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Weather Index User's Guide

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Aurora Project 2012-02

User's Guide
October 2012

About Aurora

Aurora is an international program of collaborative research, development, and deployment in the field of road and weather information systems (RWIS), serving the interests and needs of public agencies. The Aurora vision is to deploy RWIS to integrate state-of-the-art road and weather forecasting technologies with coordinated, multi-agency weather monitoring infrastructures. It is hoped this will facilitate advanced road condition and weather monitoring and forecasting capabilities for efficient highway maintenance and real-time information to travelers.

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16. Abstract

Weather indices are powerful tools that can help observers quantify the severity of a winter season and allow comparison of the severity from one region or year to another. Such comparisons provide very useful information for those studying winter maintenance costs or other department of transportation (DOT) functions that are influenced by weather.

While weather indices can be powerful tools, they must be used appropriately. An agency must select the right weather index for the job and have the data needed to compute the chosen index. This guide describes weather indices in general, shows how they are used and misused, refers to some existing indices and identifies the data needed for computations, and presents an example showing how to use an index to understand other winter maintenance issues.

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WEATHER INDEX USER'S GUIDE

October 2012

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INTRODUCTION

Weather indices are powerful tools for describing or normalizing the impact of weather over a given period of time. They can help observers quantify the severity of a winter season and allow comparison of the severity from one region or year to another. Some indices can also help describe the severity of a given storm or even a moment of time within a storm.

Comparisons like these provide very useful information for those studying winter maintenance costs or other department of transportation (DOT) functions that are influenced by weather. For example, it is reasonable to assume that more resources may be spent on maintenance during a very severe winter than would be used in a mild winter. In order to determine costs accurately, the impact of weather from year to year or region to region must be described and adequately factored out in the analysis. Otherwise, it is difficult to know whether a cost difference resulted from differences in management, techniques, or other factors or from weather conditions. A weather index can be helpful with that process.

Weather indices can be powerful tools, but they must be used appropriately. An agency must select the right index for the job and have the necessary data to compute the chosen index. This guide will describe indices in general, show how they are used and misused, refer to some existing indices and identify the data needed for computation, and present an example showing how to use an index to understand other winter maintenance issues.

INDICES IN GENERAL

In the most general terms, a weather index is a formula that uses some combination of weather observations to create a single number that describes the severity of the weather conditions as a whole. Using this formula, the weather observations are often multiplied or otherwise modified by factors that affect the influence of that weather observation on the resulting number. For example, a very simple index can be as follows:

$$\text{Inches of Snow} \times (0.5) - \text{Average Air Temperature °F} \times (.1) = \text{Index Score}$$

As snowfall increases, the index score also increases. As air temperature increases, the index score decreases. The weighting factor for snow is bigger than that of air temperature, indicating that a one-inch change in snow amount has a bigger impact on the index score than a one-degree change in average air temperature.

The weather factors included in an index and their weights depend on the intended purpose of the index and the data available. For example, the weather parameters important to salt use may be quite different from those that influence the amount of crew or truck hours. And, if a particular type of weather observation is not available or reliable, it can’t be included in the index and some other weather information will need to be used. For this reason, there are many existing indices from which to choose.

A good weather index should never include factors for crew activities, material use, traffic conditions, or anything else governed by outside factors. The use of outside factors creates a cyclical reference and will invalidate any use of that index in studies on DOT activities. For example, material use depends on weather and on decisions made by the DOT. If material use is included in the index, it also incorporates dependency on DOT actions as part of the index score. Indices that rely on weather *and* DOT actions cannot be used to separate weather *from* DOT actions. It would be self-referential and invalid to attempt.

SPECIFIC INDICES

The following table mentions several existing weather indices, with a description of their intended purpose, the time period it is designed to cover, the weather data needed to run the index, and a literature reference or DOT contact for more information.

