Maintenance Decision Support System (MDSS)
Field Trial – Preliminary Report

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Dear Gary,

Subject: MDSS – A Field Trial of the Implementation in Canada

Please find enclosed the report of our Field Trial of the Implementation of the Maintenance Decision Support System (MDSS) in Canada.

The report provides the background to the development and evolution of MDSS in the U.S. It then documents our implementation of MDSS with five Ontario road authorities for typically two patrol sections per road authority. The first winter storm identified for the MDSS evaluation occurred on January 18th and the study period continued to March 29th, 2012.

Running MDSS for a storm situation generates a unique Mobility Index. The MI indicates in a single number, a measure of predicted road traction which, as seen in this study, fell with the onset and worsening of weather conditions.

Perhaps the strongest asset of MDSS is that it provides a standardized decision-making framework for winter road maintenance monitoring and operations. This will lead to greater consistency in road maintenance decisions and optimized salt use to be compliant with salt management plans.

This preliminary study was beneficial in identifying the strengths of MDSS and areas requiring more modification of the NCAR MDSS version with Canadian operating standards.

We look forward to working together with agencies responsible for road maintenance to refine and evolve MDSS for the Canadian operational environment.

Yours sincerely,

Robert Boggs
Manager, Commercial Services
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1. Executive Summary

Maintenance Decision Support Systems (MDSS) went through a lengthy development in the United States and has evolved into a mature road operations decision tool. The aim of this field trial of MDSS was to adapt the NCAR version of MDSS to operate in the Canadian road maintenance environment, and to assess whether it has merit as a tool to optimize salt use and control costs. Moreover, can it function as a standardized decision-making tool for road maintenance and lead to greater consistency in anti-icing operations?

This initial implementation of MDSS and field trial generated encouraging results. Comparing the actual treatment to the MDSS prescribed treatment, it appears there is a potential to control salt use and at the same time maintain the standards of road mobility. A summary of the results is given below:

- The various modules of the NCAR MDSS were successfully implemented to generate the associated outputs.
- Output from the MDSS produced a 24 hour forecast of pavement and atmospheric conditions, a suggested pavement treatment, and a Mobility Index.
- Following the suggested treatment of this trial run would have resulted in a reduction of salt used, and a cost savings attributed to the salt reduction. There would have been additional savings in diesel fuel and reduced wear and tear of vehicles (depreciation).
- MDSS should be evaluated over a greater range of climate areas with differing rules of practice and traffic influences.
- The documentation for the NCAR MDSS did not match the software. Further work is required on several MDSS modules, such as updating to the latest version of the METRo model, the GUI, and Rules of Practice.
- Roads maintenance authorities should be engaged in consultation about the Rules of Practice. For example, MDSS assumes plowing will always be used for snow clearing (which may be more oriented to U.S. states). In Ontario by contrast, DLA or salt treatment may be used without plowing. Assumptions of the NCAR MDSS should be verified against Ontario practices.
- MDSS requires further evaluation in greater consultation with the potential end users. Feedback from potential end users should be incorporated into the product enhancements.

1.1 Objectives of the project:

The objectives of the project were:

- To validate MDSS for Canadian winter road maintenance operations.
- To assess potential financial savings benefits of MDSS.
To promote MDSS familiarization amongst stakeholders as we collectively head down the road of RWIS evolution to the benefit of all.

Examine the potential for MDSS to be used for related tasks such as performance monitoring; staff decision-making consistency; and using the Mobility Index for gauging winter severity.

Engage stakeholders for feedback on this particular implementation of MDSS.

Conduct a Field Trial of MDSS with a cross-section of different road authorities including MTO Area Maintenance Contractors, a private sector road authority, large regional municipal transportation department, and a medium-sized municipality, all situated in the same climate region.

Provide data-driven performance results, based on the field trial to demonstrate operational benefits at the MTO Technology Workshop in June 2012.

1.2 Goals of the project:

1. Develop a MDSS that will enable the Winter Maintenance Service Providers to:
   a. Automatically generate weather forecasts, on road segments between RWIS stations, and provide a view of predicted weather and road conditions on a road segment basis, at a scale of RCS reporting sections or shorter.
   b. Calculate road conditions (road temperature and chemical concentration), and snow depth.
   c. Predict the impact of upcoming weather on specific road segments.
   d. Provide recommended treatment guidance based on MTO standards/best practices.
   e. Allow users to view time series information for weather and road condition parameters.
   f. Provide post-storm analysis.
2. Evaluate an operational deployment of the MDSS and any enhancements.

1.3 Essential Functions of MDSS

MDSS integrates ensemble forecasts, with multiple weather and road observations, the METRo road forecast model, algorithms for chemical concentration and road mobility, the rules of practice for the road authority to which it is being applied, and a display system.
1.4 Research Methodology

Study Area

As one of the key objectives was to evaluate the implementation of MDSS for a cross-section of various road authorities including provincial Area Maintenance Contractors, a private sector highway owner and operator, a large regional municipality and medium-sized municipality, it was decided that the study should be conducted in one homogeneous climate area.

Figure A shows the MDSS Field Trial Area. It included the western Oak Ridges moraine spanning the north through the Niagara Escarpment to Orangeville and included sections descending north into the Simcoe Lowlands and south into northern Toronto.

There are several overlapping road authorities that are responsible for road maintenance in the selected study area. The study area is also data rich in RWIS stations. Patrol routes were selected that had at least one operational RWIS station. The locations of RWIS stations and patrol study sections are shown in Figure B - MDSS Study Area and Stakeholder Routes. The different coloured patrol segments indicate the segments of the various road authorities.
Once the study area was selected and the road segments were determined, then the route details, standard rules of practice, levels of service, equipment capabilities and geographical data was needed for each road authority. This included such items as:

- Segment name, location, type, length, number of lanes and treatment time;
- Number of layers, type and thickness of road and road bed;
- Traffic volumes;
- Maximum allowable snow accumulation before plowing is mandated;
- Chemical and Pre-treatment (i.e. prior to storm) chemical types, forms and rates options.

