Maintenance Decision Support System (MDSS)

Field Trial – Final Report

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EXECUTIVE SUMMARY

We are pleased to deliver the results of the Field Trial of the implementation of the Maintenance Decision Support System (MDSS).

A high level summary of the Field Trial results are:

- Promoted community effort in Ontario as a first step in collaboration of winter road maintenance practices across the province; including the efficient use of RWIS technologies.

- MDSS clearly demonstrates gains in efficiencies with potential for considerable savings in salt and resources. On average, MDSS recommended treatments resulted in:
  
  - 37% less chemical
  - 21% faster time to dry roads
  - 11% reduction in duration of operations
  - 44% reduction in truck hours
  - 51% reduction in number of trips
  - 351% increase in operational lead time.

- Following the MDSS treatment suggestions would have resulted in a reduction of 387 tonnes of salt for the three storms (total salt use was 1,046 tonnes) and $23,220 savings (based on $60/tonne) for the reduction of salt before other resource savings for vehicle use and staff time (see Appendix C). To put the salt savings in the context of the Ontario Ministry of Transportation's salt use for the whole province, a 37% reduction would equate to 185,000 tonnes or $11,100,000 (based on $60/tonne).

- MDSS’s Mobility Index offers the promise of providing a basis of a new “standard” for describing and monitoring winter weather impacts on roads.

- Three out of five operators found the chemical application rates were “just right”.

- MDSS’s user interface is clear, easy to use and to navigate.

- Significant insight was gained which will further assist with tailoring MDSS to winter road maintenance operating standards.

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

Maintenance Decision Support Systems (MDSS) went through a lengthy development in the United States and has evolved into a mature road operations support tool. The aim of this MDSS Field Trial 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. When comparing the actual treatment to the MDSS prescribed treatment, it appears that 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 48-hour forecast of pavement and atmospheric conditions, a suggested pavement treatment, and a Mobility Index.
- Following the suggested treatment of this Field Trial run would have resulted in a reduction of salt used and related cost savings attributed to the salt reduction. There would have been additional savings in diesel fuel and reduced wear and tear of vehicles (depreciation).
- Further work is required on several MDSS modules, such as the treatment module, updating to the latest version of the METRo model, the Rules of Practice, and investigating the relationship between the Mobility Index and treatment recommendations. For a detailed list of potential enhancements, see Section 5.

1.1 **OBJECTIVES OF THE FIELD TRIAL**

The objectives of the Field Trial were:

- To validate MDSS for Canadian winter road maintenance operations in real time.
- 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.
- To evaluate the implementation of MDSS for a cross-section of various road network densities and operations.
- Provide data-driven performance results, based on the Field Trial to demonstrate operational benefits.
- Develop a MDSS that will enable the Winter Maintenance Service Providers to:
  - Automatically generate weather and road condition forecasts on a winter road maintenance route basis.
- Calculate road conditions (road temperature and chemical concentration), and snow depth.
- Predict the impact of upcoming weather on specific road segments.
- Provide recommended treatment guidance based on stakeholders standard operating procedures.
- Allow users to view time series information for weather and road condition parameters.
- Provide post-storm analysis.
- Evaluate an operational deployment of the MDSS and any enhancements.

1.2 **RESEARCH METHODOLOGY**

1.2.1 **Study Area**

One of the key objectives of the Field Trial was to evaluate the implementation of MDSS for a cross-section of various road authorities. As such road authorities were chosen with varying road class responsibilities and the study was performed in one homogeneous climate area.

![Figure A - MDSS Field Trial Area](image)

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.

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 were 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.

1.2.2 Experiment Outline and Execution

The experiment for this MDSS Field Trial was designed to 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 back) and chemical usage.

A schematic of the Field Trial is shown below in Figure B. 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.
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) require additional system modifications to make it work in a Canadian operational environment with standard rules of practice used locally. 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. A final wrap-up session where the results were presented was held with all participants on May 25th.
2.0 MDSS FEATURES

A high level description of MDSS features, history, core components, 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.

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)
- Massachusetts Institute of Technology (MIT)
- NOAA National Severe Storms Laboratory (NSSL)
- NOAA Forecast Systems Laboratory (FSL)

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 in parallel to the designation of salt as a controlled substance by Environment Canada. There is a 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. In a discussion with Paul Pisano, the coordinator of the MDSS Pooled Fund for the FHWA, Mr. Pisano 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 **CORE COMPONENTS OF A MDSS**

MDSS is an integration of the maintenance decision components creating an end-to-end capability. The essential components of MDSS include:

2.3.1 **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 SNTHERM 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 instrumental in the long term development of MDSS, it was NCAR that integrated all of the modules that are needed for the system. The required modules are linked together with a piece of code developed by NCAR which is the “glue layer”. Additional information about the NCAR MDSS Functional Prototype Overview Description is available at:


2.3.2 **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 (PFE) to incorporate Canadian models and the value added forecast modifications of The Weather Network’s meteorologists.

