Operational Winter Severity Indices in Canada – From Concept to Practice

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ABSTRACT
Public agencies are under increasing scrutiny to use their resources effectively and to demonstrate their effectiveness through performance measures. A variety of measures have been developed for winter maintenance operations, but the measures only provide meaningful information when they are normalized to the weather conditions that vary significantly from year to year and place to place. One method of normalizing is to use a measure the severity of winter weather conditions as they relate to winter maintenance activities. The challenge is to develop a WSI that explains temporal and spatial variations in winter road maintenance activities across varied geographic areas. In this paper, a methodology for developing a province-wide and simple-to-use winter severity index (WSI) is described using a case study approach on the provincial highway system of Ontario, Canada. This methodology combines the use of expert knowledge and mathematical optimization to develop a WSI that assigns daily weather scores for each day based on weather triggers and an adjustment factor. These daily scores are aggregated to the 14-day period and are then correlated to maintenance activities. The WSI for Ontario provincial highways has a strong fit with maintenance measured as equipment-hours. Correlation of WSI values with equipment-hours at this temporal aggregation level vary from moderate to very high for each of the 20 maintenance areas across Ontario. When spatially aggregated to the provincial fit improves further to between 0.959 and 0.989 over seven seasons. This study demonstrates the utility of a province-wide WSI and describes how a WSI can be developed for road authorities.

KEYWORDS
Winter Severity Index, Winter Road Maintenance, Snow and Ice Control, Weather, Transportation Planning, Optimization
INTRODUCTION

Road authorities allocate a substantial portion of road budgets to snow and ice control. It is estimated that more than three billion dollars is spent annually on winter road maintenance activities on North American roads. However, WRM practices and expenditures vary both spatially and temporally for numerous reasons (1). Temporal variations in expenditures are partially explained by the phasing in of new technologies such as innovations in plow design, fuel efficiency, GPS tools, anti-icing chemical compositions, and communication technologies. Spatial variations in WRM practices can be partially attributed to dissimilarities in road networks (e.g., road classes, network length, population density). However, the most important consideration is variations in winter weather (1).

Road authorities are seeking tools that facilitate the planning, management, and communication of maintenance operations in the context of variable and changing winter weather. One such tool is winter severity indices (WSIs) that are used to quantify the severity of winter weather conditions for a specific location at a particular time. An index is a measure that simplifies complex information (e.g., a number of different weather variables) for a particular application, typically representing this information as a single numeric value. Research on transportation-related weather indices has been ongoing for more than three decades (2,1,3) and WSIs have gained increasing prominence over the past decade because they can explain how different weather conditions impact maintenance costs or materials use.

A variety of WSIs have been developed in North America and Europe with the goal of helping road authorities plan for and communicate WRM programs and expenditures. The most widely cited is the WSI designed by the US Strategic Highway Research Program (SHRP) (2); this WSI has been used to benchmark winter maintenance activities in some jurisdictions (4). The regression-type approach used in developing the SHRP model was also used in subsequent efforts by Venäläinen (5), Venäläinen and Kangas (1), and Strong and Shvetsov (6). These WSIs are based on temporally aggregate data (e.g., monthly snowfall) and a small number of key weather variables as model inputs: temperature, snowfall and ground frost or freezing rain. A key disadvantage of this approach is that the weather severity scores cannot be directly linked to discrete storms or weather events. Furthermore, many of these WSIs can only be used for comparing WRM activities or expenditures between seasons in a single location. While these regression-type models may work well for the specific areas for which they were developed, sometimes reporting R^2 values above 0.9, they do not perform as well when applied to jurisdictions in Canada (7).

There have since been efforts to create an operational WSI for Canadian jurisdictions (3, 8, 9, 10). These more recent approaches have assigned a point value to each day, and the points were then aggregated at coarser temporal resolutions and correlated to materials use. An important advantage of working at the daily level and then aggregating the scores is that these indices are more easily interpretable as they are linked to distinct daily weather conditions/events. Another important innovation is the application of an optimization algorithm to define the key weather thresholds and weightings for daily scores which are then summed to the weekly, monthly, or seasonal levels and correlated to maintenance activities or expenditures. A similar approach has been used in the development of generic WSIs (11) and has shown promise for use in a WRM context (10, 12, 13, 14).