**Experiment Outline and Execution**

The experiment for this MDSS Field Trial was designed provide insight and feedback from end users on how plausible MDSS results would be for use operationally. The experiment consisted of three parts; each of which would assess different performance aspects of MDSS based on time back to bare road, duration of storm operations (i.e. time from first truck out to last truck out) and chemical usage.
A Schematic of the field trial is shown below in Figure C. Running the MDSS model generated the recommended treatment strategy and predicted road conditions and mobility index as shown in the blue flowchart symbols. Information obtained from the participating road authorities is represented by the green flowchart symbols. The central task of the field trial was to compare simulated versus actual performance metrics between the MDSS output in the first section with the observed values obtained from the road authorities as indicated in the second section.

**MDSS Field Trial Schematic**

*Using select storms:*

1. **Document the MDSS-predicted road conditions and performance metrics** which result from the simulated default treatment.

2. **Compare simulated vs. actual performance metrics** between predictions in 1 and observed values in 2.

   - Main Performance metrics were:
     - Time length back to bare road:
     - Duration of storm operations:
     - Chemical usage

**Figure C. MDSS Field Trial Schematic**

Road authorities involved in the field study were given access to a newly developed MDSS interface. The interface provides the treatment recommendations along with tables giving snowfall accumulation with or without chemical treatment, mobility index with and without treatment, and chemical concentration.

During the set-up of MDSS for the preliminary investigation and the field trial it became apparent that some of the hard-coded components of MDSS as bundled by NCAR for distribution to service providers requires additional system modification to make it work in a Canadian operational environment with standard rules of practice used locally. Additionally, some of the accompanying documentation for system operators and set up are incorrect and will need
resolution before MDSS can be fully realized. As part of the learning experience with the field trial process, this is valuable information as it uncovered mandatory additional work, hitherto unknown, which can now be anticipated and accounted for when planning the needs of subsequent implementation phases. It does, however, point to the possibility that other unknown hurdles are a potential as we move forward.

The winter season of 2011/2012 was characterized by lighter snowfall than normal, warmer temperatures, and more frequent fluctuations through the freezing mark. The first storm advisory sent to the participating road authorities was on January 18th and the last one for the winter season was sent on March 29th. The road authorities were asked to particularly document all road maintenance operations during the declared MDSS storm events and send the maintenance logs to The Weather Network for comparison against MDSS treatment recommendations.

An orientation session was held prior to the start of the evaluation period with all the road authorities to demonstrate how to navigate through the MDSS user interface, to review the objectives of the field trial, and to review the operational process for the field trial. Meetings were held with the individual road authorities during the winter season to gather user comments.

2. MDSS Features

A high level description of MDSS features, history, essential functions, and MDSS interfaces is given in this section.

2.1 MDSS Definition/Description

MDSS is an integrated software application that provides users with real-time road treatment guidance for each maintenance route, addressing the fundamental questions of what, how much, and when according to the forecast road weather conditions, the resources available, and local rules of practice. In addition, MDSS can be used as a training tool, as it features a what-if scenario treatment selector that can be used to examine how the road condition might change over a 48-hour period with the user-defined treatment times, chemical types, or application rates.

2.2 MDSS History

The U.S. Federal Highways Administration (FHWA) in collaboration with the National Centre for Atmospheric Research (NCAR) developed the MDSS with a consortium of subject matter experts including:

- Army Cold Regions Research & Engineering Laboratory (CRREL)
- National Centre for Atmospheric Research (NCAR)
MDSS was developed over a twenty year period and was first implemented as a prototype in Iowa in 2002. The first trial year yielded poor results when maintenance users gave the system a low rating for accuracy and application to maintenance decisions. This was attributed to poor user end support and training. Subsequent trials have built on this experience by ensuring thorough user training and support prior to the beginning of the winter season, and then during and after winter storm incidents.

To provide encouragement to MDSS development and implementation, the FHWA funded a MDSS Pooled Fund Study involving the snow belt states including South Dakota, North Dakota, Wyoming, Colorado, Minnesota, New Hampshire, New York, Indiana, Iowa, California, Kansas, Kentucky, Nebraska, and Virginia. MDSS has subsequently been implemented in 30 states by a number of different private sector weather service providers.

Between the years 2003 to 2010, various pilot projects were run in these states. There have been several studies which document the quantitative and qualitative benefits of implementing MDSS into winter maintenance decision-making. (refer to Section 3.0 Literature Review). Almost all studies of the application of MDSS to road maintenance operations have demonstrated cost savings, but more importantly, a consistency of maintenance standards to the application of anti-icing chemicals.

The development of MDSS must be considered parallel to the designation of salt as a controlled substance by Environment Canada, and the requirement to demonstrate through salt management plans that salt or other chloride-based chemicals are being used in the most cost-effective manner with respect to best practices. MDSS appears to provide an established solution to minimize salt use.

To date, MDSS was developed in the United States for American road maintenance authorities. MDSS has not been implemented by any Canadian provincial, municipal or private road authorities. In a discussion with Paul Pizano, the coordinator of the MDSS Pooled Fund for the FHWA, Mr. Pizanno encouraged the development of a Canadian version of the MDSS system, using Canadian weather models, Canadian Rules of Practice, the geographic shaped files for Canadian highways, and of course metrification of the software.

### 2.3 Essential Functions of a MDSS

MDSS is an integration of the Maintenance Decision components creating an end-to-end capability.

MDSS components include:

a) Ensemble forecasting system. In this version, the Pelmorex Forecast Engine (PFE) is used to initialize the weather forecast component.
c) METRo road weather forecast system  
d) Road temperature algorithm  
e) Road chemical concentration algorithm  
f) Road mobility algorithm  
g) Rules of practice logic (from MTO)  
h) Display system  

These are described more fully in the following section.  