*Pelmorex Forecast Engine (PFE)*

To streamline the handling of many weather forecast parameters in fine spatial and temporal detail, The Weather Network 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.

2.3.3 **Road Weather Forecast System**

During the early years of development MDSS used SNTHERM as the Road Weather Forecasting module. When the METRo model was recognized by the AURORA group as the pavement model of international standard, METRo replaced SNTHERM in the Road Weather Forecast Module.
Operationally and for the Field Trial, Pelmorex utilizes/utilized the latest version of METRo (Model of the Environment and Temperature of Roads) developed by Environment Canada to forecast pavement temperature and road conditions. METRo 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 METRo model to account for complex energy fluxes at a specific site which are beyond the ability of even the highest resolution weather forecast models. The weather forecast input to METRo 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 some routine plowing is done.

**Improvements and Verification of Heat Balance Models**

The METRo model has been chosen officially by the U.S. Department of Transportation’s (USDOT) Federal Highway Administration as the preferred heat balance model to be used in RWIS applications. The Weather Network 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.

### 2.3.4 Rules of Practice

Rules of practice must be input based on the specific rules of the maintenance authority. Therefore, MDSS will be configured specifically 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 stakeholders.

### 2.3.5 Road Mobility Module

The USDOT users indicated a desire to have a single metric to identify the predicted state of the roadway relative to winter road conditions. Consequently, a mobility index metric was developed which takes into account pavement condition (wet, dry, snow, snow depth, ice, etcetera). Figure C below shows a breakdown of the Mobility Index.
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 / impassible roads) to 1 (optimal mobility / bare and dry roads). NCAR has stated that the Mobility Index requires additional research and development, as it does not currently take into account some of the subtle factors (e.g. wet snow, dry snow, snow on ice, etc.) that impact mobility. This is evident in Figure C where gaps in the values are present due to the uneven increments between successive MI values. Logically intermediate conditions which one might expect, such as a Damp pavement lying somewhere between Dry and Wet, are not listed either. In addition, the delineations between the pavement conditions which are listed seem rather coarse where a road with 1 cm of snow on it would have the same MI as one covered by 9 cm of snow.

2.3.6 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.
3.0 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 similar in scope and analysis to the 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.
- 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.
4.0 MDSS Field Trial Assessment

The Field Trial was initiated during the winter of 2011/2012 to implement and assess the performance of the Maintenance Decision Support System (MDSS) developed for the U.S. Federal Highways Administration. The study covered areas of the northern Greater Toronto Area (GTA) and included six winter road maintenance participants.

For the period covering January 19 through April 7, 2012 observational data from standard weather and climate stations were gathered along those from Road Weather Information System (RWIS) environmental sensor station (ESS) sites.

Winter road maintenance logs for select routes from the participants were screened for a selection of 3 winter storms in order to compile an “order of battle” chronology of the actions taken by each of the operators in meeting each storm’s hazards. The actions taken were then compared to those recommended by MDSS 4 to 6 hours ahead of the storm and quantitative differences assessed.

The storms selected were randomly chosen, based only on the interest factor each storm would have from a winter road maintenance point of view, as available from a limited amount of events due to the relatively benign winter experienced in southern Ontario this season. This random selection helped to ensure that there was no attempt to use events where MDSS appeared surficially at least to perform well in terms of predicting how the event would unfold prior to the analysis. That pre-empted slanting the performance analysis results in MDSS’s favour and so artificially presenting MDSS in its best light.

Feedback was solicited and compiled from the stakeholders throughout and after the actual Field Trial component of the overall project was completed.

This section is subdivided into 3 subsections. The first provides a brief summary of the three storms used while the second presents the results of the quantitative analysis. A qualitative results subsection follows within which is compiled stakeholder feedback and other subjective insights gained.
4.1 STORM SUMMARIES

Three storms were selected from the rather meager list of events for the latter half of winter 2011-12. These occurred during portions of the periods January 30-31; February 10-12; and February 23-25.

The Event of January 30-31, 2012

This was a light evening snowfall with temperatures a bit below freezing giving about 2 to 5 cm (though Buttonville Airport reported 7 cm this is suspect due to an observation coding error).

Figure D - Surface Weather Map; Tuesday January 31, 2012 at 7:00 a.m. EST

Milder air trying to invade the study area from the south brought light snow Monday evening with below freezing temperatures thought the night. The area of snow is the one shaded in green over southern Quebec and northern New England on Figure D above after it had moved well east of the study area. Temperatures rose above freezing Tuesday morning after the event with pavements drying out by midday (See Appendix A).
The Event of February 10-12, 2012

This storm was a straightforward 2 to 7 cm evening and overnight snowfall with temperatures falling below freezing during the storm’s onset, and continuing so, accompanied by brisk winds. Residual flurries of the Great Lakes and cold temperatures prolonged the tail end of the event.