By comparing the performance of three WSIs that were developed for snow and ice control activities, Gustavsson (15) outlined four attributes of a functional WSI. A WSI must 1) show a relationship between weather attributes and the need for WRM; 2) provide numeric values that can be easily interpreted on physical grounds; 3) use data at a time resolution that reflects the need for maintenance activities; and 4) include weighting functions that are directly related to maintenance demand. The WSI developed in this study for the province of Ontario meets all four of these conditions. The WSI has the advantage of being transferable over space and time, having a strong relationship with WRM activity at the 14-day period, using variable weights that are directly related to WRM demand, and being easy to interpret.
RESEARCH CONTEXT

In this paper, an optimization approach is used to develop, test and implement a WSI with application to snow and ice control activities on provincial highways in Ontario, Canada. The Province of Ontario, located in central Canada, extends approximately from 42°N at the United States border to 57°N and from 75°W at the provincial border with Quebec to 95°W with the provincial border of Manitoba (16). Ontario is approximately one million square km in size and has a mostly humid continental climate with cool winters and warm summers (16). Ontario has a population of 13.8 million and a provincial highway network that is 45,169 single-lane kilometres long.

The highway network is grouped into 20 maintenance contract areas, and five winter maintenance road classes, mainly by traffic level and with adjustment for surrounding population. Class 5 highways have WADT<500 and Class 1 have WADT >10,000. Classes 3 through 5 are found mostly in the northern and rural areas of the province, whereas areas around the Greater Toronto Area are exclusively Class 1. Contract areas have centerline length of 600 to 1000 km, and each area has a different mix of highway classes. Direct annual costs of WRM on provincial highways amounts to approximately $140 million annually (17). As of 2014, five contractors are responsible for WRM in the 20 AMCs.

Developing a WSI that works equally well across the entire provincial network is a challenge given the variations in geography throughout the province. Ontario is a large province and is characterized by variations in topography, meteorology, road network attributes, population density, and traffic volume. Dissimilarities between north and south, and east and west of the province are notable and thus the purpose of this research is to develop a WSI that performs equally well across the province. For this study, the WSI is developed at the AMC (contract) level. This is an appropriate spatial unit of analysis because of the terms of maintenance contracts, purchases of equipment, implementation of practices, and monitoring of service performance are conducted at the AMC level.

DATA AND METHODS

Information Needs

As its name implies, a WSI is based entirely on weather information. There are two data sources that are used in this research—weather station networks and road weather information systems (RWIS). Weather stations operated by Environment Canada have many positive attributes including high levels of quality control, extensive historical records, and stations with trained personnel (usually airports), report a range of precipitation variables such as blowing snow, freezing rain, and fog. The records are publicly available and can be downloaded online for all stations and time periods of interest. However, the relatively sparse network of stations, especially in the north, is a limitation for their utility in developing WRM indices on a province-wide basis, and they do not include information on road surface conditions.

RWIS networks record data that is directly relevant to WRM operations and are collected specifically for use by road authorities including variables such as road surface conditions and pavement temperature. Despite the added benefit of the transport-specific variables, the RWIS data have a lower level of quality control than Environment Canada stations, and few RWIS stations have historically recorded rain and snowfall data – two variables that are crucial for WRM decisions. Both data sources were used in this project to provide the benefits of each. Overall, 103 RWIS sites and 64 Environment Canada climate stations were selected to cover all 20 AMCs. This resulted in two to four Environment Canada stations and three to nine RWIS stations in each AMC area (Figure 1).
While weather data are required for developing the WSI, there is also a need for maintenance data to be used as the response variable for model calibration. Winter maintenance data for provincial highways is collected through a Maintenance Management Information System (MMIS). Once the data are quality-controlled all of the MMIS data are then aggregated to the daily level for each AMC. While the intention was to include data for each season for all 20 AMCs in Ontario, only 132 AMC-seasons were included due to incomplete MMIS data. Equipment-hours of operation during the seven-year study period varied by AMC. The seasonal equipment-hours recorded range from 2,750 hours for one AMC in the 2011-2012 season to 48,801 hours in the 2013-2014 season. In the 2014-2015 season (the season that was selected as the testing set) 432,744 equipment-hours were recorded across the province, marginally higher than the average of 387,958 equipment-hours were recorded over the six seasons in the training set (2008-2009 to 2013-2014). Altogether, there were over 2.7 million hours of maintenance recorded in the MMIS system during the seven-year study period across all 20 AMCs.