2.4 MDSS Interfaces  

MDSS was designed so that the individual components or models could be replaced or enhanced as new technology is developed. The system originally used SnoTherm as the Road Weather Forecast System and this has been commonly replaced with the METRo model. Value added meteorological service providers are encouraged to use their own weather prediction models to generate unique value-added forecasts. Although several agencies were instrumentation in the long term development of MDSS, it was NCAR that integrated all the modules that are needed for the system. The required modules are stuck together with a piece of code developed by NCAR which is the “glue layer”. A brief description of the modules used in this initial study is given below. Anyone interested in further information about the individual modules could read the detailed description in the NCAR MDSS Functional Prototype Overview Description.  

2.4.1 Weather Forecast Module  

NCAR’s “out-of-the-box” version of MDSS used Dynamic Model Output Statistics (DMOS), which is a compilation of ensemble forecasting weighing the weather models that have been performing well during the most recent time period. Service providers are encouraged to substitute their own forecast preferences for the weather forecast module. The Weather Network has substituted the Pelmorex Forecast Engine to incorporate Canadian models and the value added forecast modifications of The Weather Network’s meteorologists.  

Pelmorex Forecast Engine – The PFE  

To streamline the handling of many weather forecast parameters in fine spatial and temporal detail, Pelmorex has operationally implemented the Pelmorex Forecast Engine (PFE) into its Forecast Centre and ancillary Operations units. This state of the art software-hardware system allows for rapid modification of weather forecasts in a real time environment despite the high level of detail and the amount of data.  

This PFE technological “backbone” is built around the Graphical Forecast Editor (GFE) which is the same graphical user interface used by U.S. National Weather Service forecasters. Developed by the Forecast Systems Laboratory at the National Centre for Atmospheric Research in Boulder, CO, the GFE was incorporated into the core of numerical weather forecast data flows at Pelmorex through the creation of the PFE. This is the same NCAR group that coordinated the development of MDSS.
To feed the PFE, Environment Canada (EC) supercomputers provide numerical weather prediction (NWP) data to Pelmorex via dedicated fiber optic land lines from Montreal, QC to Oakville, ON. Similarly, digital NWP guidance from the U.S. National Centre for Environmental Prediction (NCEP) feeds in via a NOAAPORT satellite downlink to our Oakville ground station. Models used include Environment Canada’s Global Environmental Multiscale (GEM) Regional (short-range) and the GEM Global (long-range) models. From NCEP we receive the AVN (formerly Eta) and GFS (Global Forecast Suite) forecast datasets. Pelmorex forecasters thus have rapid access to digitized and graphically plotted data from the four preeminent North American forecast models as each one updates over the course of the 24-hour day.

The raw NWP data is ingested into the GFE using a PFE initialization process. This process adds value to the data in several ways including taking the coarser resolution NWP data and interpolating it into the GFE’s fine resolution grid. During the initialization, the PFE operates using a one-hour time resolution for all atmospheric forecast values. Also, forecast air temperatures are weighted with Model Output Statistics (MOS) data. Dew point temperatures are likewise adjusted to maintain consistent relative humidity values. The temperature adjustments directly affect the weather-type forecasts as well where, for example, rain would be adjusted to freezing rain or snow as merited by the situation. All of this dramatically improves upon the raw data. Our meteorologists then use the GFE to add additional value to the forecast grids. The enhanced forecast data is fed into the PFE’s forecast database.

By incorporating all of this data through the PFE into the GFE’s high resolution grid with 1-hour time precision, customized forecasts can be generated that focus in on a client’s infrastructure in a highly detailed, efficient and accurate manner. Supplementing the numerical forecast are real time observations including surface weather and upper air reports, satellite imagery and data from NOAA GOES and polar orbiting platforms, radar imagery and data from EC and NWS Doppler Radar networks, and real time data from networks such as MTO RWIS. Monitoring of real-time sources of observed conditions allow Pelmorex’s forecasters to respond to rapidly changing weather conditions, thus providing amended or updated forecasts to clients in a proactive versus reactive manner.

2.4.2 Road Weather Forecast System

During the early years of development MDSS used SnoTherm as the Road Weather Forecasting module. SnoTherm was developed by the U.S. Army Corps of Engineers. When the METRo3 model was recognized by the AURORA group as the pavement model of international standard, METRo3 replaced SnoTherm in the Road Weather Forecast Module.

Pelmorex utilizes the METRo3 (Model of the Environment and Temperature of Roads) developed by Environment Canada to forecast pavement temperature and road conditions. This is the current and third major release of this heat balance model. METRo3 solves the radiative and thermal energy balance at the road surface to predict the pavement temperature. It does this using current observations of the weather, pavement and subsurface conditions at the time the model is run coupled with a detailed time-series forecast of the atmospheric conditions. By including heat conduction in the road and subsurface along with other energy transfers the model budgets energy gains and losses at the pavement surface so as to predict the future temperature of the pavement as influenced by weather, sun and road conditions. Combining a weather forecast with the observed conditions is critical as it allows the METRo3 model to account for complex energy fluxes at a specific site which are beyond the ability of even the
The highest resolution weather forecast models. The weather forecast input to METRo3 is provided by the PFE. As a consequence of using observed conditions and its ability to predict the pavement temperature, METRo can also forecast pavement conditions assuming no winter road maintenance other than plowing is done.

Improvements and verification of Heat Balance Models:

The METRo model has been chosen officially by the U.S. Department of Transport's Federal Highway Administration as the preferred heat balance model to be used in RWIS applications. Pelmorex has been using the METRo model exclusively since 2005 and as a matter of policy, keeps pace with implementing all subsequent versions of METRo as they are released. Implementation occurs only upon passing a rigorous internal testing process on dedicated test machines to ensure stability and accuracy. Pelmorex interacts with the EC developers of METRo3 to help improve the model and propose to beta-test future versions of METRo. Advanced heat-flux calculations developed by two federal U.S. agencies are possible future enhancements. It is envisioned that verification results from the Ontario RWIS project will provide valuable data to help evaluate current and future versions of METRo. The performance of the system in the Great Lakes Basin will be of interest to stakeholders in this project.