Figure E - Surface Weather Map; Saturday February 11, 2012 at 7:00 a.m. EST

A developing low passed south of the study area Saturday morning (Figure E) and continued to track northeast to lie over the Gulf of St. Lawrence Sunday morning (Figure F). As the system approached, snow developed early Friday evening and continued through the overnight until late Saturday morning. Air temperatures were near to a little below freezing when the snow developed while pavement temperatures were about 1°C to 3°C above freezing except for the cold Orangeville ESS site at -1.5°C (See Appendix A).
In general, temperatures fell to subfreezing values within 2 hours of the snow beginning and continued to slowly edge down though midmorning Saturday. Brisk winds developed overnight as well bringing extensive drifting snow.

After the storm’s passage, cold air continued to deepen with snow showers off the Great Lakes lingering for hours afterwards overnight Saturday into Sunday. This made post storm mop-up less than straightforward requiring additional road treatments in both reality and in recommendations from MDSS as late as 11 p.m. EST Saturday evening.

The third and final event for the field studies was a forecast to be light snowfall with temperatures a little below or equal to freezing, except for southern areas where wet snow was expected, but which ended up being above freezing for much of the study area much of the time.

![Surface Weather Map; Friday February 24, 2012 at 7:00 a.m. EST](image)

This event was forecast to bring a snowfall in the 9 to 17 cm range, wet at times, starting in the pre-dawn hours Friday and ending Friday evening as a fairly organized low approached from the southwest (Figure G). However, the low tracked a little farther north than expected and allowed for milder air to move in. Though the timing of the event was reasonable, air temperatures were higher than forecast in all areas as some point during the storm if not through the entire episode. As this slight increase in temperatures meant the difference between sitting at zero with accumulating snow and being above so as to promote melting there was less accumulation than the snowfall forecast might have otherwise indicated. (see Appendix B).
Interestingly, the MDSS road temperature forecasts for most routes were calling for above freezing temperatures for much of the time centered on the midday hours Friday. As a consequence MDSS had pulled back on recommended treatments both in terms of the application rates and the number of applications beyond what the maintenance logs indicated was actually done. Despite the warmer than forecast air temperatures observed that day, the road temperatures were the opposite, i.e. colder than forecast but they were still above freezing. This tends to validate MDSS less aggressive suggested strategies yet contrarily supported the stakeholder’s more aggressive activity since it was in fact observed to be colder from a road temperature perspective at least.

Generally, MDSS suggested pre-storm treatments to get through the onset of the storm when pavement temperatures were forecast to be near to a little below freezing. In addition, for most areas, a subsequent light treatment Friday evening was suggested in anticipation of pavement temperatures falling below freezing before midnight and the road had a chance to dry out as the storm to the east and cold air flooded in on brisk northwest winds (Figure H). In the colder northwestern area of the study zone and less heavily trafficked roads, light mid-afternoon and mid-evening applications were suggested for similar reasons.
4.2 QUANTITATIVE ANALYSIS

Metrics examined for the quantitative analysis included chemical usage (dry, wet and total solid equivalent), time to bare roads, duration of operations, truck-hours worked, number of truck-trips and proactive lead times. In general, across all routes and storms combined, when compared to what was actually observed, MDSS recommendations called for less chemical use with other theoretical savings or gains in efficiency.

Specifically, by weighted average, MDSS used 37% less total chemical and 38% less solid chemical.

Also, MDSS led to a 21% faster time to dry roads; an 11% reduction in duration of operations; a 44% reduction in truck-hours worked; and a 51% reduction in number of trips; while yielding a 351% increase in operational lead time (see Figure I).

However, this was taken at face value without compromise and based on the assumption that MDSS simulates reality perfectly which it does not. Additionally, there was a 22% increase in the amount of liquid chemical recommended by MDSS compared to what was actually used by operators with DLA and/or pre-wetting capabilities.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Global MDSS vs. AMC Performance Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Use - Total (solid equivalent)</td>
<td>tonne</td>
<td>-387 -37%</td>
</tr>
<tr>
<td>Chemical Use - dry</td>
<td>tonne</td>
<td>-389 -38%</td>
</tr>
<tr>
<td>Chemical Use - wet</td>
<td>liter</td>
<td>8897 22%</td>
</tr>
<tr>
<td>Chemical Use - wet (solid equivalent)</td>
<td>tonne</td>
<td>2 22%</td>
</tr>
<tr>
<td>Time to Bare Roads</td>
<td>hour</td>
<td>-31 -21%</td>
</tr>
<tr>
<td>Duration of Operations</td>
<td>hour</td>
<td>-41 -11%</td>
</tr>
<tr>
<td>Truck Hours Worked</td>
<td>hour</td>
<td>-220 -44%</td>
</tr>
<tr>
<td>Proactive Lead Time</td>
<td>hour</td>
<td>60 351%</td>
</tr>
<tr>
<td>Number of Trips</td>
<td>truck-trips</td>
<td>-124 -51%</td>
</tr>
</tbody>
</table>

**Figure I – MDSS Metrics**

The values in bold green indicate performance boosts theoretically offered by MDSS (these are generally negative numbers (i.e. a reduction in tonnes or liters or hours) except for lead time where a positive value indicates a potential gain by MDSS over what was actually observed. Values in white italics indicate that MDSS had recommended the use of more brine than the participant’s field operations used with a corresponding percentage increase. This does represent more liquid being recommended but whether or not this meant a decrease in performance by MDSS or would have proved more effective overall by mitigating dry salt use is
not clear. In any case, the solid equivalent of the excess brine recommended was only about 2 metric tonnes.

