DEVELOPMENT OF WINTER SEVERITY INDICATOR MODELS FOR CANADIAN WINTER ROAD MAINTENANCE

Jeff Suggett, M. Sc., Synectics Transportation Consultants Inc.
Alireza Hadayeghi, Ph. D (Candidate), Synectics Transportation Consultants Inc.
Mr. Brian Mills, B.E.S, Environment Canada
Dr. Jean Andrey, Ph. D, University of Waterloo
Mr. Geoff Leach, P. Eng, IMOS Inc.

Paper prepared for presentation at the
Success in Road Salt Management Session

Of the 2006 Annual Conference of the
Transportation Association of Canada
Charlottetown, Prince Edward Island

Research conducted by the authors was solely funded by the Transportation Association of Canada.

ABSTRACT

This paper discusses the development of two winter severity indicator models that will be used to evaluate the relative harshness of a winter in comparison with a base period, by using meteorological data through the Meteorological Service of Canada (MSC) alone, and MSC data together with Road Weather Information System (RWIS) data. A winter severity index is a measure of the relative impact of winter weather on winter road maintenance (WRM) operations using historical meteorological or RWIS data.

A review of past research led the project team to develop their own set of models using Canadian WRM, MSC and RWIS data. WRM data were collected from across Canada from a total of eight provincial road authorities and seven cities. Salt usage in tonnes (salt (t)/lane-km/day) was chosen as the dependent variable, standardized to account for differences in road network and the number of days in the observation period.

The first model developed based on MSC data alone achieved a goodness of fit of **0.54.** Explanatory variables were based on snowfall occurrence, air temperature, freezing rain occurrence, and an east-west dummy variable to account for differences in winter road maintenance practices in different parts of Canada. A second model was developed based on MSC data together with RWIS data. This achieved a goodness of fit of **0.60,** but was based on a significant smaller sample size. In this model, pavement temperature was substituted for air temperature. An Index was developed based on the predicted values using a scale between 1 and 100.

Calibration factors were developed for twenty different homogeneous groupings across Canada using the Bayesian method. Based on the calibration, thirteen of the twenty groups achieved a better goodness of fit compared to the national model results. The model results show a better performance in heavily populated areas and in eastern Canada. Limitations of the models and recommendations for further research are presented in the paper.

1 Background

The Transportation Association of Canada through the Maintenance and Construction Standing Committee retained a project team led by Synectics Transportation Consultants to develop two winter severity indicator models that can be used by Canadian jurisdictions to evaluate the relative harshness of a winter in comparison with a base period, by using readily available meteorological data through the Meterological Service of Canada (MSC) alone, and MSC data together with Road Weather Information Systems (RWIS) data. A winter severity index is a measure of the relative impact of winter weather on winter road maintenance (WRM) operations using historical meteorological or RWIS data. Simply, it is a measure that simplifies one or more complex variables, or sets of information, for a particular application.

A Steering Committee consisting of members representing a variety of provincial highway authorities and urban municipalities was formed to oversee the project. The Steering Committee identified the following tasks for the project team.

- Conduct a review of past literature to identify a Winter Severity Index model of potential applicability to this project;
- Conduct a review of data availability including WRM, MSC, road weather information system (RWIS), and road classification data;
- Select potential variables that should be considered in the model;
- Create a national model that hindcasts winter severity using MSC data on its own, or MSC data in conjunction with RWIS data;
- Calibrate the national model findings to local areas; and
- Identify the data requirements needed for a jurisdiction to calculate their own Index.

2 The Need for a Winter Severity Indicator

While a range of responses is available to public transport agencies to mitigate risks associated with driving in inclement winter weather, including warning messages and enhanced driver training, the primary response is the prevention and clearing of snow and ice from highways through WRM (Winter Road Maintenance). WRM programs have been established and are continuously being refined by virtually every provincial and municipal road authority in Canada. Collectively, it is estimated that about $1.3 billion and over 4.5 million tonnes of road salt are expended by these agencies each year **(1,2).** In addition to the considerable direct costs of WRM activities, salt has been shown to cause significant damage to the environment and infrastructure. The use of salt varies, both temporally and spatially, partly because of the emergence of new technologies, regional variations in maintenance practices, and growth or contraction of road networks. However, the most significant reported influence is variability in weather.

It is precisely this uncontrollable variability associated with weather that predicates the need for, and the utility of, winter severity indices. Weather variability complicates assessments of the relative efficiency and effectiveness (i.e., meeting Levels of Service standards, salt reduction and budget targets) of different road maintenance programs, technologies, policies and jurisdictions. It also must be accounted for in the performance and justification of cost-sharing adjustments with private contractors. What proportion of reported savings during a given season were due to a mild, relatively snow-free winter relative to that portion attributable to new operational measures or a reduced road network? Were a contractor's operations inefficient or were they justifiable given the severity of a particular winter? Among other things, an index can help answer such questions by standardizing the costs or maintenance in terms of winter severity.

3 Review of Past Research

The first step taken by the project team was to conduct a review of past research. Work on the development of winter severity indices has been ongoing for the past twenty-five years in Canada, United States and northern European countries (United Kingdom, Finland, France, Norway, Sweden and Denmark). A list of references pertaining to these indices is provided in the reference section of this paper **(3-18)**. On the basis of the literature review, the project team did not identify any model that would be applicable to Canada. Potential difficulties encountered in the past by previous researchers were:

- Some models appear to have poor transferability;
- Some models failed to adequately control for non-weather related variables;
- Some models lack information on how they were developed or are to be applied; and
- Some models would require an extensive amount of data extraction and manipulation to calculate the Index.

On the basis of the literature review, the project team recommended that they develop their own model based on Canadian WRM, MSC, and RWIS data. Road network data would also be required for the normalization of WRM activity.

4 Data Availability

The project team proceeded to determine data availability across Canada. They needed to identify what types of WRM and RWIS data were commonly available across Canada – to ensure that the Winter Severity Index would be straightforward to calculate for a typical Canadian road authority.