2.4.3 Rules of Practice

Since each road maintenance authority, whether a provincial transportation department, municipality or private roads maintenance company will have different and independent Maintenance Standards or Rules of Practice, the Rules of Practice must be input into this module based on the specific rules of the maintenance authority. Therefore, this module will be different for each maintenance authority served, unless two of them share the same rules. The Rules of Practice were input separately for each of the participating road authorities.

2.4.4 Road Mobility Module

The U.S. DOT users indicated a desire to have a single metric to identify the predicted state of the roadway relative to winter road conditions. A mobility metric was developed that takes into account pavement condition (wet, dry, snow, snow depth, ice, etc.).

The Net Mobility Module reads in the meteorological and road surface conditions and outputs an index describing the amount of mobility a vehicle could encounter on the road. This index ranges from 0 (no mobility or impassible roads) to 1 (optimal road conditions or bare and dry roads). Refer to Table A on page 18 to see a breakdown of the mobility index. NCAR has stated that this metric needs additional development, as it does not currently take into account some of the subtle factors (eg., wet snow, dry snow, snow on ice, etc.) that impact mobility.

2.4.5 Chemical Treatment Module

The Chemical Concentration Module predicts the dilution of chemicals existing on the roads. Given an initial concentration applied as part of the treatment process and the weather forecast, the module generates an hourly time series of expected chemical concentrations. The concentration is dependent on the road surface temperature and precipitation amount, and secondary factors including traffic volume and road spray. A difficulty is that the road temperature and the chemical concentration are interrelated. Given the predicted precipitation, it can be determined when the chemicals put down on the road will become ineffective.
The “out-of-the-box” MDSS software includes most of the commonly used anti-icing chemicals. One of the Area Maintenance Contractors in the test section of highway uses a “natural brine” which is not exactly identical to the chemicals included in the NCAR version. The mid-sized municipality uses a 50/50 sand/salt mix which is commonly used in many parts of Canada but sand application is not recognized by MDSS. NCAR states in the documentation that “there is a desire to add additional chemicals to the system”. Further work is required to ensure all anti-icing chemicals that are used be included in this module.

2.4.6 Glue Layer

Essentially, the glue layer is the core processor that runs on the service provider’s server to compile all the necessary module inputs to run the MDSS simulation. Processes in the MDSS are run on a schedule. The schedule is determined by examination of typical data arrival times and process run times. As much of the MDSS processing is sequential, it is necessary to allow sufficient time between process invocations to ensure that the preceding process will have finished. On the other hand, these inter-process scheduling gaps should be as short as is reasonable to ensure more timely end-to-end processing time. Rather than using a custom scheduler, the MDSS uses the UNIX system scheduling utility cron. This is the glue layer.

3. Literature Review

Various MDSS assessments have been done in the U.S. The reports available present the methodology used and the findings. This field trial uses the lessons learned from the other studies for structure and methodology. The study most like this field trial is the Denver assessment by Battelle.

**Analysis of MDSS – Benefits and Costs.** 2009. “Western Transportation Institute and Iteris Inc”.
- Presents benefit/cost analysis of New Hampshire, Minnesota and Colorado.
- Includes MDSS Stakeholder interviews from a number of states.
- Used simulations, not actual implementation.
- The study also analyzed qualitative benefits, such as to motorists and traffic.
- Colorado uses a variety of de-icers; MagCl₂, Ice Slicer, Apex, Caliber

**Indiana – MDSS – Statewide Implementation.** 2009. “INDOT”.
- They compared salt, diesel fuel, and overtime savings from the winter of FY09 (a very light snow year) to the 3 year average, 5 year average and FY08 totals.
- There was a 40.9% savings from FY08 to FY09.
- This overlooks “normalized” snow years and trying to compare values for annual seasonal severity.

**A Benefit-Cost Assessment of MDSS Implementation in the City and County of Denver.** 2009. “Battelle and the City and County of Denver”.
- Compared MDSS recommended treatment on an experimental patrol segment against a control segment.
This study is most like the intended proof of concept.
The authors derived quantitative and qualitative comparisons of applying MDSS recommended treatments to control segments.

Development of MDSS for New Jersey. 2009. “New Jersey Institute of Technology”.
- Primarily a literature review.
- Contains several sample images of MDSS displays.

4. Two Phases of Proof of Concept Project

4.1 Configure the model for Canadian Standards

4.2 Road Weather Simulations and Maintenance Summary

The POC MDSS model was used with archived data from the March 22-23 storm to run simulations of the forecast road surface temperature and road mobility. The resulting output is shown in Figure C and Figure D.

This section discusses what Scan Web displayed during the course of the event and how the Area Maintenance Contractor (AMC) handled the situation. It compares this to what MDSS presented and advised for the same event. It then theoretically summarizes what might have been done differently by the AMC and some operational efficiencies which may have been gained.

Scan Web and the AMC’s Response

In the early evening, just prior to the event, Scan Web was displaying the following RWIS forecast:
Figure A. Scan Web Forecast Summary page valid c. 6:45 p.m. EDT March 22, 2011.
On this webpage, Scan Web was displaying the latest (2 p.m.) METRo model forecast run output along with the corresponding atmospheric forecast data. METRo called for icy roads to develop at Southwold, if left untreated, at 1:40 a.m. on the 23rd.

Figure A shows that observed (Obs) and forecast (FX) pavement temperatures during the afternoon prior to the event were well above freezing, as were the air temperatures. Dew points were below freezing and this can be an indication that precipitation will fall as snow when it starts or sometime afterwards. The forecast also called for about 9 cm of snow by 2 p.m. the following afternoon.

With this information along with similar for neighbouring RWIS stations and a number of Local Area Forecasts (LAFs) in hand calling for freezing (as opposed to frozen) precipitation later on during the event (not shown), the AMC implemented a winter road maintenance plan in the study area tailored for this particular event. A Gantt depiction of the AMC’s plan as implemented along with observed road and weather conditions is found in the following chart “Weather and Maintenance Log Event Chronology” (Figure B).
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**Figure B**

Weather and Maintenance Log Event Chronology, March 22-23, 2011

Date: April 9, 2012

The Weather Network Commercial Services - Confidential
From the chart, we can see that a round of salt was applied just after the outset starting 8:25 p.m. on the 22nd with another round at 10:15 p.m. and another at 0:15 a.m. just past midnight into March 23. These were done at light application rates. For much of this time, it was either raining or transitioning to wet snow via a one-hour long period of a rain-snow mix.

