A DECISION-SUPPORT SYSTEM FOR WINTER WEATHER MAINTENANCE OF BRIDGES, ROADS, AND RUNWAYS

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ABSTRACT

Maintaining control of snow/ice buildup on roadway surfaces during winter storms is challenging for road maintenance entities. Some of the critical challenges include making effective and efficient decisions for treatment types and timing of treatments, and knowing the location of greatest impact to the roadway based on precipitation rates/types and other weather conditions. These decisions are critical because of the implications to roadway safety, as well as economic impacts to the agency and the environmental impacts of treatments. In order mitigate the challenges associated with winter-road maintenance; the United States Department of Transportation (USDOT) Federal Highway Administration (FHWA) initiated the development of the Maintenance Decision Support System (MDSS) in 1999.

MDSS provides a single platform that blends existing road and weather data sources with numerical weather and road condition models in order to provide information on the diagnostic and prognostic state of the atmosphere and roadway (with emphasis on the 1- to 48-hour time period) as well as a decision-support tool for roadway maintenance treatment options. In the past, the system has been used mainly for strategic purposes in the 12-24 hours prior to a storm's arrival in order to prepare the maintenance vehicles and schedule personnel. However, since the 2008–2009 winter season, MDSS has been modified and applied for tactical use (0-6 hours) over Denver International Airport (DIA), including all six runways and the main arterials leading into the airport.

Currently, MDSS uses three numerical weather models, model output statistics from two models, and various pavement and weather–related surface observations in order to generate both weather and road surface forecasts. In order to address the short-term forecasting needs, radar data assimilation and/or high resolution mesoscale numerical weather models are being assessed for possible inclusion into MDSS. Additionally, a non-wintertime MDSS is also being developed that may provide decision support to the surface transportation community by possibly providing diagnostic and prognostic information regarding convective weather and visibility.

The objective of this paper is to provide an overview of the capabilities of the MDSS system as they relate to the diagnoses and forecasting of weather that may impact the roadway/runway maintenance operations for various decision-makers.

1. INTRODUCTION

The NCAR MDSS (Mahoney et al. 2005) is a decision-support system designed to give winter-road maintenance decision makers both tactical and strategic guidance for planning and executing different aspects of winter-road maintenance. The original plan for the system was to combine weather data, road data, and winter road maintenance rules of practice into one system that could provide useful road-weather specific atmospheric information (e.g. weather observations, road surface observations and forecasts) as well as recommendations (e.g. treatment recommendations) for actions to be taken with respect to physical maintenance of the roadways and bridges. While the treatment recommendations were built as a tactical tool for the maintenance managers, the overall use of the system was originally intended to be strategic (1-2 days).

As the system has matured and the requirements of the various types of users have changed, the need for a more accurate tactical component (0-6 hours) to the weather and road forecast engines of MDSS has become apparent. This is especially important for the prediction of precipitation over the short-term.

This purpose of this paper is to describe the MDSS system, show some results from previous verification studies performed on the system, and discuss the future needs with respect to adding a more accurate short-term nowcast/forecast capability as well as components that will enable the system to be utilized for non-winter weather decision support.

2. MDSS SYSTEM

2.1 Technical Overview

The NCAR MDSS is a computer-based and customizable system that can be configured to provide route-specific weather/road observations and forecasts and road maintenance treatment recommendations. The MDSS project integrates state-of-the-art weather forecasting, data fusion, and optimization techniques with computerized winter road maintenance Rules of Practice (RoP) logic (Mahoney et al. 2005). Over the years MDSS has proven to be a vital strategic decision-making tool with benefits that are included as follows:

- Route-specific forecasts
- Customizable treatment recommendations
- Material (e.g. salt, sand) savings
- Reduced impact on the environment
- Savings on man-power and fuel

Figure 1 shows a high-level flow diagram for MDSS. The upper left –hand box represents data received from the United States National Weather Service (NWS) National Centers for Environmental Prediction (NCEP). These data include: surface observations, statistical guidance products, daily weather summaries, and numerical weather prediction model output from national-scale numerical weather prediction models called the North American Model (NAM) and Global Forecast System (GFS). The NWS models are supplemented by a high-resolution model - the Rapid Update Cycle (RUC; Benjamin et al. 2007) which is generated by the U.S. National Oceanic and Atmospheric Administration (NOAA) Global Systems Division (GSD).