Index Name	Category	Details
SHRP-H-350 Index	**Purpose/Description**	This index was designed for general highway maintenance needs. It was developed to run on daily air temperature and snowfall records from the National Weather Service and features a relatively simple computation. Therefore, this index should be usable by many agencies.
	Time Period	It is designed to cover an entire winter season or several months of the season.
	Variables	• **Temperature index (TI):** TI = 0 if the minimum air temperature is above 32°F (0°C); TI = 1 if the maximum air temperature is above 32°F (0°C) while the minimum air temperature is at or below 32°F (0°C); TI = 2 if the maximum air temperature is at or below 32°F (0°C). The average daily value is used. • **Snowfall (S):** mean daily values in millimeters (the number of days with snowfall was also considered but did not improve the index). • **Number of air frosts (N):** mean daily values of number of days with minimum air temperature at or below 32°F (0°C) ($0 < N < 1$). • **Temperature range (R):** value of mean monthly maximum air temperature minus mean monthly minimum air temperature in °C.
	Formula	$WI = -25.58\sqrt{TI} - 35.68\, ln\left(\frac{S}{10}+1\right) - 99.5\sqrt{\left(\frac{N}{R+10}\right)} + 50$ The index (WI) has a value ranging from -50 (most severe and maximum level of snow and ice control) through 0 (not too severe and mean level of snow and ice control) to +50 (warm and no need of snow and ice control).
	Reference	Published in the 1993 Strategic Highway Research Program (SHRP) publication *Road Weather Information Systems Volume 1: Research Report*, page 93.

Index Name	Category	Details
Iowa Hour Use Index	**Purpose/Description**	This index was designed by the Iowa DOT to estimate the amount of personnel hours required for plowing and treating winter storm events in a given time period, when combined with the Iowa DOT's level of service index and average plow run length.
	Time Period	Flexible. Can be computed for time frames less than an hour or up to entire winter seasons.
	Variables	• **Precipitation Hours (PH):** Number of hours of snow, sleet, freezing rain, or mixed precipitation. • **Blowing Snow Hours (BH):** Number of hours in blowing snow conditions.
	Formula	Base Crew Hours = PH + BH × 0.5 The index (Base Crew Hours) can be used as a standalone index, but it was designed to be combined with the Iowa DOT's level of service index and average plow run length to estimate total personnel hours.
	Reference	Unpublished. Contact Tina Greenfield at Iowa DOT. Tina.greenfield@dot.iowa.gov

Index Name	Category	Details
Iowa Salt Use Index	**Purpose/Description**	This index was designed by the Iowa DOT to estimate the specific impact of the weather on salt use. When combined with the Iowa DOT's level of service index, it will produce an estimate of salt use in tons for the given region. It requires regular data to run the index, and the formula is more like a simple computer model with decision points and conditional statements than a traditional equation. Therefore, it is difficult to reproduce with a standard spreadsheet or manual calculations.
	Time Period	It requires regular, concurrent observations with frequencies ranging from a few minutes to an hour. Estimates for longer periods can be computed by summing up the results of the smaller time frames.
	Variables	• **Pavement Temperature** (F) • **Precipitation Type** (Light Snow, Medium Snow, Heavy Snow, Sleet, Freezing Rain, Road Frost, Refreeze, Blowing Snow, Rain)
	Formula	Results stem from a lookup table based on the concurrent pavement temperature and precipitation type and Iowa DOT Instructional Memorandum 8.400. A multiplier is applied if the previous storm type was "Rain" or if precipitation began before pavement temperatures dropped below 33.5°F. This multiplier erodes linearly after 2 hours have elapsed. The effect of the weather on salt use is assumed to linger for variable amounts of time after the "end" of the precipitation, based on the former precipitation type and the subsequent pavement temperatures.
	Reference	Unpublished. Contact Tina Greenfield at Iowa DOT for model code or more detail on the model result lookup table. Tina.greenfield@dot.iowa.gov