Meteorological (MSC) observations of weather were available to the project team through Environment Canada. The remaining three types of data were provided to the project team by the road authorities represented on the Steering Committee as well as additional jurisdictions identified by the project team. For this task, the project team sought to collect a wide range of data sets from each of the participating Steering Committee members that would represent different climates, storm types, and winter road maintenance practices across Canada in a variety of settings. A questionnaire was sent out at the beginning of the project to identify the type of data potentially available.

The results of the questionnaire indicated that data sets were for the most part available in a digital format. Various regions in Canada were represented, as well as a combination of both provincial road authorities, primarily responsible for maintaining rural highways, and large urban municipal road authorities. Three road authorities not currently represented on the Steering Committee were also invited to complete the questionnaire. One of the project team members also provided data from the New Liskeard area of Ontario. A significant absence from the data was the province of British Columbia. The project team was unable to obtain any WRM data from the province. WRM data were therefore available representing the provinces of Newfoundland, Nova Scotia, New Brunswick, Quebec, Ontario, Manitoba, Saskatchewan and Alberta and the cities of Halifax, Ottawa, Toronto, London, Winnipeg, Calgary and Edmonton. The provincial road authorities provided WRM data reflecting multiple reporting districts.

The questionnaire respondents indicated that overall, the various road authorities kept records of a wide range of WRM activity variables (materials, equipment, and expenditure information). These were recorded by various time increments and differing geographical units. Almost all of the data were available in a digital format. While a few jurisdictions had data available for ten or more years, the majority offered data sets covering less than five years.

RWIS data, in contrast, were not so widely available. The project team obtained RWIS data from a relatively small number of road authorities. In most cases, these data represented only a couple of winter seasons. RWIS data were only available for matching to portions of the provinces of Newfoundland, Quebec, Ontario, Nova Scotia, Saskatchewan and Alberta and the cities of Ottawa and Calgary.

5 Normalization of the Dependent Variable

As directed by the Steering Committee, the project team chose to use salt usage as the dependent variable, given the priority salt management has had in Canada over the past number of years. However, the manner in which salt usage is measured and documented differed in each jurisdiction. This required the study team to confer with each of the road authorities in order to ensure that the data were being interpreted correctly. Four issues emerged through these discussions that had to be addressed for the analysis to proceed.

1. The salt usage data needed to be converted into a common reporting unit. The majority of jurisdictions reported salt use in metric tonnes which was therefore chosen as the desired unit. Other jurisdictions report salt usage in kilograms, cubic metres (m^3) or litres (L - when used in a brine). Kilograms were straightforward to convert to tonnes, while the volumetric units required an understanding of the standard density of salt, either as a solid or dissolved in a liquid.

2. The selection of an appropriate analysis period is in part a function of the available data and the type of model being developed. A sufficient number of data points are required to capture both the variability in salt use and in weather variables to say anything meaningful about the relationship between the two. Most jurisdictions collected and provided salt usage data for bi-weekly or monthly periods. Others provided daily, weekly or seasonal data. In order to compare, analyze and model the information, all variables had to be standardized by number of days. It was important to know exactly how many days were represented in the salt usage totals so that the project team could know the amount of salt used per day. (For example, February 2005 has only 28 days compared to March 2005 having 31 days).

Due to the wide variation in temporal scale, the project team decided to use bi-weekly or monthly intervals as the base temporal unit. Where necessary, salt usage totals were 'rolled up' to bi-weekly and monthly intervals to allow their comparison to other jurisdictions. Seasonal totals were set aside, they are believed to be of little benefit to the development of the model.

3. In addition to reporting periods, the salt usage data needed to be standardized in terms of the length of the road network that is treated. In several jurisdictions, this variable changes each season as new roads are constructed or responsibilities are reassigned to other jurisdictions (e.g. province to a municipality). Lane kilometers were most often used in past studies and thus were the standard in the current investigation.

4. Some of the jurisdictions report salt usage in combination with sand usage. For these jurisdictions, the study team needed to determine what proportion of the salt and sand mixture was salt, in order to calculate the amount of salt used. Salt and sand ratios could vary by road class and time of year as well, requiring additional calculations. For the model preparation, the project team calculated and elected to include all salt usage, whether on its own, or in combination with sand.

The results of the above efforts are salt usage data expressed in tonnes, and standardized by day and lane kilometers. The dependent variable to be used in the model is salt tonnes per lane kilometer per day, hereafter referred to as salt (t)/lane-km/day.

6 Possible Independent Variables

For the modeling of the relationship between winter severity and winter road maintenance operations, the project team considered a number of independent variables that would explain the variability in salt (t)/lane-km/day.

Based on the findings of the literature review, the review of data available among the jurisdictions contacted, and the opinions of the project team, the following variable groupings were identified, being:

- Precipitation variables;
- Temperature variables;
- Drifting variables;
- Winter road maintenance practice variables; and
- Roadway characteristics variables.

The relative importance of each of these groupings of variables is discussed.

Precipitation data are available from Environment Canada at various levels of temporal aggregation (hourly, daily and monthly). Key variables that affect winter maintenance activities include:

- Number of days of snowfall accumulation above a particular threshold;
- Snowfall accumulation; and
- Number of days in which a particular precipitation type was observed.

Data are also available to a limited degree from RWIS sensors.

MSC and RWIS temperature data are also readily available at various levels of temporal aggregation (hourly, daily and monthly). Temperature data will be critical to the model as it will dictate when salt is applied to a road. Temperatures outside a certain range will result in little or no salt application. Air, pavement surface and dewpoint temperature were considered to be key variables. Dewpoint and pavement surface temperature were considered important in determining the occurrence of frost.