**Approach to Index Development and Testing**

The WSI is designed so that each day during the study period is characterized as a single weather condition with an associated weather-severity score. The study period includes seven complete seasons of data. Six seasons were used to calibrate or train the model (2008-2009, 2009-2010, 2010-2011, 2011-2012, 2012-2013, and 2013-2014) and 2014-2015, was used to test the model. Daily weather severity scores range from zero (no weather that would reasonably trigger winter maintenance occurred) to a
possible maximum of 1.5. The actual maximum value is determined though the optimization process. The daily scores are summed to provide a 14-day or seasonal score.

Six weather conditions were selected for inclusion in the WSI based on both previous work (10, 13) and data availability:

1. Snowfall (snowfall data from Environment Canada)
2. RWIS pavement ice warnings (ice warnings based on RWIS data)
3. Rain with low temperatures (rainfall data from Environment Canada, temperature data from RWIS)
4. Blowing snow (wind speed data from RWIS, snowfall data from Environment Canada)
5. Series of cold days (temperature data from RWIS)
6. Warm weather adjustment factor (temperature data from RWIS)

The first five weather conditions represent different weather triggers of maintenance activity. The sixth condition is a warm-weather adjustment factor that reduces daily weather severity scores during the times of the year when the average mean temperature remains above freezing for an extended period. The numerical order listed above reflects the hierarchy of weather triggers used in assigning daily scores. If two (or more) conditions were observed on the same day, the daily score was based on the condition that is higher on the hierarchy. For example, if measurable snowfall is observed on a given day, that day is assigned a ‘snowfall’ score, even if pavement ice warnings or blowing snow are also observed. Similarly, if measurable snowfall is not observed on a given day and there are no RWIS pavement ice warnings on that day, but rain with low temperatures are observed, that day would be assigned a ‘rain with low temperatures’ score, even if there is also blowing snow.

After the weather triggers are selected it is also necessary to decide the temporal unit of analysis for the calibration of the WSI itself. The first option is to work at a fine resolution. However, working at a fine resolution, such as the day, compromises model fit because of the maintenance lag that occurs after active winter weather, especially large snowfalls. A second possibility is to work at a coarse resolution, such as a season or month, but this approach violates Gustavsson’s (15) third criteria for a useful WSI, i.e. that the temporal resolution should connect with how maintenance decisions are made. The best alternative, therefore, is to work at an intermediate resolution. Thus, it was decided that 14-day reporting periods would be used. These reporting periods are predetermined by the provincial road authority and correspond directly to their reporting schedule. There are up to 18 reporting periods in a given winter season and the reporting periods are consistent across all AMCs.

Once the weather triggers are identified and the unit of analysis is determined then an optimization routine is executed in Microsoft Excel to simultaneously define weather trigger thresholds values as well as the daily scores. For example, for the snowfall trigger each day with measurable snowfall is identified (i.e., ≥ 0.2 cm of snowfall or ≥ 0.2 mm liquid precipitation equivalent). The optimization routine allocates each day to one of the possible three categories: low accumulation, moderate accumulation, or high accumulation. In addition to determining the cutoff values, the optimization algorithm assigns a score of between 0.0 and 1.5 for each of the weather triggers. This is completed in a way that maximizes the average fit across the 20 AMCs over the six years in the training set. Days that do not meet the criteria for any of the weather triggers are assigned a daily score of zero. The benefit of using an optimization approach is that the method ensures that thresholds and weighting of the triggers are directly related to maintenance demand (15).

The daily upper limit determines that a value of 1.0 represents weather that typically triggers continual maintenance throughout the day of a weather event, and a score of 1.5 representative more severe weather that is associated with continual maintenance throughout the day with additional clean-up operations extending into the next day. The extra 0.5 points reflect the maintenance lag that can be observed on the day following a winter weather event. A score of zero indicates an absence of weather sufficient to trigger winter road maintenance.
Index Components and Optimization

The information produced by the WSI can be used to characterize the winter weather for any given place and time using a single number. More specifically, for each AMC in the province of Ontario, every day in the winter maintenance season is assigned a winter severity score. The optimized threshold values and WSI scores for days with weather falling within each threshold are shown in Table 1. This table is valid for all highways in the Province or for any Contract Area within it. The table is organized such that, for each of the six weather triggers of winter maintenance, information is provided on the how “trigger days” are classified and also on the weather scores for each category. Further, the number of days (n) in the study period that were classified to that weather trigger are identified in the last column. For example, snowfall days are organized into three categories – low, moderate and high amounts of daily snowfall accumulation – with threshold cutoffs that are determined through optimization. The corresponding weather scores for these three types of days are 0.5, 1.0 and 1.3; again these were derived through optimization.