Index Name	Category	Details
Iowa General Winter Index	**Purpose/Description**	This index was based loosely on an index developed by the Wisconsin DOT and modified for Iowa conditions and data availability. It was designed to score the impact of the winter weather on general winter operations.
	Time Period	Flexible, but must be long enough to include at least a few storm events. Generally used as a seasonal index.
	Variables	• Number of snow events (S) • Number of freezing rain events (F) • Snowfall in inches (SIN) • Hours of snow (HS) • Hours of mixed precipitation (HM) • Hours of freezing rain (HF) • Hours of blowing snow (HB) • Hours of sleet (HSL) • Average of lowest temps during snow events (sind) • Average of lowest temps during mixed precipitation events (mpind) • Average of lowest temps during freezing rain events (frind) • Average of lowest temps during sleet events (slind) • Average of lowest temps during blowing snow events (bsind)
	Formula	Index = 0.175 × S + 0.656 × F + 0.147 × SIN + 0.00835(HS+HM+HF+HB+HSL) – 0.25 × ((wsind-29.6) + (mpind-30.22) + (frind-26.42) + (slind-29.52)) + 0.0345 × ((bsind-20)^2)
	Reference	Unpublished. Contact Tina Greenfield at Iowa DOT. Tina.greenfield@dot.iowa.gov

Index Name	Category	Details
Clear Roads Weather Severity Map Index	**Purpose/Description**	This index was developed by Meridian/Iteris under contract with the Clear Roads pooled fund. Clear Roads wanted an index that many states could use to assess their operations and learn how their weather severity compares to that of other similar states. This research also involved mapping the nationwide severity zones, similar to plant hardiness zone maps used for agriculture.
	Time Period	Annual/seasonal.
	Variables	• Average annual snowfall accumulation (inches) (SA) • Average annual duration (hours) of snowfall (SD) • Average annual duration (hours) of freezing rain (FD) • Average annual duration (hours) of blowing/drifting snow (BD)
	Formula	Winter Severity = 0.50 × (SA) + 0.05 × (SD) + 0.05 × (BD) + 0.10 × (FD)
	Reference	Clear Roads final report: http://clearroads.org/wp-content/uploads/dlm_uploads/MappingWeatherSeverityZones-FinalReport.pdf
Wisconsin Winter Severity Index	**Purpose/Description**	The index was designed by the Wisconsin DOT in an attempt to measure the impact of various weather factors on winter operations.
	Time Period	Flexible. Can be computed for individual storm events or for longer periods.
	Variables	• **Number of snow events (SE):** Defined as more than 0.1 inch of snow • **Number of freezing rain events (FR)** • **Total snow amount (AMT):** Inches • **Total storm duration (DUR):** In hours • **Number of incidents (INC):** Items such as frost, refreeze, drifting
	Formula	$10 \times \frac{SE}{63} + 5.9 \times \frac{FR}{21} + 8.5 \times \frac{AMT}{314} + 9.4 \times \frac{DUR}{1125} + 9.2 \times \frac{INC}{50}$
	Reference	Unpublished. Contact Mike Adams at Wisconsin DOT. michael.adams@dot.wi.gov
Ministry of Transportation Ontario (MTO), Canada	**Purpose/Description**	A province-wide index of the variation in demand for winter maintenance from year to year.
	Time Period	Winter season (October through March).
	Variables	Y = total estimated salt use (tonnes per season) X = seasonal average number of hours per snowstorm event
	Formula	Y = 0.935X (regional coefficients also available)
	Reference	Unpublished, internal. Contact Max Perchanok at MTO. Max.Perchanok@ontario.ca

USING AN INDEX IN WINTER MAINTENANCE STUDIES

The first step in using an index to study winter maintenance practices is to select an appropriate index. The most desirable choice would be an index that is tailored to the specific winter maintenance need to the greatest extent possible, uses only weather variables that are reliable and accessible to you, and is designed to cover the time period of interest. Compromise may be necessary when the available options are not suitable. For example, if you wanted to study salt use and rely on the Iowa Salt Use Index but did not have access to pavement temperature data, you would need to select a different, perhaps more generic, index.