In the absence of snowfall, drifting snow may also affect salt usage. Some Environment Canada data are available in the form of hourly observations of blowing snow or number of days in which blowing snow was observed, but is not uniformly available at all meteorological stations across Canada or at all times. Alternatively, a hybrid variable was under consideration by the study team using a threshold wind speed, snowfall, snow on the ground, and temperature data provided by either Environment Canada or RWIS sensors.

Winter road maintenance practices were considered to be a variable of secondary importance to the model, but worth consideration. There is a wide variation in the way in which salt is applied across Canada. The project team considered using a variable that accounted for varying winter road maintenance practices (basic salt, pre-wetted salt, salt with sand, and brine); however, this information was not uniformly available across Canada. Also considered among winter road maintenance practice was the use of an east-west dummy variable to reflect differences in winter road maintenance practices in the Western provinces (Manitoba, Saskatchewan, and Alberta) versus the Eastern provinces.

The final set of variables considered in the modeling was based on roadway characteristics. A basic variable considered in the modeling was whether the jurisdiction in question was primarily rural or urban, given that roads in rural areas are likely treated differently than urban areas, due to differing traffic volumes and traffic control measures. For this reason, the project team considered a rural versus urban variable. Another consideration was the road class or priority. Roads having a higher class or priority will receive attention first during winter road maintenance operations, or will require more salt per lane kilometer, depending on the practice in each jurisdiction. Each jurisdiction uses its own classification system and associated level of service condition, making it difficult to develop a variable that accounts for individual road classification, yet can be used universally. It was also noted that many of the jurisdictions did not have information on the number of lane kilometers subgrouped by road classification. Therefore a variable reflecting road class or priority could not be developed.

Spatial considerations

Upon preparing the dependent and independent variables, some consideration needed to be made to how the dependent variable (salt (t)/lane km/day) would be matched to the independent variables relating to weather observations (Environment Canada and RWIS sensor data). The dependent variable data are drawn from a geographic area defined as being a single reporting district (for rural highway jurisdictions, such as Carberry district in the province of Manitoba) or a single urban area (Calgary). The Environment Canada Meteorological Service of Canada (MSC) data and RWIS sensor data are observations of weather taken at fixed locations. In matching the Environment Canada and RWIS sensor data to the dependent variable, the study team chose a location within or in close proximity to each reporting district. For example, in Newfoundland, salt usage data were made available from roads within the Avalon district (located in the extreme eastern portion of the province). This data were then 'matched' to MSC data taken from St. John's Airport. St. John's is located within Avalon district. Alternatively, in Ontario, salt usage data taken from New Liskeard was 'matched' to data from an RWIS sensor located on Highway 11 in close proximity to the New Liskeard district (identified as the Temagami RWIS station).

7 Model Development

A data set was prepared containing data from eight provincial road authorities and six urban road authorities, representing:

- The provinces of Newfoundland, Nova Scotia, New Brunswick, Quebec, Ontario, Manitoba, Saskatchewan and Alberta; and
- The cities of Halifax, Ottawa, Toronto, Winnipeg, Calgary, and Edmonton.

A total of 1,276 individual periods of observation of the dependent variable were included in the data set. These represented bi-weekly or monthly periods of salt usage representing either reporting districts (for the provincial road authorities) or cities. Salt usage data are predominantly from provincial road authorities, representing 1,124 (89 percent) of the observations. The remaining 152 (11 percent) were from an urban road authority. Among the provincial road authorities, Quebec has the largest sample, followed by Nova Scotia. Edmonton and Winnipeg are the largest urban contributors.

Table 1 shows the average salt (t)/lane km/day within each road authority and district. The exhibit shows a distinct split in salt usage between Eastern and Western Canada. Eastern Canada (areas east of the Manitoba-Ontario border) generally uses between 0.01 – 0.10 tonnes of salt per lane km/day on average. Western Canada (areas west of the Manitoba-Ontario border) generally uses significantly less salt on a per lane km per day basis, less than 0.02 tonnes of salt per lane km/day. According to the road authorities in Western Canada, for a majority of the winter season salt is not applied on its own. Sand is the primary material of choice to which salt is added in small quantities.

The two primary groups of independent variables required for the modeling are meteorological variables extracted/derived from MSC data and RWIS variables extracted/derived from the various road authorities.

MSC data were relatively straight forward to extract. The following variables were extracted/derived:

- Air temperature in Celsius (averaged over the entire period);
- Absolute difference between air temperature (averaged over the entire period) and a selected temperature between -12 Celsius and 0 Celsius;
- Temperature range (between daily minimum and maximum air temperature) in Celsuis;
- Average daily snow accumulation in cm (snow accumulation);
- Average daily snow accumulation in cm including trace snow (snow accumulation with trace);
- Average daily occurrence of snow per period (snow occurrence);
- Average daily occurrence of freezing rain/drizzle per period (freezing rain occurrence);
- Average daily rainfall accumulation in cm (rain accumulation);
- Average daily occurrence of rainfall per period (rain occurrence);
- Average daily occurrence of blowing snow per period (blowing snow occurrence); and
- Average daily occurrence of snowfall (above 1 cm) per period (threshold snow occurrence).

Values were essentially complete for all periods in all areas, although the reporting of blowing snow per period was somewhat lower than the other variables, therefore of limited use for the modeling.

The Steering Committee made available to the project team a number of RWIS data sets corresponding to different locations across Canada, geographically matched to the different WRM data. In order to reduce file sizes and make the data more manageable to work with, the project team decided to keep only the first observation after the top of the hour and filter out all subsequent observations. Typically, RWIS data sets report observations every 10 – 20 minutes, therefore the filtering reduces the size of the data sets substantially.

Generally speaking, the RWIS data was only available for a limited time period and for a limited number of variables. The only variable available for all RWIS data sets is pavement temperature (also known as surface temperature). This variable and to a lesser extent, dewpoint temperature, became the focus of several different quality checks.