The Road Weather Forecast System (RWFS) is tasked with ingesting reformatted meteorological data (observations, models, statistical data, climate data, etc.) and producing meteorological forecasts at user-defined forecast sites and forecast lead times. The forecast variables generated by the RWFS are used by the Road Condition and Treatment Module (RCTM) in order to calculate the road surface temperature as well as to calculate a recommended treatment plan. The RCTM uses the Model of the Environment and Temperature of the Roads [METRo; Crevier and Delage (2001)]. Linden (2010) provides and in-depth discussion of the use of the METRo model in the NCAR MDSS.

A single consensus forecast from the set of individual forecasts is provided for each user-defined forecast site or district (e.g., plow route and zone) based on a processing method that takes into account the recent skill of each forecast module. This consensus forecast is nearly always more skillful than any component forecast. The RWFS is designed to optimize itself using available site observations along or near the routes (e.g. RWIS, METARS). The forecast modules that perform the best are given more weight over time. In addition, Dynamic Model Output Statistics (DMOS) are calculated weekly using observations and model output. The DMOS process is used to remove model biases. The optimization period of the RWFS is approximately 90-100 days.

The final module in the system contains the RoP algorithms. The RoP are customized rules and techniques that are used at DOT maintenance garages for maintaining mobility during winter conditions. These rules tend to vary from state-to-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. Treatment recommendations include the following information:

- Recommended treatment plan (e.g. plow only, chemical use, and abrasives)
- Recommended chemical amount (e.g. pounds per lane mile)
- Timing of initial and subsequent treatments
- Indication of the need to pre-treat or post-treat the road

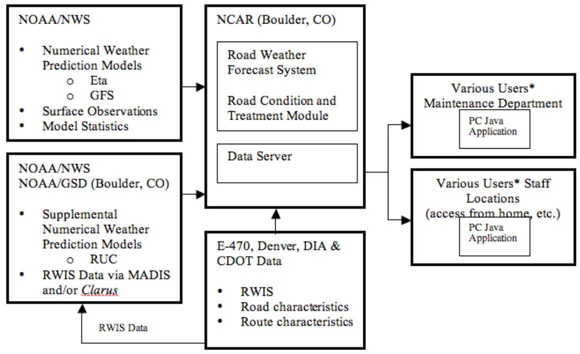

Figure 1. Flow diagram for MDSS

An easy to use Java-based Graphical User interface (GUI; Figure 2) ties all of the pieces of MDSS together and helps to organize (graphically) the information for the user.

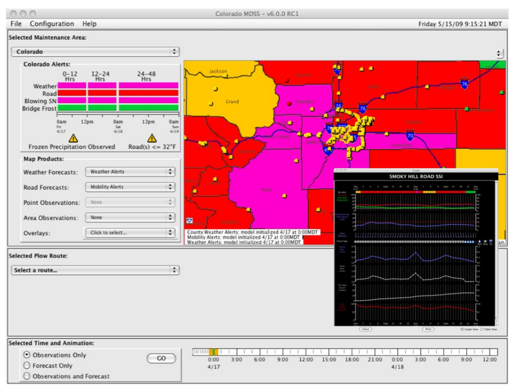

Figure 2. An example of the MDSS GUI

3. VERIFICATION

3.1 Methods

This section provides MDSS results from the winter 2008-2009 MDSS field demonstration in Colorado. Objective analyses of the weather forecasts were performed as well as analyses of the road temperature model. Obtaining sufficient, high quality verification data, especially precipitation information, is an on-going challenge for this project.

Surface weather observation quality from standard road weather information systems was assessed in 2003 via coincident observations of state and road parameters (Bernstein et. al. 2003). Differences apparent in the observations themselves set an acceptable threshold of deviation of the forecast from the observations, or a lower bound for the accuracy one can expect from the MDSS forecasts; in other words, if the observations can only be measured within a certain tolerance, then differences between such observations and the MDSS forecasts can be attributed to uncertainty in the observations themselves.

Objective verification is achieved via direct comparisons of MDSS forecasts to reliable observations from National Weather Service and roadside Environmental Sensor Stations. These results are presented through diagrams of root mean squared error (RMSE), median absolute error (MAE), bias for state parameter fields (e.g. air temperature, dew point, and wind speed), and road and bridge temperatures. In an attempt to examine MDSS precipitation forecasts, two case studies are presented herein.