As the precipitation picked up and temperatures edged to and below freezing, the snow began to accumulate and a fourth round of salt along with an echelon plowing took place starting at 2:05 a.m. along with a repeat performance starting at 4:40 a.m. using the same application rates and echelon plowing. During this fifth round, snow transitioned to patchy freezing rain and steadier freezing drizzle. By the time the fifth deployment was complete at 6:15 a.m., echelon plowing would no longer be needed for the rest of the storm and only salt spreading with some plowing was employed. For the AMC, the observed and forecast freezing precipitation called for a heavier (6th) round of salt between 6:35 a.m. and 8:25 a.m. during which time light snow grains mixed in with the freezing drizzle.

By 9:00 a.m. most of the precipitation, but not all, had long since fallen for this event with forecast and observed road temperatures rising above freezing by around 10:00 a.m. despite air temperatures below freezing. This is a testament to the strength of the late March sun’s ability to penetrate the cloud cover during daylight hours and raise the pavement's temperature above the air temperature; in this case to above freezing as well. Recall that the atmosphere is heated from below during the daytime and that, as the pavement tried to heat the air, the storm system’s cold northeast winds were continually blowing in colder air from that direction at a rate which could more than offset the ability of the pavement to heat the air to a higher temperature. Additionally, sub-surface temperatures were above freezing as well thus adding heat to the pavement from below. The result was pavement temperatures more than negligibly above freezing during the late morning and afternoon of the 23rd even though air temperatures sat around -2°C to -3°C.

Despite this, the AMC deployed a 7th round of spreading, also at the heavier application rate to see the road through midday and much of the afternoon. It may be that the forecast of above freezing pavement temperatures was discounted and a more conservative operating posture preferred to be on the safe side. Another consideration was the extensive drifting and blowing snow observed through much of the day on the 23rd. A final, 8th, "mop-up" round of light spreading was implemented on the damp roads toward the end of the event in the early evening of the 23rd in order to ensure that refreeze would not occur prior to the roadway drying out as the pavement was forecast to fall below freezing during the cold of the upcoming night.

**MDSS Simulation**

The MDSS simulation was manually run from the back end for this phase and the run time was 10:00 p.m., about two hours after the actual and forecast start of the precipitation. The actual PFE atmospheric forecast data and observational data valid at that time was used for initialization. MDSS recommended (default) treatment based on this input data was “plow as necessary”. The basic idea here being that the predicted pavement temperatures would be warm enough so that ice was not likely to bond to the pavement during the event but, at the height of the storm, snowfall rates would be high enough such that it would accumulate to thicknesses deep enough to impede travel and would therefore have to be periodically cleared.
Other metrics from the MDSS forecast included a Mobility Index (MI) and a prediction of the 40 cm deep sub-surface temperature. These are presented on Figure C while the predicted snowfall curve is presented on Figure D instead of the sub-surface temperature.

Figure C

Figure D
Figure C shows a warm start to the storm as far as the pavement temperature goes and a warm sub-surface at 40 cm depth with temperatures steady a little under +6°C. The pavement temperature was forecast to only go down to freezing and bottom out at about -0.1°C for approximately 3 hours near dawn on the 23rd before recovering. By 7 p.m. it was expected to have dipped back down to freezing. This is likely the reason that MDSS only recommended plowing as necessary, but it is perilously close to having ice bond to the pavement in a non-negligible manner that morning.

Much of this is reflected in the Mobility Index (MI) which is a non-dimensional metric on a scale from 0 to 1 in tenths. Figure D shows that as the pavement temperature goes down and with the onset of precipitation there is a drop in the MI, which assumes the road will have no treatment, from 1.0 down to 0.7. It then levels off through the wee hours of the overnight period until the snow starts to stick and the pavement temperature dips down to just below the freezing mark whereupon the MI slips a notch to 0.6. Despite the forecast for continuing snowfall after dawn on the 23rd, the rising pavement temperature improves the MI up to 0.7. As the evening progressed, snow tapers off but temperatures dip once more with the MI slipping back to 0.6.

The MI, as one can see, offers a convenient single value variable which can be used to describe road friction as a function of precipitation and temperature combined. It can therefore be used for communication and for MDSS to have an index through which it can calculate the impact of various winter road maintenance actions against each other and, thus, decide which one offers the best solution considering such things as consumables and labour. Table A shows a descriptive breakdown of the MI. The Road Alert category is an example of using the MI for communication purposes while the General Mobility scheme implicitly takes into account temperature and precipitation severity and their impact on pavement surface friction.

<table>
<thead>
<tr>
<th>Road Condition Alert Category Table</th>
<th>General Mobility Index Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road Alert Category</td>
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<tr>
<td>OK</td>
<td>0.76 to 1</td>
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<td>Marginal</td>
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<td></td>
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<tr>
<td>Extreme</td>
<td>0 to 0.25</td>
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</tbody>
</table>

Table A

During the study event, conditions were forecast to be between marginal and OK, but generally marginal for most hours and either in the Wet category or the Snow less than 10 cm category under the assumption that no winter road maintenance was done. As most levels of service
dictate that only about 2 cm can accrue on the pavement before plowing becomes mandatory, we can see why MDSS would indicate “plow as necessary” as the default strategy.

MDSS versus Scan Web

The METRo model (version 3.2.1?) embedded in MDSS initialized at a higher pavement temperature than the METRo model used operationally by Scan Web (v.3.2.6) as can be seen in Figure E. However, within 6 hours from runtime MDSS was within about 0.5°C of the operational forecast and 1°C of the actual observed value (4:00 a.m.). In either case, for about the first three hours of precipitation on the evening of the 22nd, rain, not snow, was falling at London Airport and likely at Southwold as well; though wet snow is not out of the question there until about 2:00 to 3:00 a.m. when air temperatures went below 0°C.