In reviewing the RWIS data sets, it quickly become apparent that there is no standard format in the way RWIS data are recorded. In addition, the quality of the data varied from location to location. Two of the data sets initially considered were discarded due to quality issues. In other instances, the data set was kept, however certain time periods were discarded due to quality issues. The project team undertook a series of quality checks in order to identify which data sets and time periods within the data sets could be kept.

The quality check undertaken involving checking for time gaps in the data. Many of the data sets had significant time gaps. These ranged from a whole years worth of missing observations down to smaller gaps ranging between a couple of hours up to a couple of days. Due to this, it was decided to exclude all months and bi-weekly periods having greater than a 24 hour gap.

Additionally, erroneous observations were noted for pavement and/or dew point temperature, such as:

- A default value, noted as being the number 0 or a number well outside the range of possible values; and
- A repeated value.

Once the above screening was accomplished, the study team had a total of 169 potential observation periods with usable RWIS data that could be matched to the corresponding dependent variable. This represented 13 percent of the original data set but is representative of a variety of locations across Canada, both within provincial road authorities and in urban areas.

Additional variables were considered. These included:

- **Geographic groupings** – All road authorities in eastern Canada (within the provinces of Ontario, Quebec, Nova Scotia, New Brunswick and Newfoundland) were assigned the value 1, reflecting the additional salt used in these provinces, while the remaining road authorities were assigned the value 0. This reflects the division in salt usage quantities observed earlier;
- **Urban and rural groupings** – The road authorities were divided into urban (cities) and provincial (rural) groups; and
- **Year** – This variable was considered for the modeling in order to account for a downward trend in salt usage over time due to salt management.

Variables considered and rejected were road class and winter road maintenance practices (several road authorities did not provide a breakdown by road class and many of the road authorities did not provide data on how the salt was applied).

Model options

In the model development, the project team attempted three approaches, referred to as:

- Individual variable modeling (MSC only and MSC-RWIS);
- Composite variable modeling (MSC only and MSC-RWIS); and
- Creation of an index based on composite variables weighted according to expert opinion (MSC only and MSC-RWIS).

Individual variable modeling involved developing a relatively simple model using daily meteorological data (MSC) on its own or in combination with RWIS data, in order to identify a statistical relationship between the dependent variable (salt (t)/lane-km/day) and weather conditions. Individual variable modeling of daily MSC data is straightforward to use. Future users would rely on MSC data that is available from the Environment Canada website. Nationally, this model achieved a modest goodness of fit which was expected to improve when calibrated locally.

Composite variable modeling was more prescriptive, it involved the creation of four general types of potentially saltable hourly events (snowfall, freezing rain, drifting snow, frost) that were modeled as a set of composite variables, again to identify a statistical relationship between the dependent variable and the composite variables separately. This was attempted using MSC data only and MSC data combined with RWIS data. Modeling of composite variables at the hourly MSC level was an attempt by the study team to be more prescriptive by focusing in on the exact weather conditions that would likely require salting by carefully defining temperature and precipitation conditions based on expert opinion. As such, this model was less straightforward to conceptualize and would have required more data as inputs, both in the number of variables used and due to the temporal scale (hourly compared to daily). Nationally, the composite model yielded a comparable goodness of fit to the modeling of daily MSC data using simple variables. Due to its complexity and results that were no better than individual variable modeling, it was not carried forward.

Finally, the **creation of an index** involved using the composite variables to develop a weighted index and modeling it as a single variable, in order to identify its relationship to the dependent variable. The weightings are based on the expert opinion of the study team and reflect their relative importance in terms of required salt usage during different weather events, being snowfall, freezing rain, drifting snow, and frost, predicated on the temperature being within a certain range. Nationally, this approach achieved a poorer goodness of fit compared to the other models. As with the composite variable modeling, the development of an index using composite variables based on hourly data were considered less straightforward to conceptualize and will require more data as inputs. The weighting of the different variables is also arbitrary, in that they have been assigned based on the judgment of the team, not based on statistical modeling. For this reason, this model was also not carried forward.

8 Model Results

The study team then proceeded to develop a national model using individual variables. Aside from linear modeling, the study team also decided to examine different mathematical distributions of the dependent variable, including exponential and logarithmic functions. It was found that a natural log (ln) of the dependent variable produced the best fit with the independent variables. The function (ln) is commonly used by engineers in modeling relationships between different variables. The natural log (ln) of salt (t)/lane-km/day was used as the dependent variable for the remainder of the modeling.

Model using MSC data alone

Table 2 shows the correlation coefficients and R-squared values for a selected group of non-weather variables and individual daily MSC variables, using the natural log (ln) of salt (t)/lane-km/day. The table suggests that there are some variables showing a higher correlation and goodness-of-fit. Variables showing promise are all of the variables relating to snowfall. The temperature and freezing rain variables had a lower degree of correlation, suggesting their potential as a secondary variable. The east-west dummy variable also showed a high degree of correlation and clearly demonstrates the difference in salt usage in western Canada versus Eastern Canada.

The variables were used in various combinations in order to identify a model that had the highest goodness of fit. In addition, the temperature variable was modified to account for temperature range in which salt is applied (between 0 Celsius and -12 Celsius). A variable was derived from the mean air temperature by calculating the absolute difference between the mean air temperature and a temperature between 0 Celsius and -12 Celsius, accounting for the fact that salt usage should decrease as the mean air temperature range moves outside the range of temperatures at which salt is applied. The variable with the best result was the absolute difference between -6.5 Celsuis and the mean air temperature (for a given time period), yielding a correlation of **-0.52** or an R-squared value of **0.27**.

The final model is shown in **Table 3**. A total of 1,255 observation periods were used for this model (some of the periods did not have a value for the required variables). The correlation between the dependent variable (the natural log of salt(t)/lane-km/day and the independent variables is **0.74**. The model has a goodness of fit of **0.54**, in other words, the model explains **54** percent of the variation in salt usage (expressed as a natural log).