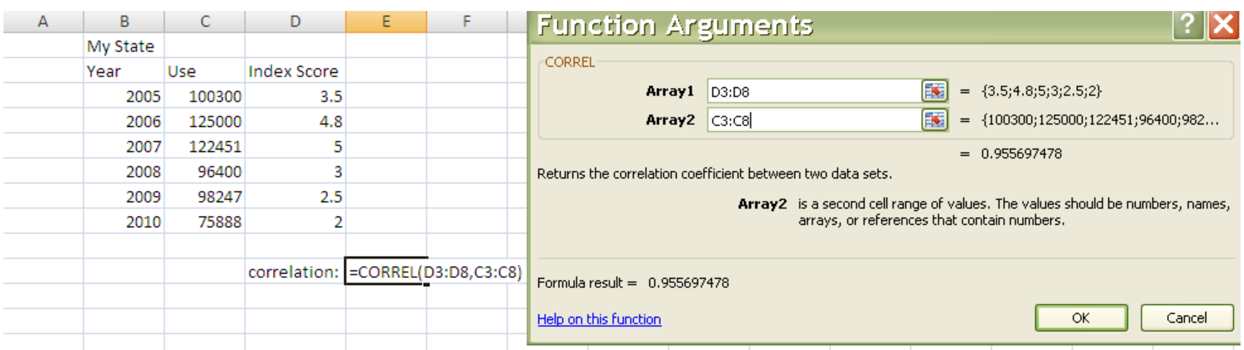
Study Changes Over Time

The easiest way to use an index is to study how a maintenance activity varies over time in the same region. For example, you may want to see to the extent to which weather conditions impact salt tons used in your state from year to year. In that case, these steps might be followed:

1. Gather several years' historical data and compute a statewide index for each year.

2. For each year, compute the statewide salt use.

3. Put the results in a spreadsheet, as in the illustration, and compute a correlation.

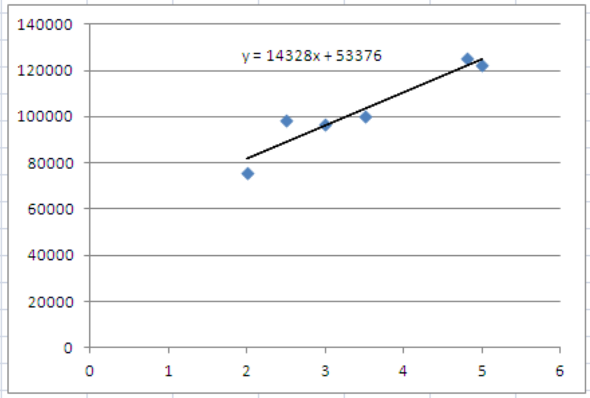


The correlation for this example is quite high, indicating that the index score and the amount of salt used in a year are strongly related. This means that the agency's salt use is highly variable based on the weather. If the correlation is weak (near zero), it suggests that either the index is a poor descriptor of salt use or the agency tends to use salt in a way that is not necessarily weather dependent.

4. If the correlation is high, consider using the index as a predictor of salt use; or, in other words, use the index to calculate estimated salt use under a given severity of conditions. This will let you detect and study any differences between actual use and expected use. For example, the index will show whether this year's salt use was unusually high or low, given

the weather. You can do this in a spreadsheet by creating a scatterplot and adding a trend line, as in this figure:

B	C	D	E
My State			
Year	Use	Index Score	
2005	100300	3.5	
2006	125000	4.8	
2007	122451	5	
2008	96400	3	
2009	98247	2.5	
2010	75888	2	
		correlation:	0.955697



The x-axis is the index score and the y-axis is salt use. If in 2011 the index was 4, salt use that year would be expected to be 14,328 × 4 + 53376 = 110,688. If actual salt use in 2011 was 115,000, it would appear that while actual use was much lower than in some recent years (2006 and 2007 were both higher), it was a little high given the severity of the winter. There are other statistical tests that can be performed to indicate whether this difference was statistically significant, but they are outside the scope of this document.