3.2 Data

During the 2008-2009 season there were several winter weather events, which resulted in a very diverse season in terms of event snowfall amounts, duration, and large-scale characteristics. There was one major snowstorm during the 2008-2009 winter-season, which resulted in just under a foot of snow for DIA compared to zero major snowstorms for the 2007-2008 season. In total, there were 41 snow events but only 7 events of 2 inches or greater over DIA during the demonstration period (Chapman et al. 2009).

The following weather observation data sources were used for verification and analysis:

a) Colorado DOT and E-470 RWIS
b) NWS ASOS/AWOS
c) Local observer surface data
d) Weather satellite
e) Weather radar
f) NWS storm summaries
g) GEONOR precipitation gauge (Denver International Airport)
h) Denver Urban Drainage and Flood Control District precipitation observations

The following road condition data sources were used for verification and analysis:

a) Colorado DOT and E-470 road temperature sensors
b) NCAR personnel observations

4. RESULTS

In this section, performance results are described for the entire winter 2008-2009 Colorado field demonstration for specific components of the MDSS. Bulk statistics based on the weighted average root mean square error (RMSE), median absolute error (MAE) and bias (forecast minus observation) are calculated. The statistics were calculated for 71 sites along the Colorado Front Range. The weighted average RMSE is calculated in the following manner: for each lead-time, RMSE is calculated for each site and then weighted based on the total number of valid errors for that site. The RMSE values (for each site) are then summed over all sites and divided by the sum of the errors for each site.

4.1 RWFS - Meteorological

The RWFS consensus forecast was compared to the forecasts from the individual models included in the ensemble in order to discern whether the RWFS statistical post processing methods and techniques added value (e.g., increased skill).

The results are based on average RMSE and bias per lead time (1 to 48-h) of forecasts initiated at 12 UTC for the entire season (01 November 2008 – 30 April 2009).

For all three variables, the RWFS performed well with the consensus forecasts having lower RMSE values compared to the individual forecast module components for all lead times (Figures 3-5). Forward Error Correction (FEC), which is applied to all the verifiable variables (variables that have corresponding observations), reduces the RMSE within the first three hours.

The reduction in overall error provided by the consensus forecast is most evident for air temperature and dew point temperature. In general, there is a more pronounced difference in skill (i.e. larger spread among the forecasts) between the final consensus forecast and its components for air temperature and dew point temperature (Figures 3 and 4) than for wind speed (Figure 5).

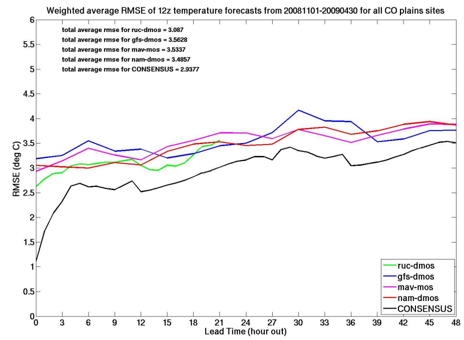

Figure 3: Weighted average air temperature RMSE computed from the 12 UTC forecasts for the entire demonstration season (01 November 2008 – 30 April 2009). The consensus forecast (black line) and the individual forecast module components for the Colorado plains sites are shown.

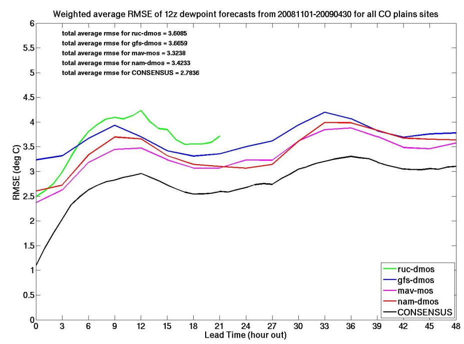

Figure 4: Weighted average dew point temperature RMSE computed from the 12 UTC forecasts for the entire demonstration season (01 November 2008 – 30 April 2009). The consensus forecast (black line) and the individual forecast module components for the Colorado plains sites are shown.

