed to interested parties during the fall of 2004 via the NCAR MDSS web site.

6.0 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 winter of 2003. Reviews from this first demonstration were mixed. The system showed consistent improvement as the season progressed. However, there were some problems with obtaining ground truth observations both from automated stations and from paper log forms. There were problems with the weather models capturing some “light” precipitation events. And, because some of the weather forecasts missed their marks, some of the treatment recommends did too.

However, in a post demonstration presentation, the participating IADOT maintenance supervisors all agreed that the system had tremendous promise and was worth the effort to continue to work with the laboratories to make the system better.

A summary of the winter 2004 demonstration will be provided to this forum at the 2005 annual meeting.

Current documentation, progress reports and contact information for prospective stakeholders can be found on the NCAR web site:

http://www.rap.ucar.edu/projects/rdwx_mdss/index.html

7.0 Acknowledgment

The authors would like to acknowledge some of the major contributors to the MDSS project. First, this project would not be possible without the continuing support and leadership from the FHWA Office of Operations, the Joint Program Office and the Highway Research Division. These individuals include Jeff Paniati, Shelley Row (now of the Institute of Transportation Engineers), Mike Freitas, James Pol, Toni Wilbur, Rudy Persaud and Henry Lieu.

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- From MIT/LL: Robert Hallowell
- From FSL: Paul Schultz
- From CRREL: George Koenig

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