In practice, the use of MDSS will likely result in operating efficiencies somewhat more conservative than the values above due to operators erring on the side of caution. This is because MDSS uses a simple approach to what is a complex and dynamic problem so that its algorithms are workable but also result in recommended treatments which are straightforward and therefore easy to “absorb”. In part, this is because one of the inputs to the system is the weather forecast and MDSS can therefore be no better than that is accurate. Also, without being able to take into account actual work already done operationally to an operator’s road, mid-storm MDSS utility will necessarily be limited due to the lack of real time insight into treatments to date. The evaluation identified some modules that require further modification. MDSS should be used as a guidance tool in combination with the operators’ knowledge of the complex maintenance situation.

Some of the MDSS simplifications alluded to include treatments which always assume plowing when applying chemical even for pre-storm direct liquid application (DLA) anti-icing operations when no snow has fallen yet. Another is that for operators capable of pre-wetting salt as it is about to hit the spinners MDSS seems to always recommend pre-wetting even if snow is on the road to any depth. This is contrary to most operators’ standard practice in such scenarios where they will take advantage of the snow or slush cover on wet roads to mitigate salt bounce naturally while avoiding the negative consequences of pre-wetting such as equipment clogging and premature salt burn-through by wetting and activating it unnecessarily.

For the three storms examined and the associated RWIS station observations, MDSS performed well in terms of predicting road temperature values and their time through zero Celsius on an hourly basis. Environment Canada observations also confirmed reasonable forecast quality for these events based on reported snowfalls, air temperatures and timing. This lends credence to the conclusion that MDSS tends to naturally suggest efficiency-leaning treatments rather than being the result of flawed weather forecasts and/or observations which underestimated snowfall or overestimated temperatures; though this did occur to a small degree in some cases.

MDSS exhibits a non-negligible sensitivity to predicted road temperature in making suggested treatments. This is hardly a surprise but it should be underscored that for predicted scenarios a degree or two below freezing it tends to claw back on salt amounts much more than it would for scenarios where it is a couple of degrees colder than that. This is due to the non-linear increase in efficiency of various chemical freeze point depressants as road temperatures rise toward zero. MDSS may be taking this into account more readily then operators tend to and benefitting from its reliance on predicted road temperatures rather than air temperatures to greater advantage.

To offset this sensitivity of MDSS to input errors, such as a too warm weather forecast, a possible solution would be to have MDSS output, as standard, alternative suggested treatments based on temperatures playing out a bit warmer or a bit colder than the "official" forecast. Envelops based on simple +/− 2°C air or road temperature values either side of the official forecast time series could conceivably be displayed along with the corresponding alternative strategies. Ahead of a storm, this will give the operator an idea of possible range of application rates, number of applications, etc. he may be looking at that shift. In this way, if the storm evolves in such a way which is colder or warmer than originally forecast based on real time
RWIS ESS observations, the operator can adjust application rates and/or timing, etcetera, more in line with the appropriate envelope strategy.

It is understandable and indeed commendable that an operator will err on the side of safety. This is especially so in scenarios where operator performance is being audited by independent observers. MDSS can offer a means to counter erring on side of caution to excess by providing an alternative “voice” in the decision making process erring to the side of minimal activity. This tendency of MDSS may also offer a protective advantage in cases where an operator does not “obey” MDSS but goes beyond it in terms increased chemical usage and other road-mobility-improving activity than what MDSS suggested if an accident occurs. If the argument is made that the operator should have used the MDSS recommended treatment but did not and, as such, the accident resulted, it can be demonstrated as a false conclusion since MDSS does not err on the side of safety but, on the contrary, to the side of efficiency.

On the technical side, there were questions about MDSS performance for bridge sites. There were two occasions when the treatment manager did not suggest treatment strategies when clearly its output of snow depth on the road and temperature would seem to indicate a need for it otherwise. Due to the small amount of road involved, the impact on the performance differentials was negligible for chemical use, time to bare roads, proactive lead time and number of trips. On the other hand, this stakeholder’s logs reported hours worked across their whole domain and not just the route segments in the study. This would impact the duration of operations metric in Figure 1 above by reducing the gain 8 percentiles from -11% to -3%; the truck hours worked by 11 percentiles from -44% to -33%; and number of trips by 3 percentiles from -51% to -48%. This sensitivity to exactly what the logs contained and what insight can be gleaned from them underscores that conclusions about these metrics and what MDSS can do to improve them is not as clear as for the other metrics such as chemical usage, time to bare roads, lead time and number of trips.