![Figure E](image)

What is interesting as well is that MDSS and Scan Web had identical pavement temperatures for the period March 23 / 5:00 to 7:00 a.m. in the same critical predawn hours discussed above and yet MDSS still only recommended “plow as necessary”. Also, the observed pavement temperature is a bit colder than forecast (though the secondary sensor at Southwold ESS was often about 0.5°C warmer than the primary puck). This helps explain why the AMC spread salt, especially through the middle of the overnight period (midnight to dawn), as the pavement temperature by 3:00 am dipped a fraction of degree below freezing and stayed there until about 9:20 in the morning. The operational forecast did a bit better than MDSS from around 7:30 to 8:30 in predicting that the pavement temperature would indeed be below freezing as ended up being observed.
Figure F shows a 24-hour historical observation plot from Scan Web starting on the left edge just prior to the onset of the rain. One can see the drop in the pavement temperatures at both pucks as the precipitation started just before 7:55 p.m. (solid thick red line and dotted blue line) and how the Freeze 0 temperature primary sensor plot (solid thin red line) picks up the salt spreading rounds during the rain on the evening of the 22nd, in the predawn hours of the 23rd, followed by the late morning and early evening applications as well. One can also see the above freezing temperatures of the pavement through much of the daylight hours along with the wet road conditions. Chemical Wet/Slush is reported only when chemical is present and the pavement temperature is below freezing. If the pavement temperature is above freezing then Scan Web reports Wet conditions regardless of whether chemical is present or not.

Pavement temperatures peaked at about 3:15 p.m. near 6°C and though they dipped to near freezing near 5:15 p.m. a temporary rebound to 2°C occurred thanks to the evening commute though this benefit was gone by about 6:30 p.m. and only crudely predicted by Scan Web and MDSS (Figure E). With the benefit of hindsight and, thus, with no need to consider safety margins, the use of salt nevertheless, at least at Southwold, from about 10:00 a.m. through to about 5:00 p.m. on the 23rd is questionable.

Though not implemented as simulated “what-if” scenarios in MDSS as originally envisioned, it proved possible to review the AMC strategy has implemented and modify it in a way which was
highly unlikely to jeopardize safety not with the benefit of hindsight but only looking at the Scan Web or MDSS forecast.

Figures G1 and G2 are presented below which shows the observed pavement and air temperatures along with the application round numbers and consumables used. The review indicated that the first round of salt spreading in the evening of the 22nd (#1) could likely have been eliminated without any loss of safety or violating levels of service. Additionally, round #7 could have been dropped and round #6’s application rates mitigated with non-trivial savings in salt and two fleet deployments, as well as reduced duration of operations, the result.
### Maintenance Decision Support System (MDSS)

#### Field Trial

<table>
<thead>
<tr>
<th>Date [EDT]</th>
<th>March 22, 2011</th>
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</thead>
</table>

#### Weather

- **Precipitation or Weather Groups**
- **Blowing or Drifting Snow**
- **Snowfall**

#### Fleet Deployments

- **Plow & Salt**
- **Salt**

#### Truck OTW/14

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</table>

#### Route Length

- **100.0** km
- **1.25** kg/l

#### Observations

- **Temperature**
- **Pavement Temperature**

#### Possible application and dry rate mitigation

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<thead>
<tr>
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<th>Bine</th>
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#### Fleet Utilization

- **Utilization Rate**

---

*The Weather Network Commercial Services - Confidential*

*April 9, 2012*
<table>
<thead>
<tr>
<th>Date</th>
<th>March 23, 2011</th>
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**Weather Conditions**

- **Time | EDT** | 07:00 | 07:15 | 07:30 | 07:45 | 08:00 | 08:15 | 08:30 | 08:45 | 09:00 | 09:15 | 09:30 | 09:45 | 10:00 | 10:15 | 10:30 | 10:45 | 11:00 | 11:15 | 11:30 | 11:45 | 12:00 | 12:15 | 12:30 | 12:45 | 13:00 | 13:15 | 13:30 | 13:45 | 14:00 | 14:15 | 14:30 | 14:45 | 15:00 | 15:15 | 15:30 | 15:45 | 16:00 | 16:15 | 16:30 | 16:45 | 17:00 | 17:15 | 17:30 | 17:45 | 18:00 | 18:15 | 18:30 | 18:45 | 19:00 | 19:15 | 19:30 | 19:45 | 20:00 | 20:15 | 20:30 | 20:45 | 21:00 | 21:15 | 21:30 | 21:45 | 22:00 | 22:15 | 22:30 | 22:45 | 23:00 |

| **Time | EDT** | 07:00 | 07:15 | 07:30 | 07:45 | 08:00 | 08:15 | 08:30 | 08:45 | 09:00 | 09:15 | 09:30 | 09:45 | 10:00 | 10:15 | 10:30 | 10:45 | 11:00 | 11:15 | 11:30 | 11:45 | 12:00 | 12:15 | 12:30 | 12:45 | 13:00 | 13:15 | 13:30 | 13:45 | 14:00 | 14:15 | 14:30 | 14:45 | 15:00 | 15:15 | 15:30 | 15:45 | 16:00 | 16:15 | 16:30 | 16:45 | 17:00 | 17:15 | 17:30 | 17:45 | 18:00 | 18:15 | 18:30 | 18:45 | 19:00 | 19:15 | 19:30 | 19:45 | 20:00 | 20:15 | 20:30 | 20:45 | 21:00 | 21:15 | 21:30 | 21:45 | 22:00 | 22:15 | 22:30 | 22:45 | 23:00 |

**Maintenance Decision Support System (MDSS) Field Trial**

- **Plow & Salt Deployment**
  - Plow & Salt: Yes
  - Salt: Yes

- **Plowing Status**
  - Plowed: Yes
  - Salted: Yes

**Route Length**

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<td>Brine</td>
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<td>7078</td>
<td>7078</td>
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</tbody>
</table>