The parameter estimates for the measurable or trace snowfall occurrence, east-west dummy variable and freezing rain occurrence are all positive, suggesting a positive relationship with the dependent variable, as expected. The absolute air temperature difference has a negative parameter estimate, suggesting a negative relationship with salt usage, as expected. As the difference between average air temperature and -6.5 Celsius increases (in other words, it moves out of the range of temperatures at which salt is applied), the level of salt usage decreases. The first three variables are significant ($p<0.0001$), indicating that they are each contributing to the goodness of fit of the model. The freezing rain occurrence variable is showing a lesser degree of significance ($p<0.039$).

It should be noted finally that the weather variables (without the benefit of the east-west dummy variable) had a goodness-of-fit of **0.42**. In other words, the weather variables are explaining **42** percent of the variation on salt usage.

Model using MSC and RWIS data

Average pavement temperature, being the variable most often reported within the RWIS data were then substituted for average air temperature. As mentioned in the previous section, based on a number of quality checks, the project team was able to extract 169 observations of pavement temperature. The correlation between pavement temperature and the dependent variable was determined to be **-0.50**, in other words, as pavement temperature increases, the dependent variable tends to decrease. The goodness-of-fit was **0.25**. Modeling of a variety of different combinations of variables was attempted.

As with the air temperature variable, the pavement temperature variable was modified to account for temperature range in which salt is applied (between 0 Celsius and -12 Celsius). A variable was derived from the mean pavement temperature by calculating the absolute difference between the mean air temperature and a temperature between 0 Celsius and -12 Celsius, accounting for the fact that salt usage should decrease as the mean pavement temperature range moves outside the range of temperatures at which salt is applied. The variable with the best result was the absolute difference between -5.5 Celsuis and the mean air temperature (for a given time period), yielding a correlation of **-0.46** or an R-squared value of **0.21**.

The model with the highest correlation and goodness-of-fit is shown in **Table 4**. A total of 157 observations were used for this model (some of the periods of observations did not have a value for measurable or trace snowfall occurrence). Freezing rainfall occurrence, while significant in the previous model, was not significant in this model. Therefore, it was removed.

The correlation between the dependent variable and the independent variable is **0.77**. This model has a goodness of fit of **0.60**, in other words, the model explains **60** percent of the variation in salt usage. The higher correlation and goodness-of-fit is somewhat misleading given the smaller sample size.

The parameter estimates for the east-west dummy variable and the measurable or trace snowfall occurrence are positive, suggesting a positive relationship with the dependent variable, as expected. As well, the absolute air temperature difference variable has a negative parameter estimate, indicating a negative relationship with the dependent variable, as expected. All variables are highly significant ($p<0.001$), indicating that they are each contributing to the goodness of fit of the model.

It should be noted that the two weather variables (measurable or trace snowfall occurrence and absolute pavement temperature difference) are again explaining **42** percent of the variation in salt usage without the benefit of the east-west dummy variable.

Index development

A Winter Severity Index using a scale between 1 and 100 was then developed based on the predicted salt usage (expressed as a natural log). First, the predicted range of salt usage determined in the national model using MSC data only (a total of 1255 observations) was taken as the working range of possible values. The lowest and highest predicted salt usage was used to identify the lower and upper range of values for the Index. A predicted salt usage value below the minimum predicted salt usage value in the model would be 1. A predicted salt usage value above the maximum predicted salt usage value in the model would be 100. A lower and upper range of values was determined for the values 2 through 99, with the upper range for 50 being set at the median predicted value. Thus half of the predicted salt usage values in the model are between 1 and 50 and the remainder of the predicted salt usage values are between 51 and 100. The increments defining the lower and upper range of values for 2 through 50 and 51 through 100 were divided equally.

The distribution of calculated Winter Severity Index values based on the 1255 observations used in the national model is shown in **Figure 1**.

9 Local Calibration

The project team was directed to calibrate the national model to local geographic areas within Canada. This was done for the model shown in Table 3, using MSC data only, as there was insufficient data to conduct the calibration for the second model using both MSC and RWIS data. The first task involved in local calibration was grouping the various geographic areas represented in the model into homogenous groups. Two different road authorities (or individual districts within a provincial road authority) were considered homogenous if:

- The observed salt usage (salt (t)/lane-km/days) in each was similar; and
- They were considered to be in the same climatic zone.

The observed salt usage (salt (t)/lane-km/days) of two different groups were considered to be similar if the mean and standard deviation were found to be similar using a t-test. On the basis of this process, a total of twenty calibration groups were developed.

Several different possible methods of calibrating the results of the national model to the local results were attempted. They were:

- Creating a single local calibration factor that would be applied to the national model results for each area;
- Calibrating the individual model parameters independent of the national results; and
- Calibrating each of the national model parameters to the local model (Bayesian method).

For all three methods of calibration, the east-west dummy variable was not used.

The first method involved creating a single calibration factor to weight the local results. This involved calculating the ratio of total observed salt usage from each calibration group to the sum of the predicted salt usage using the national model for the same calibration group. Then, the calibration factor estimated for each group was simply multiplied by the national model in order to "transfer" the national model for application to local conditions. However, this method was rejected as it did not substantially improve the goodness of fit of the model locally.

The second method considered was calibrating the individual model parameters independent of the national results. This method did improve the goodness of fit in some of the jurisdictions, however, some of the parameter estimates changed substantially, producing results that were counterintuitive (i.e. a negative parameter estimate for snow occurrence, meaning that snowfall had a negative relationship with salt usage in the model) due to lack of representative data. For this reason, this method was rejected.

The third method considered involved using the Bayesian method. The Bayesian method combines the information from the national model with the information obtained from local calibration in order to achieve more accurate updated information. The Bayesian approach provides an opportunity to solve the problem encountered in the second method. The results generated using the Bayesian method improved on the national results yet did not produce any counterintuitive results.

Therefore, the Bayesian method was used to calibrate the results of the national model to the local results. The results of the local calibration using the Bayesian method are shown in **Exhibit 2** along with the comparable national model goodness of fit that did not include the east-west dummy variable (**0.42**).