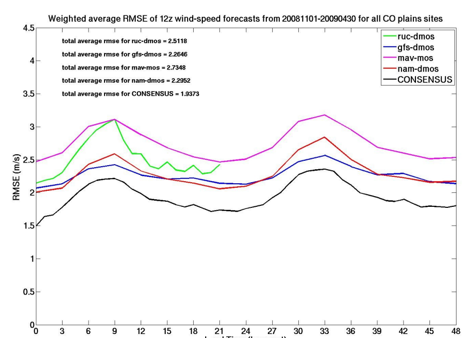

Figure 5: Weighted average wind speed RMSE computed from the 12 UTC forecasts for the entire demonstration season (01 November 2008 – 30 April 2009). The consensus forecast (black line) and the individual forecast module components for the Colorado plains sites are shown.

4.2 RWFS – road temperature

This section examines the road and bridge temperature forecasts using recommended treatments as determined within the MDSS Road Condition and Treatment Module (RCTM). Measurement differences between the predictions and pavement sensors were used to calculate median absolute error (MAE) and average bias (forecast minus observation) per lead time (e.g., 1 to 48-h) for 12 UTC forecasts generated over the entire season (01 November 2008 – 30 April 2009). Statistics were calculated for 9 road sites in the Denver area and 2 bridge sites along E-470.

The road temperature MAE (Figure 6) ranges from around 1.5-2.0°C during the evening and overnight hours, but increases to a peak of about 3.5°C in the afternoon, which corresponds with the hours of maximum solar insolation. There is a cold bias evident in the late morning hours (lead times 0-6 and 18-30-h) turning to a warm bias during the afternoon (lead times 7-18 and 32-41-h) (Figure 7).

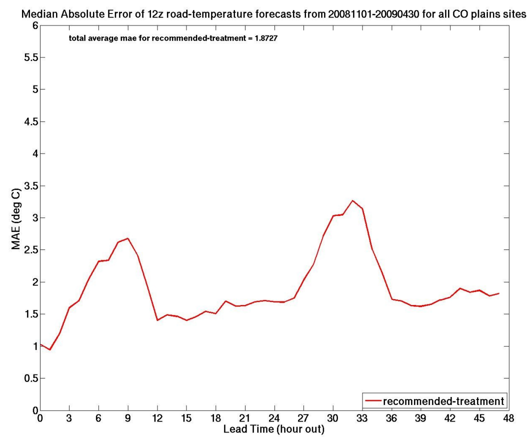

Figure 6: Road temperature MAE, computed based on 12 UTC forecasts from 01 November 2008 – 30 April 2009 for the Colorado plains sites. Local noon is at hours 7 and 31.

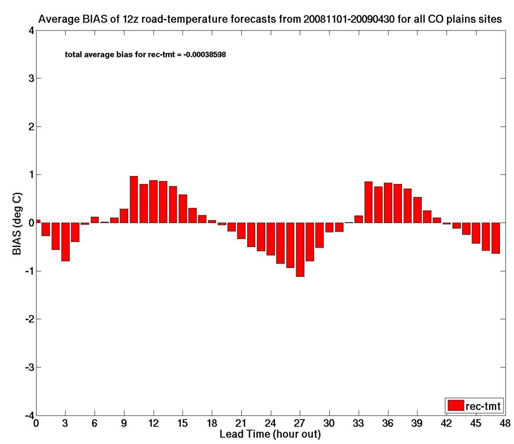

Figure 7: Average road temperature bias from the 12 UTC forecasts for 01 November 2008 – 30 April 2009 for the Colorado plains sites. Local noon is at hours 7 and 31.

There is still some uncertainty as to whether part or all of the bias in the forecasted road temperatures is real or due to differences between the measurements made by the road temperature sensors (pucks), which have different thermal properties than the road surface, and the road temperature model, which was configured to predict the pavement skin temperature.

4.3 Quantitative Precipitation Forecasts

The concept behind the RWFS is based on having good observations near the forecast points that feed back into the system and tune each forecast parameter dynamically in order to optimize the contributions from each model in the ensemble on a run-to-run basis. However, forecasting any characteristic of precipitation (i.e., timing, rate, and phase) is very difficult, in part, due to problems with the forecasting process, an insufficient observation network, and the inability to verify actual precipitation amounts, particularly for winter precipitation (e.g., snow, sleet, etc.) (Linden et al. 2007).