**TABLE 1. Optimized Weather Thresholds and Weather Severity Scores for Winter Weather Factors in Ontario**

<table>
<thead>
<tr>
<th>Weather Component</th>
<th>Component Thresholds</th>
<th>Score</th>
<th>% of total WSI score</th>
<th>n days</th>
</tr>
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<tbody>
<tr>
<td>Snowfall component</td>
<td>Low amount of snow (0.2 to 1.9 cm)</td>
<td>0.5</td>
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<tr>
<td></td>
<td>Moderate amount of snow (1.91 to 4.9 cm)</td>
<td>1.0</td>
<td>84.9%</td>
<td>8,161</td>
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<tr>
<td></td>
<td>High amount of snow (&gt; 4.91 cm)</td>
<td>1.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface ice warning component</td>
<td>Low: &lt; 0.2 cm daily snowfall, and between 25% and 70% of road surface ice warnings</td>
<td>0.3</td>
<td>7.5%</td>
<td>1,890</td>
</tr>
<tr>
<td></td>
<td>High: &lt; 0.2 cm daily snowfall, and more than 70% of road surface ice warnings</td>
<td>0.8</td>
<td></td>
<td></td>
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<tr>
<td>Rainfall with low temperatures</td>
<td>Daily snowfall &lt; 0.2 cm, Conditions for ice warnings not met, Daily rainfall ≥ 0.4 mm, Min temp &lt; -0.2 °C</td>
<td>0.4</td>
<td>5.8%</td>
<td>1,148</td>
</tr>
<tr>
<td>Series of cold days</td>
<td>Daily precipitation &lt; 0.2 mm, Conditions for ice warnings not met, Conditions for rainfall with low temperatures not met, Conditions for blowing snow not met, Max temp in previous three days &lt; -12 °C</td>
<td>0.5</td>
<td>0.9%</td>
<td>137</td>
</tr>
<tr>
<td>Blowing snow</td>
<td>Daily precipitation &lt; 0.2 mm, Conditions for ice warnings not met, Conditions for rainfall with low temperatures not met, Wind speeds ≥ 15 km/h, Snowfall accumulations of previous three days ≥ 5 cm</td>
<td>0.5</td>
<td>1.0%</td>
<td>150</td>
</tr>
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</table>
The second last column of Table 1 indicates that snowfall is the most frequent weather condition that triggers winter maintenance activity on provincial highways in Ontario. The second most frequent condition for which daily scores are assigned is ice warnings, based on recordings in the RWIS data. The ice warning variable for each AMC is calculated by recording the total number of valid surface readings per day for each of the 19 pavement surface conditions. Subsequently five ice readings (“Black ice warning”, “Ice warning”, “Ice watch”, “Snow/ice warning”, and “Snow/ice watch”) are counted to obtain the daily total number of ice warning readings. The surface ice warning component is normalized to a percentage of all valid surface readings. In previous studies the use of surface ice warnings was defined as a binary variable where either a threshold had been triggered and that day was given a score — or there was no trigger and thus a score of zero was assigned. Given the significant influence of the surface ice warning trigger in Ontario, other options were explored. The decision was made to split this trigger into two categories, low and high.

Rainfall with low temperatures, series of cold days, and blowing snow are triggered less frequently. It should be noted that in the absence of RWIS data, these final three weather components would be triggered more frequently. A situation that can lead to potential icing occurs when rainfall is coincident with or followed by cold temperatures. Since this component of the index is about liquid precipitation, only those days when measurable rainfall of 0.2 mm is recorded, are considered. With a daily score of 0.4, the rainfall with cold temperatures component accounts for an average of 5.8% of the weather severity scores in Ontario. Secondly, some have found a clear link between very cold temperatures and the need for winter road maintenance, which may relate to the polishing effect that tire friction can have on snow-covered roads in very cold temperatures. The criterion for this series of cold days component simply counts days when the maximum temperature does not exceed -12 °C at any point in the previous three days.

The final weather trigger in the index is blowing snow – an important driving hazard. Often blowing snow happens during precipitation events, and these occurrences are included in the snowfall component described earlier. Here the focus is on days where there is no measurable precipitation but where higher winds may be relocating snow from nearby fields and roadside deposits. While at times Environment Canada reports on hourly occurrences of blowing snow, these observations can be inconsistent. As such, we allowed for inclusion of a proxy variable for blowing snow based on two criteria: fresh snowfall accumulation above 5cm over the preceding three days, and average daily wind speed that exceeds 15 km/h. These last two weather triggers in the WSI both contribute a score of 0.5 points per day and each contribute approximately 1% of the total WSI scores in Ontario.