The results of the local calibration suggest a wide variation in the goodness of fit across Canada. The local calibration was able to improve upon the national model in thirteen out of twenty of the groups. A higher goodness of fit was realized in all districts of Newfoundland, Nova Scotia, Quebec (with the exception of Rouyn District and Gaspe/ Sept Iles), Ontario, and Manitoba (Brandon only), and all of the Cities (except Edmonton). These areas achieved a goodness of fit of **42** percent or greater.

All of New Brunswick, the two areas (Rouyn, Gaspe and Sept Illes) within Quebec, the district of Carberry in Manitoba, districts within the provinces of Alberta and Saskatchewan, and the City of Edmonton all achieved a somewhat lower goodness of fit than the national model results. There are several possible reasons for this.

First of all, road authorities in these areas of Canada do not respond to weather conditions in a similar manner to the rest of the jurisdictions in terms of their salt usage. Generally speaking, it was noted that the areas with a poorer fit were in western Canada. Western Canada was noted to use less salt than eastern Canada. Some of these jurisdictions may either use sand as an alternative, or plow, or may only use a small amount of salt mixed in with sand during weather conditions in which another road authority would chose to use salt.

Second, it was noted that generally the districts that had poorer results were those that are rural with a low population density (such as Rouyn District in Quebec and Carberry District in Manitoba). These areas likely have lower priority roads which may not require immediate attention (in terms of salting). As mentioned earlier, a variable reflecting road class was not available for use in the model, as this information is not consistently available across Canada.

10 Data Requirements

The last stage in the project involved the creation of a software interface that would allow road authorities to calculate their own Index values for a given time period by means of a set of inputs based on the independent variables identified in the two models. An MS-Excel spreadsheet created by the project team allow for the selection of any one of twenty different calibrations (based on the twenty different calibrated areas across the country). It will allow road authorities to calculate the Index based on either MSC data or a combination of MSC and RWIS data. The spreadsheet also indicates the predicted salt usage based on the model. This will allow each road authority to assess the relative severity of a given winter compared to past winters, in order to determine whether or not salt usage was justified.

Figure 3 shows observed salt usage and the calculated Index in the Province of Newfoundland in Central District, based on the calibrated factors for the model using MSC data alone. As shown, the Index is correlating well with the observed salt usage and would be an effective tool for the province in evaluating salt usage on a monthly basis. In other areas of Canada where the local calibration did not achieve as high of a correlation, the Index may still be valuable, although it is recommended that it only be used for evaluating salt usage for an entire winter season.

11 Concluding Remarks

With respect to the goodness of fit revealed in the models in this paper, it should be pointed out that past literature indicates that the correlation between winter severity indices and WRM variables does vary considerably. In many cases, less than half of the total variability in WRM is explained by weather, as measured by the r-squared value (goodness of fit). Past models that had a better goodness-of-fit were those that focused either on a single region (such that the model was calibrated to local conditions and needed to only account for temporal variations), or those that examined a larger unit of analysis (typically a whole winter season). In contrast, the focus of the modeling discussed in this paper has been on explaining variations both temporally and spatially at the city/district level for individual biweekly or monthly periods, across an entire country with differing winter road maintenance practices and climatic regions. As such the model has been a significantly more ambitious undertaking than past efforts.

The models presented in this report show clear evidence that geographic variation is a significant factor in modeling salt usage in Canada. The east-west dummy variable was a significant variable on all of the models – reflecting the fact that there is a significant difference in WRM practices in western Canada compared to eastern Canada that cannot be explained by weather variables alone. It is likely that there are other geographic variations that relate to the unique climate of different regions of Canada and differing WRM practices at the local level.

Several limitations of the models should be noted. Weather plays a key role in the variability in salt usage, however, apart from the east-west dummy variable, non-weather related variables such as winter road maintenance practices and varying standards of service across the country have not been considered in the model due to a lack of data. Therefore, the predicted salt usage developed in the model may be lower or higher than observed salt usage due to these local variations. For this reason, it is not recommended that the model or the Index be used to make comparisons among different road authorities. Rather, the model with its predicted salt usage and index should be used to make comparisons between a given winter and past winters and make assessments regarding the reasonableness of salt usage for a given period of time.

As also revealed in the discussion on local calibration, the model generally appears to perform better in areas that are more heavily populated and in eastern Canada. Results in these areas would be more reliable than rural districts and western Canada.

It is not recommended that a road authority without a locally calibrated result use a calibrated factor from a nearby road authority. Rather, the road authorities should use the national model.

Lastly, the model cannot be used in British Columbia due to the absence of any WRM from that area.

12 Future Research

Several recommendations for future research came out of this project. First, it is recommended that a winter severity index model be developed for sand usage or equipment hours. Sand usage is more heavily used in Western Canada. It is believed that a better fit could be developed in Western Canada using sand as the dependent variable. Alternatively, equipment hours could be a potentially useful variable in that it predicts winter road maintenance activity independent of the choice of materials. It is widely known that labour costs (as indicated by equipment hours) contribute to the largest portion of a WRM budget.

Second, it is recommended that winter road maintenance authorities standardize their reporting of materials (into a common reporting unit, such as tonnes). This will better facilitate any future modeling. Information on road class (as expressed in lane kilometers) would also likely strengthen any future model predicting WRM activity based on weather.

Last of all, it is recommended that as RWIS data becomes more widely available, another national model be developed using MSC data supplemented by RWIS data. The results shown in this paper are promising but are limited value based on the relatively small number of observations.

13 Acknowledgements

The authors would like to acknowledge the help and support of the Project Steering Committee, particularly in the data collection portion of this project.