**Observed Air Temperature (°C)**

| Observed Air Temperature (°C) | 2.3 | 2.9 | 2.7 | 2.2 | 1.9 | 1.7 | 2.2 | 2.1 | 2.2 | 2.6 | 2.9 | 3.2 | 3.5 | 3.7 | 3.9 | 3.6 | 3.4 |

**Obs. Pavement Temperature (°C)**

| Obs. Pavement Temperature (°C) | 4.5 | 4.5 | 4.3 | 4.1 | 2.2 | 1.4 | 1.6 | 1.8 | 5.6 | 3.4 | 0.5 | 1.1 | 0.5 | 0.5 | 0.7 | 1.6 | 1.0 |
Compared to the 58613 kg of dry salt and salt in brine solution used, the alternative strategy would have consumed only 40770 kg of salt in total. Two fleet deployments and diesel used could have been saved. Finally, the elimination of deployment round #1 on the evening the storm started as rain could have contained the operations window between 22nd / 10:15 p.m to 23rd / 8:00 p.m. instead of between 22nd / 8:25 p.m to 23rd / 8:00 p.m. and so reduced the length of operations by 1 hour and 50 minutes.

5. Storm Analysis

March 22-23, 2011 Event Description (all times are EDT unless otherwise indicated)

The storm selected for the study area had formed by the morning of Tuesday, March 22 in Colorado and then tracked eastward to lie over northern Illinois at 8 a.m. on the 23rd (Figure x). It continued eastward to lie well southeast off of the New England coast 24 hours later.

Figure x) Surface chart valid for 8 a.m. EDT March 23, 2011.
The green shading depicts areas of continuous precipitation. The dashed pale blue line marks the 0°C air temperature while the dash-dot line marks the -18°C air temperature. At this point most of the snow had fallen in the study area on cold, blustery east winds.

Typically, such a late season storm was not a cold one with air and pavement temperatures in the study area ahead of it a few degrees above freezing. Initially, steady light rain set in near 7:45 p.m. with air temperatures of 3°C and pavement temperatures of 6°C. Easterly winds to the north of the approaching storm pumped increasingly cold air into the region such that two hours later a one-hour long rain-snow transition occurred. As temperatures continued to fall, the changeover to straight snow was complete by 11 p.m. though it remained wet at times until about 12:20 a.m. when air temperatures edged to freezing or colder for the rest of the event. As the environment cooled, pavement temperatures pretty steady near 0°C occurred by 10:40 p.m.

Snow continued, moderate at times, through the overnight with 6 cm having fallen at 2 a.m. on the 23rd. Blowing and drifting snow developing by 3 a.m. at which time another 1 cm had fallen. This was just over half the total snowfall of this 10 to 12 cm event. By this time air temperatures had fallen to near -1°C with pavement temperatures at or a little below 0°C.

At 5 a.m., a prolonged period of patchy freezing rain and drizzle, at times mixed with light snow, replaced the all-snow portion of the overnight period and lasted until 10 a.m. during which time drifting snow with some blowing snow was prevalent. Air temperatures fluctuated between -2 and -3°C while pavement temperatures bottomed out near -1°C then rose above 0°C between 9 and 10 a.m. as daylight increased. This gave the maintenance crews a break, along with a brief lull in the precipitation, despite the continuation of drifting snow.

After 10 a.m. a 2-hour period of light snow showers with blowing snow redeveloped as air temperatures remained steady at -2°C but while pavement temperatures fluctuated either side of
+2°C. Near noon, yet another change in the precipitation for about one hour and half occurred as freezing rain mixed with ice pellets hit the study area while blowing snow continued and temperatures remained unchanged.

Around 1:30 p.m. a final transition back to light snow occurred and lasted 2 hours before the main precipitation finally ended near 3:30. Air temperatures between -2°C and -3°C were accompanied by pavement temperatures near +2°C but these soared briefly to peak near +6°C about 3:30 pm as the strength of the late March sun’s radiation managed to pass more effectively through the clouds once the snow stopped.

Storm total snowfalls of 10 to 12 cm in the study area vicinity occurred by 3:00 p.m. on the 23rd with blowing snow easing to drifting snow only around 4:00 p.m. shortly after the precipitation stopped. Pavement temperatures fell back through +3°C as the sun now began to sink with air temperatures dipping to -3°C for the late afternoon.

Residual flurries redeveloped by 5:00 p.m. then ended near 6:30 p.m. with little additional snow amounts due to their light nature. As they redeveloped though pavement temperatures dipped almost to 0°C but recovered to +2°C as the flurries weakened only to slip below 0°C near 7 p.m. as the sun began to set. Drifting snow continued but ended prior to 9:00 p.m.; 25 hours after the light rain had started the previous evening. By that time air temperatures were -4°C and pavement temperatures had leveled off at between -2 and -3°C where they would remain for most of the upcoming night.

Residual moisture on the road predominantly gave pavement condition readouts of snow/ice watches though a spell of snow/ice warnings for one of the two sensors occurred for much of the evening hours on the 23rd in the post-storm environment. This was dealt with by an application of chemical in the early evening hours prior to sunset. Once the sun rose on the 24th and temperatures climbed above freezing any residual moisture on the pavement was history.

Lessons Learned

The lessons learned from the MDSS POC – Phase 1 are invaluable for moving forward. They include the following insights gleaned directly and from the PM’s MDSS Lessons Learned Document:

1. One of the things that worked well with Phase 1 was the degree of flexibility between stakeholders, particularly with regards to modifying deliverables. As it became apparent that the original plan would take more time and resources than practical within the giving project completion date it was modified in way where we would still gain knowledge. This was done without losing site of the main goal of getting MDSS up and running.

2. MDSS spin-up for simulations must be started at least 12-hours prior to each study experiment’s time frame of interest.