You can use this method to study other time frames. If the chosen index can compute indexes for shorter periods, such as for a given storm, you can use this same method to compute whether the salt use during a particular storm was reasonable given the severity of the individual storm.

Region-to-Region Comparisons

An index can be used to compare two different regions to each other, but this is considerably more challenging than other types of comparison. It may be very tempting to compare salt use versus index value across several regions, as in the figure below, but the comparison would be quite misleading.

My State			
Region	Use	Index Score	
A	15260	2	
B	12548	5.1	
C	54268	3	
D	15872	2.1	
E	26984	3.2	
F	23214	4	
		correlation:	-0.1004

This is because you will probably have to factor out more than just weather to create a “level playing field” between two regions. For example, Region A may have more miles to take care of than Region B, or maybe the service level standards are different between Regions A and B. Lane miles and service level both greatly influence the amount of effort and resources needed for winter maintenance. These factors must be understood and either bypassed or accounted for in the analysis.

One way to validly compare region to region is to first study each region’s index over time. Use the “Study changes over time” walk-through and see if that analysis shows any differences between regions. This type of comparison will bypass any issues with direct regional comparisons and instead compare how “consistent” each garage is within its own history. For example, the comparison might show whether some regions’ salt use tracks more closely with weather than do other regions. The following procedure can be used:

1. For each region, gather several years of historical data and compute an index for each year.

2. For each year for each region, compute the statewide salt use.

3. Put the results in a spreadsheet, as in the illustration, and compute a correlation for each region.

Region A					Region B			
Year	Use	Index Score			Year	Use	Index Score	
2005	15260	2			2005	12548	5.1	
2006	11456	1.5			2006	18956	8	
2007	12689	1.4			2007	20150	7.1	
2008	18959	4			2008	17843	6.8	
2009	10594	1.8			2009	19586	5.6	
2010	14564	2.6			2010	15234	3	
		correlation:	0.885829				correlation:	0.63085

4. Compare the different correlations. In the example above, Region A seemed to have a higher correlation between salt use and weather severity than Region B, indicating that either the index performs better in Region A for some reason or that salt use in Region A was more strongly linked to winter severity than in Region B. This might mean that application rates in Region A were determined to a large extent according to the weather, whereas Region B's rates were less weather dependent. Region B still has some link to weather severity, just not as much as Region A.

Direct region-to-region comparisons are possible with a weather index, but it requires an extra step of also indexing or factoring out other issues that may influence maintenance actions. As mentioned earlier, lane miles and service level both greatly affect the amount of effort and resources needed for winter maintenance. These too must be indexed before comparisons can be drawn.

How to index these factors is a topic largely outside the scope of this document, except to note that the indices function similarly to a weather index. Some measurements are manipulated in an equation that creates a single number to describe the "difficulty" of that factor. For example, a simple index to factor out the influence of level of service (LOS) and lane miles might be as follows:

LOS Index = Lane miles A × 1.1 + Lane miles B × .85 + Lane miles C × 0.7

In this example, a region with more miles of A will have a higher LOS index than a garage with the same number of miles but in the lower service categories. Likewise, a garage with fewer A miles than another might get a higher LOS index simply because it has more miles in the B or C category.

There may be additional outside factors beyond level of service or lane miles that must be understood and properly indexed. Topographical and congestion/traffic load challenges are just two potential factors.

The steps for direct region-to-region analysis over a certain time period are shown below. In this example, the question is whether certain regions use more or less salt compared to their neighbors, given the weather and the regions' lane-mile responsibilities.