References

1. Jones, B., 2003. Road maintenance costs in Canada in winter, chapter 5 in J. Andrey and C. Knapper (eds) Weather and Transportation in Canada, Department of Geography Publication Series, No. 55. University of Waterloo, Waterloo, Canada. pp.121-142
2. Morin, D. and M. Perchanok., 2000. Road salt loadings in Canada. Supporting document for the road salts PSL assessment. Report submitted to the Environment Canada CEPA Priority Substances List Environmental Resource Group on Road Salts, May 2000. Commercial Chemicals Evaluation Branch, Environment Canada, Hull, Quebec. 85 pp.

3. Adams, M. J., 2001. Winter Severity Index, Wisconsin Department of Transportation, internal document.
4. Andrey, J., J. Li and B. Mills., 2001. A winter index for benchmarking winter road maintenance operations on Ontario highways, 80th Annual Meeting Preprint CD-ROM, proceedings of the Transportation Research Board annual meeting, Washington, D.C.
5. Boselly, S, Thornes, J, Ulberg, C. and Ernest, D., 1993. Road Weather Information Systems Volume 1: Research Report.
6. Carmichael, C; Gallus, W, Temeyer, B, and Bryden, M., 2004. A Winter Weather Index for Estimating Winter Roadway Maintenance Costs in the Midwest, Journal of Applied Meteorology 43:11, 1783-1790.
7. Cornford, D. and Thornes, J., 1996. A Comparison Between Spatial Winter Indices and Expenditure on WRM in Scotland, in International Journal of Climatology, Volume 16, p 339-357.
8. Decker, R; Bignell, J, Lambertsen, C, and Porter, K., 2001. Measuring Efficiency of Winter Maintenance Practices, Transportation Research Record 1741.
9. Gustavsson, T., 1996. Use of indices for classification of winter climate, In 8th International Road Weather Conference, p 22-26, University of Birmingham.
10. Johns, D., 1996. The MOORI. A new winter index for WRM, In 8th International Road Weather Conference, p 22-26, University of Birmingham.
11. Knudsen, F., 1994. A Winter Index Based on Measured and Observed Road Weather Parameters, in Conference Proceedings 7th Road Weather Conference, Seefeld.
12. Mahle, A. and Rogstad, G., 2002. Noriks – A Winter Index for Norwegian Conditions, 11th Road Weather Conference, Sapporo, Japan.
13. McCullouch, B, Belter, D, Konieczny, T, and McClellan, T,. 2004. Indiana Winter Severity Index” in Sixth International Symposium on Snow Removal and Ice Control Technology.
14. Rissel, M. and Scott, D., 1985. Staffing of Maintenance Crews During Winter Months, Transportation Research Record 1019.
15. Venalainen, A. 2001. Estimation of road salt use based on winter air temperature, Meteorological Applications 8, p 333-338.
16. Venalainen, A. and Markku, K. 2003. Estimation of WRM costs using climate data, Meteorological Applications 10, p 69-73.
17. Nixon, W.A., and Qiu, L. 2005. Developing a Strom Severity Index, Presented at 84th Annual Meeting, Transportation Research Board, Washington D.C.
18. Strong, C., and Shvetsov, Y., 2006. Development of a Roadway Weather Severity Index, Presented at 85th Annual Meeting, Transportation Research Board, Washington D.C.

Table 1 – Salt usage per lane kilometer per day

Road Authority	Area	Average Salt (t)/lane km/day
Province of Alberta	Northern Alberta - Hangingstone	0.0182
	Southern Alberta - near Calgary	0.0045
Province of Manitoba	Brandon	0.0067
	Carberry	0.0033
Province of New Brunswick	Fredericton	0.0257
	Moncton	0.0354
	Saint John	0.0378
Province of Newfoundland	Avalon	0.0548
	Central	0.0420
	Eastern	0.0615
	Western	0.0674
Province of Nova Scotia	Central	0.0705
	Eastern	0.0797
	Northern	0.0850
	Western	0.0651
Province of Ontario	London Area	0.1046
	New Liskeard Area	0.0598
	Ottawa Area	0.1251
Province of Quebec	Chicoutimi	0.0642
	Gaspe	0.0463
	Hull	0.0301
	Montreal	0.0877
	Quebec	0.0471
	Rouyn-Noranda	0.0048
	Sept Iles	0.0344
	Sherbrooke	0.0671
Province of Saskatchewan	Findlater	0.0135
	Regina	0.0100
City of Calgary		0.0129
City of Edmonton		0.0177
City of Halifax		0.0518
City of London		0.0318
City of Ottawa		0.1242
City of Winnipeg		0.0087
City of Toronto		0.0601
Average (All)		0.0473

Table 2 – Selected key variables and their relationship to the natural log of salt (t)/lane-km/day

Variable	Correlation (R value)	Goodness of Fit (R-squared)
East-West dummy variable	0.48	0.23
Urban-Rural dummy variable	-0.18	0.03
Year	-0.02	0.00
Average air temperature (*Ta*)	-0.35	0.12
Difference between T*max* and T*min*	-0.35	0.12
Snowfall occurrence	0.58	0.34
Snowfall occurrence (including trace)	0.61	0.37
Snowfall amount	0.50	0.25
Threshold snow occurrence (>1 cm)	0.55	0.30
Freezing rain occurrence	0.34	0.12
Blowing snow occurrence	0.34	0.12

Table 3 – Final model developing using MSC data alone

Model form: ln of salt (t)/lane-km/day = -5.59431 + 2.36059 (snow) - 0.08616 (air) + 1.37785 (EW) + 0.74326 (frz)			
Observations	1255		
Correlation Coefficient (R value)	0.74		
Goodness of Fit (R squared)	0.54		
Variable Name	**Parameter Estimate**	**t-value**	**Probability>t**
1. Measurable or trace snowfall occurrence (snow)	2.36059	14.66	<0.0001
2. Absolute air temperature difference (air)	-0.08616	-10.30	<0.0001
3. East - west dummy variable (EW)	1.37785	18.20	<0.0001
4. Freezing rain occurrence (frz)	0.74326	2.07	0.039

Notes:
1. Proportion of days in which measurable or trace snowfall was reported.
2. Absolute difference between average air temperature and -6.5 Celsuis.
3. East - west dummy variable, for all road authorities east of Ontario-Manitoba border use 1, otherwise use 0.
4. Proportion of days in which freezing rain was reported.