**MDSS’s Validity**

The question of verifying MDSS’s validity in simulating reality is reasonable. From the outset, the Field Trial acknowledged and took advantage of the fact that MDSS is already being used successfully in the United States and for many winters at that. The various references cited in Literature Review of Section 3 are cases in point.

Additionally, over the course of the quantitative analysis it became evident that MDSS predictions of pavement temperature, especially regarding the time it was predicted to cross one way or the other either side of 0°C were remarkably accurate, generally only varying, if it was out at all, by plus or minus one hour. The predicted values of the pavement temperature were similarly quite favourable to the observed values. Predicted and observed snowfalls amounts and the timing of the onset and end of the precipitation was also quite good though the last storm (which busted the temperature forecast by a couple of degrees and therefore the snowfall amounts) inspired confidence that MDSS was working in a reasonable simulation of reality—at least as far as the weather forecast component of the system went.

The reader can examine this visually by referring to Appendix A’s chronological tables listing observed and the synchronized predicted values. For each storm there are two groups of tables. The first group compares forecast and observed road and air temperatures for each RWIS environmental sensor stations (ESS) used. The other compares predicted and observed precipitation types, snowfalls, snow depth on the road, and road conditions using Environment Canada weather stations and the appropriate ESS pavement sensors as applicable.
A more rigorous confirmation of the ability of MDSS to simulate the winter road weather environment and the mitigating impacts which maintenance operations provide would do more to confirm the anecdotal evidence cited above that MDSS is indeed the next best thing to heated roads. In order to do this, advantage can be taken of the maintenance and observational information gathered, filtered and organized to date. By using that data as input into MDSS running in what-if-scenario-generation mode we would in effect be assessing MDSS to see if it could successfully simulate what was known to have actually been done. If MDSS’s predictions of parameters such as time to bare road, predicted road temperature, etcetera, closely corresponded to those actually observed in the logs and by ESS sensors then confidence could be ascribed to MDSS in its ability to simulate the positive effects of winter road maintenance operations on improving the mobility state of the highway. Such a confirmation process could be a candidate for future steps.

4.3 Qualitative Analysis

4.3.1 Methodology

Participants in the MDSS Field Trial were surveyed three times during the period of the Field Trial. There was an initial survey which focused on what the participants’ objectives were going into the Field Trial. The participants were interviewed mid-way through the MDSS Field Trial during one-on-one review sessions. A final survey was distributed to the road authorities at the end of the winter season with the objective of finding out what they liked or didn’t like about MDSS.

Since there were only six road authorities involved in the Field Trial, the number of respondents was less than ten (there were multiple responses from some of the participants). This makes percentage responses disproportionately large from only one or two responses per question choice. The survey results have been synthesized into the following summary.

4.3.2 Initial Survey Results

The initial objectives of the participants were generally to improve the quality of service provided on the highways with the possibility of saving costs. A widespread theme was to save on chemical, equipment, fuel, money, and the environment.

When asked their initial thoughts about MDSS, a universal idea is that MDSS provides a good tool for developing winter maintenance activities, or as one participant stated: “MDSS provides a structured decision-making framework instead of flying by the seat of your pants, especially when the temperature is around +2⁰C to -2⁰C”.

Only one respondent voiced a concern that MDSS must be easy enough and concise enough to provide to patrollers, while another road authority was concerned about the accuracy of the information going into the Field Trial.

4.3.3 Mid-Season Comments

Interviews were held at the operations centres of the Field Trial end-users during the mid-season. Road authorities were very candid in their remarks and the interviews resulted in considerable comments. These have been synthesized into the following summary:
• There was a uniform acceptance of the MDSS interface. Users found the layout of the “Treatment Manager” screen clean and easy to follow. There was less familiarity with the graphs.
• In general, the road authorities found the treatment recommendations to be “just right” for the situation. They found treatment rates were often identical to the amount they spread.
• There was some confusion about the Mobility Index. There were times when the Mobility Index would indicate 0.6 but no treatment was suggested.
• There is a need to focus on Mobility Index numbers between 0.6 to 0.65 to 0.7. Perhaps have an expanded graph right in that zone.
• One suggestion was: could MDSS incorporate Minimum Maintenance Standards (MMS) to put a line on the graph when treatment will result in MMS compliance?
• Another suggestion was to highlight rush hour times with boxes on the treatment manager (similar to daylight and night-time shading on RWIS pavement forecasts).
• Some road authorities found MDSS didn’t seem to recommend enough successive treatments, while other road authorities specifically said they liked that MDSS provided multiple treatments.
• More than one road authority would like to be able to enter their actual treatments on the chart to compare them to the recommended treatment.
• One of the users said it would be good to be able to switch to a dark background when using a tablet in a vehicle to make it easier to read.
• Some users said they see adoption of MDSS taking about two years.
• There seemed to be a bug that the interface would drop users after a certain length of time. This was annoying when people were trying to analyze the required treatment.
• There were questions about the programming behind the treatment module. The treatment manager would often recommend treatment two hours before the snow was forecast to fall. Is this so the road would be treated by the time the snow arrived and the snow wouldn’t bond with the roadway (anti-icing)? Most patrol beats could be covered in less than two hours. Road authorities were concerned that if DLA wasn’t used, dry salt would get blown off the roadway. There was also a question about whether MDSS takes circuit time into account?
• More than one road authority would like to see separate treatment recommendations for the mainline and ramps or shoulders. In the Greater Toronto Area, shoulders and ramps are treated as Class 1 roads.
• In the GTA area, traffic volume is a major contributing factor to winter maintenance requirements. Greater granularity of traffic volume information such as weekend, overnight, and rush hour traffic would enhance the results.
• The GTA area experienced an unusually mild winter with significantly less snow than normal. A universal comment was that the Road Authorities would like to see MDSS results in a normal winter.
• Another comment mentioned by every road authority was that MDSS is another tool, just like RWIS is a winter maintenance tool, and that it helps to have all the tools available to you to support winter maintenance decisions.