One significant aspect of this WSI is the attention given to seasonality, based on residual analysis. In the initial iterations of the models through residual analysis, we appreciated the importance of seasonality. This analysis highlighted the extent to which warm weather mitigates the demand for WRM. Thus a warm-weather adjustment factor was included to reduce the WSI scores in periods that are relatively warm (>1 °C over the course of six days). The warm weather adjustment factor takes into account the fact that weather triggers that occurs in autumn or spring may not result in as much maintenance activity because of warmer temperatures. If this trigger occurs, then 45% is removed from any day with a score exceeding zero. Overall, average annual WSI scores were reduced by 18.8% because of the warm weather adjustment factor. The advantage of this approach is that while the focus is on the
shoulder seasons, the warm weather adjustment factor with reduce the scores at any time of year with warmer temperatures. For a province with substantial geographic variations in climate, the warm weather adjustment factor is crucial for ensuring the WSI performs equally well across the whole province.

After the weather trigger thresholds and weights are identified, the WSI can then be calculated at different spatial scales (AMC, regions, or province-wide) and different levels of temporal aggregation (reporting-period level, monthly, seasonal). This enables maintenance personnel or managers to compare the severity of the winter across both space and time. For each AMC, daily scores are calculated for each day during the seven-year study period. The daily scores are then aggregated to the 14-day and seasonal level (simple addition), with seasonal values ranging from 13.4 for an AMC in the 2011-2012 season to 99 in another AMC for the 2013-2014 season (Table 2).

**RESULTS**

Seasonal scores for all contract areas and the Province as a whole are shown in Table 2 and Figure 2 and the overall model fit is illustrated in Table 3. The scores and the model fit illustrate geographic and temporal trends in winter severity that can be used to understand and communicate variations in highway maintenance performance. Of the seven years for which seasonal weather severity scores could be calculated, the highest values occurred for the 2013-2014 season with an average provincial WSI score of 64.9. The least severe season was 2011-2012, with an average provincial WSI score of 33.6. Overall the scores displayed a normal distribution between a score of 10 and 100 at the AMC-season level (Figure 2).


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Table 2 illustrates how the average annual WSI scores vary across province. Northern areas of the province have the harshest winters and the southern, especially south-eastern, areas of the province experience the least severe winters (Figure 3). Furthermore, there is value in recognizing that winter weather is more variable year-to-year in some AMCs than in others. On average there is a 10.5-point standard deviation in seasonal weather severity scores. At the AMC level the standard deviations range from 7.5 to 19.7. The AMC with the highest variation in winter weather experienced their most mild winter in 2010-2011 with a score of 49.1, then in 2013-2014 this AMC experienced a very harsh winter with a score of 99.0. This 50 point spread in one AMC is particularly important to recognize when undertaking planning for equipment, materials, and labour requirements.
As an overall measure of fit, a correlation analysis is conducted between the 14-day level weather severity scores and the 14-day level maintenance activity. As indicated by the $R^2$ values, there is good fit across the AMCs. This indicates that the index explains the majority of the temporal variability in WRM equipment-hours. Overall, as the WSI increases, equipment-hours increases proportionately. Similarly, as the WSI decreases, equipment-hours also decrease. The coefficient of determination ($R^2$) between reporting-period WSI scores and reporting-period equipment-hours ranges from 0.588 to 0.985 (Table 3). Furthermore, confidence intervals are reasonably narrow for the majority of AMCs. While the $R^2$ values at the AMC level vary, the majority of seasons have an $R^2$ above 0.800. On average, for any given season, 15 of the AMCs have a fit above 0.800 and five of the AMCs are below this level.
Overall spatial aggregation increases fit. The R² for 14-day, provincial-level data (total provincial equipment-hours vs. average provincial WSI scores at the reporting-period level) is between 0.959 (2012-2013) and 0.989 (2009-2010) season. These values indicate that there is nearly perfect fit at the provincial level. Overall the R² values are very high thus indicating the WSI is an accurate tool for explaining variations in equipment-hours at both the AMC and provincial levels.