Table 4 – Final model developed using MSC data together with RWIS data

Model form: ln of salt (t)/lane-km/day = -5.1447 + 3.28835 (snow) - 0.08226 (pave) + 1.36468 (EW)			
Observations	157		
Correlation Coefficient (R value)	0.77		
Goodness of Fit (R squared)	0.60		
Variable Name	Parameter Estimate	t-value	Probability>t
1. Measurable snowfall occurrence (snow)	3.41662	7.48	<0.0001
2. Absolute pavement temperature difference (pave)	-0.08532	-4.91	<0.0001
3. East - west dummy variable (EW)	1.34889	8.25	<0.0001

Notes:
1. Proportion of days in which measurable or trace snowfall was reported.
2. Absolute difference between average air temperature and -4.0 Celsius
3. East - west dummy variable, for all road authorities east of Ontario-Manitoba border use 1, otherwise use 0.

Figure 1 – Distribution of Index values based on observations in national model

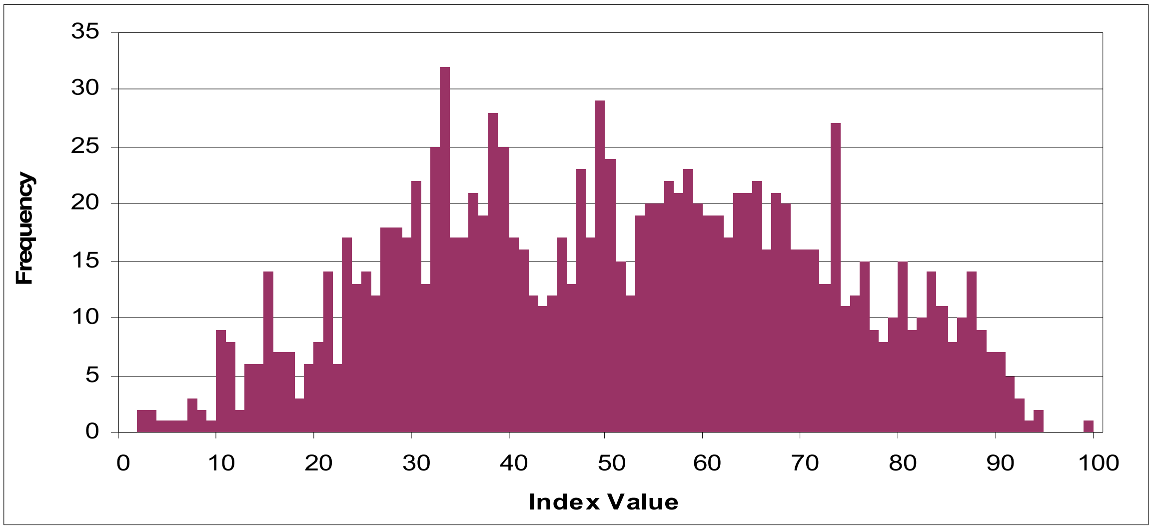

Figure 2 – R-squared values for local calibration groups

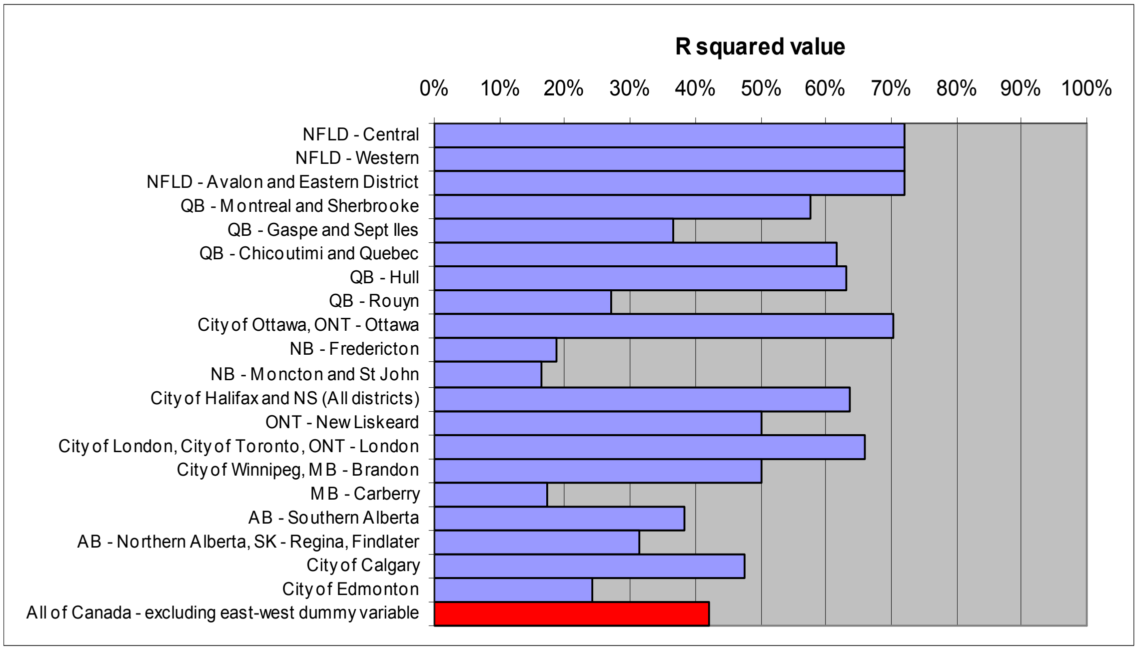

Figure 3 – Correlation between calculated Index and observed salt (t)/lane-km/day in the Central District of the province of Newfoundland