4.4 **Final Survey Results**
A final survey was distributed at the end of the season. The survey included a combination of open ended questions and close ended scaled questions. A total of eight surveys were
The Weather Network
Commercial Services

Maintenance Decision Support System
MDSS Field Trial

returned from the field trial participants (some road operators returned more than one survey). The results are summarized below.

The survey results showed that the features the MDSS participants liked the most centred around the MDSS interface. They rated highest the “ease of use”, “overall performance” (system response time), and “ease of generating report”. The MDSS participants also rated the “chemical application rates”, they agreed that the “training was sufficient”, and they agreed that establishing a close partnership is valuable.

The survey factors that had a lower rating were “level of difficulty in selecting variables to create a graph”, “number of treatments”, and “forecast road conditions with treatments”.

In the open-ended question section, participants were asked the following set of questions:

4.4.1 Most liked about MDSS?

- “The web display and data call-up functioned very well and were easy to read.”
- “Ease of viewing weather information both current and historical. Allows details to be viewed on a single page, just requires training to winter staff as they are used to viewing and interpreting RWIS data. When analyzing storms it is nice to view weather details quickly.”
- “Was somewhat helpful in advance of weather systems coming in to the area. Allowed time to prepare and a general idea of what to expect.”
- “It is a great tool to help make an informed decision.”
- “Very simple to navigate and understand, would not be difficult to introduce to field staff.”
- “I believe that it will be a useful tool for our patrollers once all the bugs have been taken out. I don’t believe that last winter season was a good winter to fully evaluate the MDSS and would like to see it tested through a normal winter to observe and possibly use its’ recommendations.”
- “Good tool for developing winter maintenance strategies.”

4.4.2 Least liked about MDSS?

- “The timing of application I found was out by a couple of hours. If we were to treat the highway as indicated by the time the snow arrived there would have been no salt left on the road surface.”
- “Should incorporate the MTO standards, did not take into consideration traffic volumes.”
- “Still very unclear about the graph portion, and the suggestions put forward were not always accurate due to local changes in the weather patterns and winds.”
- “Treatment recommendations do not correspond to treatment requirements for a 3rd generation contract for a class 1 Hwy, as it only appeared to provide recommendations at the start of the storm and nothing following. Due to light winter it was difficult to fully utilize the software since very few storm events occurred.”
- “No idea how the Mobility Index relates to the need for road treatment.”
- “No idea how the Mobility Index relates to actual conditions on the road (e.g. how good is the prediction?). Apparently no validation or checking of the prediction accuracy was included in the project.”
4.4.3 Details as to why MDSS did not meet your expectations?

- “Due to the maturity of the system, the assumption was that more items would be available and treatment recommendations would be able to be separated by salting & plowing operations. The winter just wasn’t heavy enough to fully test the software by the time it was fully accessible.”

4.4.4 Any additional feedback or comments?

- “I would like to see the recommendations that MDSS would generate in a normal winter.”
- “With some changes I believe this will be a viable tool for use in winter operations.”
- “Look forward to testing this software as it matures to determine its benefit and potential use for the future of road maintenance.”

4.5 MDSS QUALITATIVE SUMMARY

The Field Trial participants generally found the MDSS interface clear, easy to use and to navigate. Several commented that MDSS is a good tool to make informed maintenance decisions. A number of operators found the chemical application rates were “just right”, although they sometimes found the timing or treatment types were somewhat different from their actual treatment. One road authority used a sand/salt mix which isn’t programmed into the MDSS treatment module, and MDSS was rarely observed to recommend DLA. Traffic rates were also found to have significant effect on treatment requirements. Although they found the training to be sufficient, it appears some more time should be spent explaining the use of the graphs and selecting variables to create a graph. There were also questions about why a Mobility Index of 0.6 was sometimes observed, yet no treatment was recommended. These comments and suggestions have been incorporated into the MDSS – Next Steps Section.