Another way to ensure that the WSI is capturing winter maintenance activities is to compare the number of winter maintenance equipment-hours that were recorded during days with WSI scores compared to maintenance hours that occurred on days without a WSI score. Of the total winter maintenance equipment-hours that were recorded during the study period, 85.0% (2.35 million equipment-hours) occurred on days that had a weather score triggered by one of the above conditions, and a further 8.5% (234,642 equipment-hours) occurred on days that did not have a weather score but where the previous day did (e.g., cleanup after snowfall). Most of the remaining hours of maintenance involved localized or short-duration winter maintenance.

It is evident that this WSI is an effective tool for explaining variations in equipment-hours due to weather and is therefore an effective communication tool. There are three indications that this WSI will be a useful tool for explaining WRM activities due to weather in future seasons. First, the WSI has a broad spatial transferability across a province that includes a variety of climates. As measured by fit (R²), the fit is very similar in all areas of the province suggesting there is limited spatial bias. Secondly, the WSI works well in the boundary conditions of the harshest and mildest seasons. The largest residuals tend not to be found in these mild and harsh time periods. Lastly, the WSI was calibrated on the training set of data and the 2014-2015 season was reserved as the independent test period. An analysis of residuals was conducted to confirm that the WSI works equally well in the training and test periods. The Fligner-Killeen Test of Homogeneity of Variances is used to explore the assumption that the variances in the training and test set are equal. The results indicate that the variances of the residuals in the training and
test sets are the same (Figure 4). In addition to evidence that the test set performs as well as the training set, there are two other indications that there is transferability of this WSI and this tool is promising for dealing with future application under a changing climate.

**FIGURE 4.** Boxplot of Residuals for the Training Set (2008-2009 to 2013-2014 seasons) and Test Set (2014-2015 season)

It is important to note that, while the WSI is calculated in the same way for all parts of the province, the number of equipment-hours varies by AMC, primarily because of differences in the road network (length of network, mix of road classes). Jurisdictions with larger networks, typically in the north, as well as time periods where the weather is more severe, have a greater variability of equipment-hours. Differences between AMCs can be illustrated by considering the way in which maintenance activity (equipment-hours) increases when the two-week weather severity score increases from 2 (for example, during the shoulder season) to 8 (more typical of moderately-severe winter). For example, in a southern AMC, this difference in weather would result in an increase in maintenance activity from less than 400 to just over 1500 equipment-hours. In a northern AMC, by comparison, one would see much larger increases in maintenance activity—from approximately 1100 hours to more than 4700.

To further understand whether these differences in network attributes could impact WSI performance, a multiple linear regression was conducted. The multiple linear regression was developed where the 14-day level residuals are the response variable and attributes that could possibly impact WSI performance are the explanatory variables (n= 2,418 reporting periods). The following variables were tested for their significance: road network length (km), percent of the road network that is a 1st class highway (%), location (north or south), month of year, WSI score (no score, low, medium, high). The results of the multiple linear regression indicates that these explanatory variables are all insignificant at 5% significance level (p=0.079, F-statistic= 1.723, $R^2$= 0.007), suggesting that there is no spatial bias in the applicability of the WSI across Ontario.

**CONCLUSIONS**

The WSI that has been developed for Ontario highways meets a number of attributes that are necessary for an operational index. First, the WSI for Ontario highway maintenance is simple to calculate and understand since it is based on a small number of weather triggers, all of which are easily understood.
Further, when the same index is used across the province, comparisons of winter weather severity can be made across regions and over time. Second, the WSI for Ontario highway maintenance draws on available data that can be updated regularly, as they originate with the Environment Canada observation network (especially important for acquiring daily snowfall and rain amounts) and Ontario’s RWIS network (critically important for surface ice warnings). Third, the WSI for Ontario highway maintenance has strong fit with maintenance activity that occurred, when measured as equipment-hours. The majority of seasons have a fit above 0.800. At the provincial level, the WSI works well with an \( R^2 = 0.982 \) in the most recent 2014-2015 season. Lastly, the WSI for Ontario Winter Highway Maintenance performs well across different climatic regions and maintenance regimes.

The WSI that has been developed for Ontario Winter Highway Maintenance has the potential to be used in several different ways to support highway operations. A WSI can enable informed decision-making by clearly documenting the relationship between weather and winter road maintenance activities that can be applied in at least three ways to aid in agency accountability to the public. First, the WSI can be used as a tracking mechanism to monitor the severity of winter weather. As such, the WSI can be used to describe, quantify, review and compare winter weather severity from any time period to another and from one region to another. Second, it could be useful as a season-to-season risk management tool. Lastly, enables road authorities to clearly communicate winter weather severity to the public and other stakeholders in relation to observed levels of service.

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REFERENCES