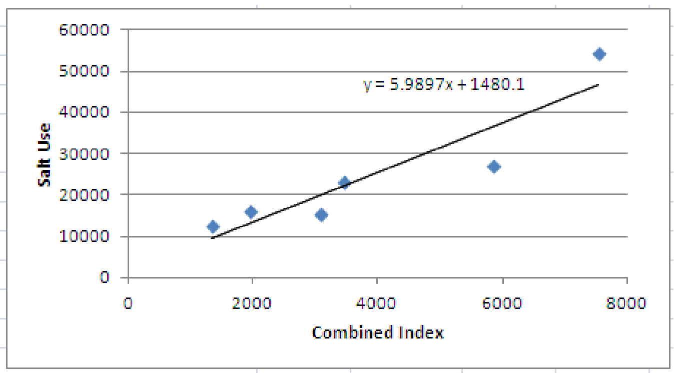
1. For each region, compute a weather index.

2. For each region, compute an appropriate index for each of the other factors that are likely to be important. This example uses the simple LOS index mentioned previously and assumes that the topographical and congestion/traffic issues between the regions are negligible.

3. Compute the actual salt use for each region.

4. Use a spreadsheet to make a combination "Weather and LOS Index." In the case shown in the illustration below, the two indices were simply multiplied together. Create a scatterplot of the combined index and salt use with a trend line and compute the correlations between salt use and each of the three indices.

Region	Use	Index Score	LOS Index	Combined Weather*LOS
A	15260	2	1540	3080
B	12548	5.1	265	1351.5
C	54268	3	2512	7536
D	15872	2.1	940	1974
E	26981	3.2	1829	5852.8
F	23214	4	864	3456



correlation (combined):	0.91802
correlation (weather only):	-0.10047
correlation (LOS only):	0.828026

The use and weather index score alone shows very little correlation. This is because other factors are involved. Once the weather index is combined with the LOS index, the correlation between the combination index and salt use becomes very high. The LOS index also has a high correlation to salt use in this case, but the correlation is not as strong as when the LOS index is combined with weather. Clearly, both weather and LOS responsibilities are important to salt use in this analysis. If the LOS index alone were found to have a higher correlation to salt use than the combined index, it may be the case that the weather index is not appropriate or that weather has little bearing on the differences in use among garages.

In this example, Region B is the lowest salt user. But the use of the trend line formula shows that the expected salt use given the weather and LOS responsibility is as follows:

$5.9897 \times \text{combined LOS} + 1{,}480.1 = 5.9897 \times 1{,}351.5 + 1{,}480.1 = 9{,}575$

Although Region B is the lowest user of salt in terms of straight tonnage, it is actually using slightly more salt than expected, given the weather and its LOS responsibilities. Region E is the second largest user in straight tons but is actually the most frugal user of salt given the weather conditions and LOS responsibilities, using nearly 9,500 tons less than expected.

SUMMARY

Weather indices can be very useful for studying winter maintenance problems, and there are many existing indices to choose from. They vary in time period covered, purpose, complexity, and the data needed to run them. It is very important to select an index that is as specific as possible to the winter maintenance issue you are trying to study and has variables that you can compute with the data available.

Index comparisons over time are relatively simple to compute and show whether weather seems to have any impact on maintenance practices in a certain region. Comparisons from region to region are far trickier and often require the use of other indices to factor out issues such as level of service requirements, amount of lane miles, topographical challenges, and the impact of congestion or traffic volume. But once other factors are controlled, comparisons from one area to another are possible.

Potential problems may occur if an index contains variables related to DOT activities such as crew hours, road condition, or salt use, since this would create an invalid or circular reference if used in DOT activity analysis. Indices that rely on weather *and* DOT actions cannot be used to separate weather *from* DOT actions. Problems may also arise if attempting to compare regions to other regions without first bypassing or factoring out other fundamental differences, such as different level of service requirements, between the regions.

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