A common thread was that the participants would like to give the program a more thorough evaluation during a “normal” winter; the winter of 2012 was unseasonably mild with half the normal amount of snow.
5.0 POTENTIAL FUTURE MDSS ENHANCEMENTS

The following items were identified as needing further investigation:

- Investigate why the Mobility Index would indicate 0.6 but no treatment was suggested.
- Incorporate the use of sand (whether a 50/50 mix or some other proportion) as a treatment option.
- Investigate the treatment module code to determine the lead time used for chemical application. Does it include time for the anti-icing chemical to become activated?
- Consider having a separate treatment guide for ramps or shoulders.
- Traffic volumes are hard coded into system per road segment based on historic daily averages. There may be an opportunity to use live, dynamic traffic data to help improve accuracy of system and differentiate weekdays, weekends and holidays.
- Further evaluation of application of MDSS on bridges should be conducted.
- Direct Liquid Application (DLA) is a common treatment used in Ontario but DLA was rarely observed as a treatment recommendation. It was confirmed that DLA is one of the treatment options included in the treatment module. Investigate the code in the treatment module to see if there is a bias against using DLA.
- Sometimes a recommended treatment time would conflict with rush hour traffic or shift changes. Investigate if MDSS could provide a treatment window suggestion; i.e. optimal treatment is at X time but alternately from sometime before X to sometime after X.
- Could a line be displayed on the treatment manager when Minimum Maintenance Standards will be achieved utilizing the suggested treatment?
- Add an additional row to the treatment manager to enable road operators to enter their actual treatment and compare it to the suggested treatment.
- During training, devote more time to explaining use of the graphs and the variables that can be analyzed.
- The application of MDSS to road operations decisions showed that it would be good to install some pucks in the shoulder of the highway or off ramps, especially in high traffic areas in conjunction with some RWIS sites.
- 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. Few treatment recommendations for DLA were observed, although DLA is a standard practice in Ontario. Assumptions of the NCAR MDSS should be verified against Ontario practices.
- The MDSS treatment module code should be examined to determine if a wider range of chemical types and abrasives could be added.
6.0 SUMMARY

Previous MDSS evaluations had demonstrated significant savings of salt and resources, so it was not unexpected that similar savings would be generated in this Canadian implementation.

To summarize the field results, on average, MDSS used 37% less total chemical, 38% less solid chemical; led to a 21% faster time to dry roads; an 11% reduction in duration of operations; a 44% reduction in truck hours; a 51% reduction in number of trips; and a 351% increase in operational lead time. It is understood that this study was carried out over 3 storms across a finite study area and that further expansion of the MDSS solution will be required to validate and refine these findings.

Following the MDSS treatment suggestions would have resulted in a reduction of 387 tonnes of salt for the three storms evaluated (total salt use was 1,046 tonnes) and $23,220 savings for the reduction of salt before other resource savings for vehicle use and staff time. To put the salt savings in the context of the Ontario Ministry of Transportation’s (MTO) annual salt use for the whole province, MTO uses about 500,000 to 600,000 tonnes of salt a year. A 37% reduction would equate to 185,000 tonnes or $11,100,000. Even if these reductions were out by an order of magnitude, non-negligible savings would result.

Qualitatively, there was a unanimous response that the MDSS Treatment Manager is clear, easy to read and to navigate. There was a good consensus that MDSS is an added tool to make informed maintenance decisions. A number of the operators found the chemical application rates were “just right”. Constructive feedback uncovered that there were some areas that will require further review in order to enhance the MDSS solution for Ontario road maintenance operating standards. These findings are incorporated into Section 5.0 Potential Future MDSS Enhancements.

The trial demonstrated that there is an opportunity to reduce chemical used and costs. More significantly, MDSS offers a structured decision tool for winter maintenance decisions.

The winter season of 2011/2012 was uncommonly mild with much lighter snow than normal. A common sentiment of the road operators is that they would like to give the program a more thorough evaluation during a “normal” winter. It would be valuable to extend the operational evaluation to a greater variety of climate regions and in areas of different traffic volumes and maintenance operators.
Appendix A
### Comparative Forecast and Observed Weather, Snowfall and Road Conditions

<table>
<thead>
<tr>
<th>Day / Date / Time</th>
<th>Toronto - Pearson (YZ)</th>
<th>Toronto - Buttonville (YZ)</th>
<th>Border QF2 (MH)</th>
<th>Road Authority #1 Patrol 1</th>
<th>Road Authority #1 Patrol 2</th>
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<tbody>
<tr>
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<td>Precip or Wx Groups</td>
<td>EIS or DS Snow</td>
<td>Cumulative Snowfall</td>
<td>Precip or Wx Groups</td>
<td>EIS or DS Snow</td>
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<td>[cm]</td>
<td>[cm]</td>
<td>[cm]</td>
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<td>-</td>
</tr>
</tbody>
</table>

**Monday**

**Tuesday**

Observed values have column headers in plain white fields while forecast value column headers are in grey.