The lack of quality real-time winter precipitation observations prevents the RWFS from tuning itself for the QPF parameter. Without quality, real-time quantitative precipitation observations (liquid equivalent), the RWFS quantitative precipitation prediction modules would end up at best being averaged (4-member average), and at worst being tuned incorrectly due to poor observation quality. Due to this fact, it was necessary to modify the RWFS to fix the QPF weights across the four modules based on expert opinion. For this demonstration season the weights were fixed for all lead times. The weights for the QPF parameter are 60% NAM, 0% RUC, 40% GFS and 0% MAVMOS.

Several case studies were performed (one is included in this paper) to compare the consensus and individual model QPF to the actual liquid-equivalent precipitation collected by a GEONOR precipitation gauge that was installed at Denver International Airport by NCAR for a Federal Aviation Administration project. Forecasts generated approximately 12 and 24 hours before the start of precipitation are used for verification. On the figures (Figures 8 and 9) that follow, precipitation start time is indicated by a dashed line.

On 26 March 2009, a major snow event occurred around the Denver metropolitan area with snowfall amounts between 7-14 inches and locally heavier (e.g. 12-24in.) in the foothills west of Denver. The event was meteorologically characterized by a strong upper-level trough which cut-off over the four corners area in Southwestern Colorado. At the surface a strong low-pressure center was located in southeastern Colorado, which provided deep cyclonic upslope over the forecast area. Over DIA the impact of the storm was felt late morning into the early evening hours with a 4-6 period of blizzard conditions.

The 1200 UTC forecasts generated on 25 March 2009 indicate that all of the models predict the onset of moderate snow 4-6 hours before the snow actually starts (Figure 8). The MAVMOS significantly under predicts the total precipitation amount while the remaining models over-predict the storm. The Consensus forecast, being heavily weighted towards the NAM, over-predicts the total amount but does a reasonable job of predicting the intensity.

Figure 9 shows the 0000 UTC runs from 26 March 2009. The results are similar to the 24h forecast with four of the five models over-predicting the storm totals. All of the models are accurate (within) one hour of the start time except for the GFS (which is three hour early). Overall this forecast was a success in that the consensus forecast predicted a very significant event for DIA 24 hours in advance and was consistent up to the start of the storm.

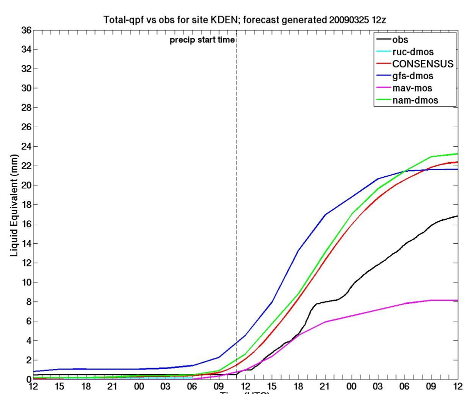

Figure 8: 12 UTC 25 March 2009 RWFS run showing a liquid equivalent accumulation time-series plot comparing the DIA GEONOR measurements to the RWFS forecasts for the DIA site.

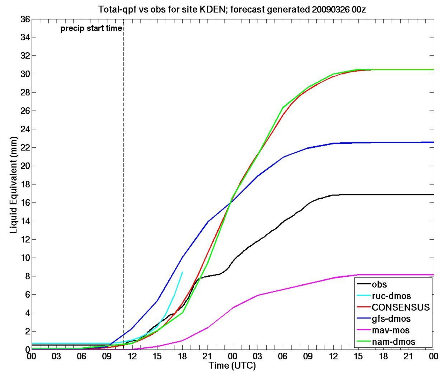

Fig. 11.2: 00 UTC 26 March 2009 RWFS run showing a liquid equivalent accumulation time-series plot comparing the DIA GEONOR measurements to the RWFS forecasts for the DIA site.

5. CONCLUSIONS AND FUTURE WORK

The results from this study (as well as past studies) indicate that MDSS is a useful and fairly accurate tool that can aid in both strategic and tactical decision-making for the winter road maintenance community. Up to this point the road maintenance community has used it to provide weather information essential for the strategic planning for labor, equipment and material. With the configuration of the system to the airport environment, the need for high-resolution short-term precipitation and storm tracking information has arisen for both winter and non-winter weather conditions. The inclusion of decision support for the surface transportation community through an MDSS type of platform for the diagnosis and prognosis of convective weather and visibility is being considered for development in the very near future.

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7. ACKNOWLEDGEMENTS

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