3. The Project Manager for this preliminary investigation of MDSS was effective in coordinating the different internal or external resources required to implement the development of MDSS and generate evaluation results. During further evaluations and enhancements to MDSS, a careful assignment of the role of various staff in liaising with external parties and
gathering data should be undertaken as other team members may be able to assist so as to yield more effective and timely results. For example, the selection of a study storm was made somewhat arbitrarily with the result that the original study area proved unsuitable as there was no working RWIS site in the said area. Recommend that a meteorologist be involved from step one of the storm selection process to avoid going too far down a road with no potential.

4. A bottleneck became apparent over the course of Phase 1 with regard to PTI Development resources. This was largely the result of somewhat lacking MDSS set up and reference documentation. It should be noted that the document if far from weak, it is simply not perfect and so may hold more than an few unforeseen landmines which may potentially lay to ruin even the best planned resource allocations for getting this software up and running.

5. As a consequence of the above, it may be advisable that time/man power estimates for development/set up either have a built in contingency of additional resources than those envisioned in the ideal scenario. Failing that, project management should take the face value estimate from PTI Development and adds the contingency in its place which strikes a balance between time to completion and man power availability.

6. It became apparent that the MDSS software program will require more than slim and passing PTI Development attention and resources. This is not surprising in light of not only the experience of Phase 1 but also that of Minnesota DOT, and the U.S. Federal Highways over much of the last 5 to 8 years.

7. It will be highly desirable for Phase II that access by the experiment’s tester to MDSS’s simulation GUI and the resultant output datasets be available.

8. It may be necessary to simplify Phase II end goals to just getting MDSS running without systematically invoking experimental scenarios and an accompanying accuracy performance assessment of the system other than the most rudimentary.

9. However, at odds with (8), if external third parties are engaged in any subsequent phases of MDSS implementation, it is strongly recommended that a more robust allocation of resources be made.

Related to (9), robustness considerations include manpower (i.e. number of bodies), dedication (i.e. adequate prioritization over other concurrent projects), and sustained effort (i.e. the above two hallmarks over a realistic period of time). Otherwise, the pooled approach will backfire as reputation in the RWIS community runs the risk of being tarnished and, unless this is accounted for in considerations other than potential revenue when prioritizing project resources, will jeopardize the maturing of a still adolescent commercial MDSS product and its long term potential. This was similarly a major conclusion of the Minnesota phased-in development and implementation.
6. Summary of Proof of Concept

The NCAR licensed copy of MDSS was successfully installed on The Weather Network’s servers and all the modules were integrated with the central “glue layer” to allow MDSS to be run operationally against a winter storm. Road patrol reports for an Area Maintenance Contractor were compared against the Mobility Index generated by MDSS to analyze the recommended treatment against the contractor’s actual treatment. The trial appeared to demonstrate that there is an opportunity to reduce salt used and costs. More significantly, MDSS offers a structured decision tool for winter (or summer) maintenance decisions.

The initial investigation indicated that there are some modules that need further work to tailor them to Canadian operating standards. Trials in the U.S. have shown that thorough training and working closely with the roads maintainers is necessary to successfully get the road maintenance community on-side to the new technology. We would recommend continued operational trials with selected new technology partners to encourage the use and application of MDSS in Canada.

7. MDSS 2012 Field Trial Results

The following results were observed:

- Chemical usage was reduced, especially in scenarios where road temperatures were at or above 0°C.
- In many cases, this appeared to be due to a proactive anti-icing type of suggested strategy.
- In scenarios where the road was above freezing, gains were more significant; perhaps due to an understandable reliance on below freezing air temperatures by decision-makers.
- As MDSS’s forecast and the corresponding observed road temperatures were very close it implies that MDSS was also accurate in its take on a lack of bonding between ice and pavement such that suggested treatments were lighter than what was actually employed.
- This was confirmed in an immediately adjacent segment where a different user was independently using a strategy identical to what MDSS had recommended for both segments; unknown to him.
- This user met their level of service obligations, as it turned out, using their strategy; and these were the same service levels programmed for MDSS to honour for both segments.
- In light of that it is no surprise that we found savings were less for the more operationally savvy user thus implying that MDSS possesses “experience”.

• Similar savings (i.e. some to not so much) were observed for duration of operations; time to bare roads; hours worked; number of fleet-unit deployments; and with proactive gains in lead times before roads deteriorated.

The following subjective observations from feedback and surveys concluded that:

- **MDSS** suggested treatments are plausible but not a substitute for the human experience factor.
- This is because the human can juggle unexpected considerations such as fleet disruptions; take into account known problem spots transparent to **MDSS** and its **RWIS** dataset, etcetera.
- Thus, **MDSS** offers guidance not gospel.
- **MDSS** can bring new staff up to speed quicker and fosters consistency between staff members.
- **MDSS** reinforces **RWIS** concepts, understanding and use; and, therefore, gains.
- A quantitative test to ascertain the ability of **MDSS** to simulate reality is needed to prove that the perceived gains in efficiencies are real and not a wishful-thinking artifact.
- This would be done by inputting actually implemented strategies into **MDSS** to see how its simulated time to bare roads compared to the actual time to bare roads from logs and collocated **RWIS** stations; amongst other test values.
- The Mobility Index provided a potentially useful and concise value for communicating expected road conditions beyond that of the more language-based descriptors typical of those put out by **RWIS** pavement sensors.
- The MI may have utility in quantitatively assessing winter road hazard intensity and duration by season to form the basis for a winter severity index.

**Summary of MDSS Field Study**

- **MDSS** clearly demonstrates at least incremental gains in efficiencies and maintaining consistency between users.
- **MDSS**’s Mobility Index offers the promise of a new metric for describing and monitoring winter weather impacts on roads.
- **MDSS** should be ground-truthed in order to support the indirectly confirmed notion that the gains are real.
- **MDSS** can offer the basis for a variety of related functionality and conveniences to the end user such as automated vehicle location (AVL) tracking as well as management modules for chemical inventories and man-hours.
- **MDSS** as innovation provides an opportunity for suppliers and users to define new standards and state-of-the-art thresholds.