Forecast values are in italics.

Colour keying and bold font is meant to highlight critical values such as freezing or below freezing, wet versus dry, no snowfall or more than 2 cm, etc., as per the examples in the colour key to the right.

Thanks to the colour formatting, scanning by eye allows the reader to quickly gauge timing accuracy between observed and forecast critical values being breached. Specific values provide more detail as desired.

Pavement sensor observed road conditions are juxtaposed with the predicted mobility.
Appendix B
### Comparative Forecast and Observed Temperatures

<table>
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<th>Day / Date / Time</th>
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<th>Road Authority #1, Patrol 2</th>
<th>Road Authority #2, Patrol 1</th>
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<td>MDSS Forecast</td>
<td>RWIS - 328003.0</td>
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<td></td>
<td>Observed</td>
<td>Forecast</td>
<td>Observed</td>
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<tr>
<td></td>
<td>Air [°C]</td>
<td>Road [°C]</td>
<td>Air [°C]</td>
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<td>9.5</td>
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<tr>
<td>23:00</td>
<td>9.6</td>
<td>4.9</td>
<td>9.6</td>
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</table>

**Colour key:**
- **Above freezing:** 2.1
- **Equal to freezing:** 3.1
- **Below freezing:** -3.1

*Surrogate for YON00 328001.0 which was offline for this event.*

<table>
<thead>
<tr>
<th>Colour</th>
<th>Key</th>
<th>2012 May 30 May 31 June 1 June 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
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</tr>
<tr>
<td>Green</td>
<td>0.7</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**Forecast values are in italics.**

- Colour keying and **bold** font is meant to highlight critical values such as freezing or below freezing as per the examples in the colour key at bottom.
- Thanks to the colour formatting, scanning by eye allows the reader to easily gauge timing accuracy between observed and forecast critical values being breached.
- Specific values provide more detail as desired.

Road temperature values are centrally juxtaposed for easy comparison by route.

Air temperature values are found on opposing flanks for each route.

**Observed values have column headers in plain white fields while forecast value column headers are in grey.**
### MDSS Real World Comparative Analysis - I

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>MDSS vs. Participant Performance by Route and Storm [actual and percentage change]</th>
<th>MDSS vs. Participant Performance by Operator and Storm [actual and percentage change]</th>
<th>MDSS vs. Participant Performance by Route [actual and percentage change]</th>
<th>MDSS vs. Participant Performance by Operator [actual and percentage change]</th>
<th>Global MDSS vs. Participant Performance Differences [actual and percentage change]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Use - Total (solid equivalent)</td>
<td>tonne</td>
<td>-0.05 -1% -6.21 -15% -24.29 -66%</td>
<td>-11.1 -79% -27.8 -29% -66.9 -69%</td>
<td>-28.6 -66%</td>
<td>-101 -48%</td>
<td>8887 22%</td>
</tr>
<tr>
<td>Chemical Use - dry</td>
<td>tonne</td>
<td>-0.05 -1% 5.12 18% 14.02 62%</td>
<td>15.9 -46% 25.1 -31% 67.6 -67%</td>
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<td>-384 10%</td>
</tr>
<tr>
<td>Chemical Use - wet</td>
<td>tonne</td>
<td>-18 -1% -7.98 -27% -46.7 -69%</td>
<td>86.8 -8% 308 -25% 493 -53%</td>
<td>204 -13%</td>
<td>-123.4 -9%</td>
<td>-384 10%</td>
</tr>
<tr>
<td>Chemical Use - wet (solid equivalent)</td>
<td>tonne</td>
<td>0.0 -1%</td>
<td>1.6 -8% 3.1 -8% 6.0 -8%</td>
<td>14.5 -8%</td>
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<td>-384 10%</td>
</tr>
<tr>
<td>Time to Bare Roads</td>
<td>hour</td>
<td>2.0 -17% -3.0 -32% -1.0 -15%</td>
<td>4.0 -5% 3.5 -50% 6.0 -10%</td>
<td>4.0 -5%</td>
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<td>4.0 -5%</td>
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<tr>
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<td>17.3 -73% 12.3 -26% 0.0 -0%</td>
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<td>4.1 -56%</td>
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<td>0.0 0%</td>
<td>0.0 0%</td>
</tr>
<tr>
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<td>hour</td>
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<td>5.3 n/a 2.5 n/a 3.2 n/a</td>
<td>5.3 n/a</td>
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<tr>
<td>Number of Trips</td>
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<td>2 -50% 2 -50% 2 -50%</td>
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<td>Chemical Use - Total (solid equivalent)</td>
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<td>-101 -48%</td>
<td>8887 22%</td>
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<tr>
<td>Chemical Use - dry</td>
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<td>9.16 -51% 19.89 -38% 43.00 -67%</td>
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<td>-123.4 -9%</td>
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</tr>
<tr>
<td>Time to Bare Roads</td>
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