Use of indices for classification of winter climate

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1 Introduction

Studies of the geographical variation of road icing, e.g. Gustavsson and Bogren (1990) and Gustavsson (1991) have shown that a most diversified pattern could be found over an area of the size of an ordinary county. Topography and road construction are two of the most important parameters which account for this variation. The use of Road Weather Information Systems (RWIS) has rapidly increased in Europe during the last decade and as a result maintenance activities have become more efficient. These systems are based on data from field stations located in areas frequently exposed to road icing. The economical benefits of using systems for road weather information has been discussed in several studies, e.g. Thornes (1994). Through analyses of stored data from RWIS stations, it has become possible to conduct detailed studies of winter weather and the associated maintenance needs, i.e. need of activities which keep roads free from ice, snow etc. Use of winter indices, together with historical RWIS data, is one way of gaining information about the winter season as it relates to the number of road icing conditions.

The present study deals with analyses of three different types of winter indices which can be used to calculate the need for maintenance activities; the modified Hulme index used in England, the COST 309 winter index used in Denmark and the GAB index used in Sweden. The indices were compared by examining the parameters included in the index calculations and, as well as by their relative performance using some test data covering a given period. Weight function and specific criteria for the parameters are also discussed. Furthermore, the indices are compared with recorded salting activities along the studied road stretch.

2 Data

The three winter indices (Hulme, COST and GAB index) were tested against a fixed data period, i.e. the 1 to the 31 of December, 1994, for an open well exposed RWIS station. The selected

station is equipped with sensors for the measurement of air and road surface temperature, air humidity, wind speed and direction and precipitation using an optical sensor which can measure both amount, type and intensity of the precipitation. The RWIS station is sited on road No. 26, in the southern part of Sweden close to lake Vättern. This station was specially chosen due to its close location to the synoptic weather station located at the airport near Jönköping. The synoptic data was used as reference to the recorded values at the RWIS station.

In Figure 1 the road surface temperature is plotted for the selected time period, December 1994. There was a pronounced variability in surface temperature during this time period. The maximum temperature was +6.2°C and the minimum -7.5°C. Both warm and cold spells were recorded during the month and rime conditions occurred in association with these weather changes. The surface temperature oscillated from plus to minus degrees on several occasion thereafter leading to a risk for the formation of black ice. Snow was recorded during four occasions.

3 Weather and slipperiness

From a study by Lindqvist and Mattsson (1979) three different events leading to slippery conditions have been selected, (i) coating of ice from in situ water or from water supplied from, for example, smelting snow at the road side, (ii) formation of rime and (iii) snow, which either could be from precipitation or from snow drift. The RWIS systems used today around the world are especially designed to give warning on these events. The stations are also located in such areas that an early warning for slippery condition can be achieved.

Three winter indices were next examined with emphases on their ability to represent winter road slipperiness. It was considered important that the three types of slipperiness events, discussed above, should be included in a proper index calculation because these types could be detected by the RWIS. Furthermore, these slipperiness types are also used by the maintenance people when taking action against road icing. That all three events are covered by an index is especially important for Swedish National Road Administration as they are used as a tool for cost regulation of winter activity

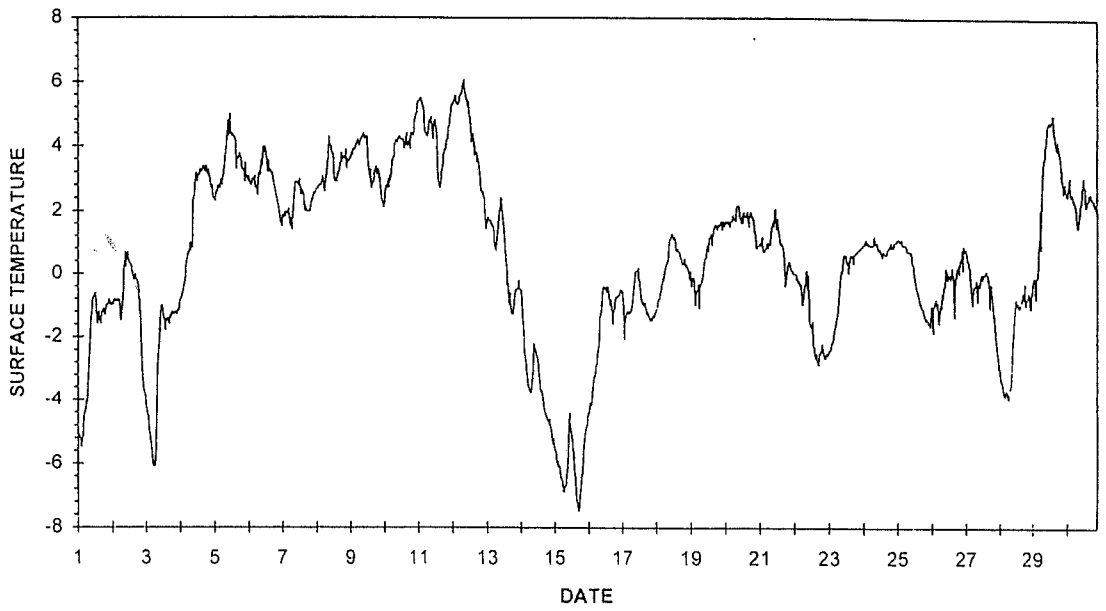

Figure 1. Road surface temperature for RWIS 16, December 1994.

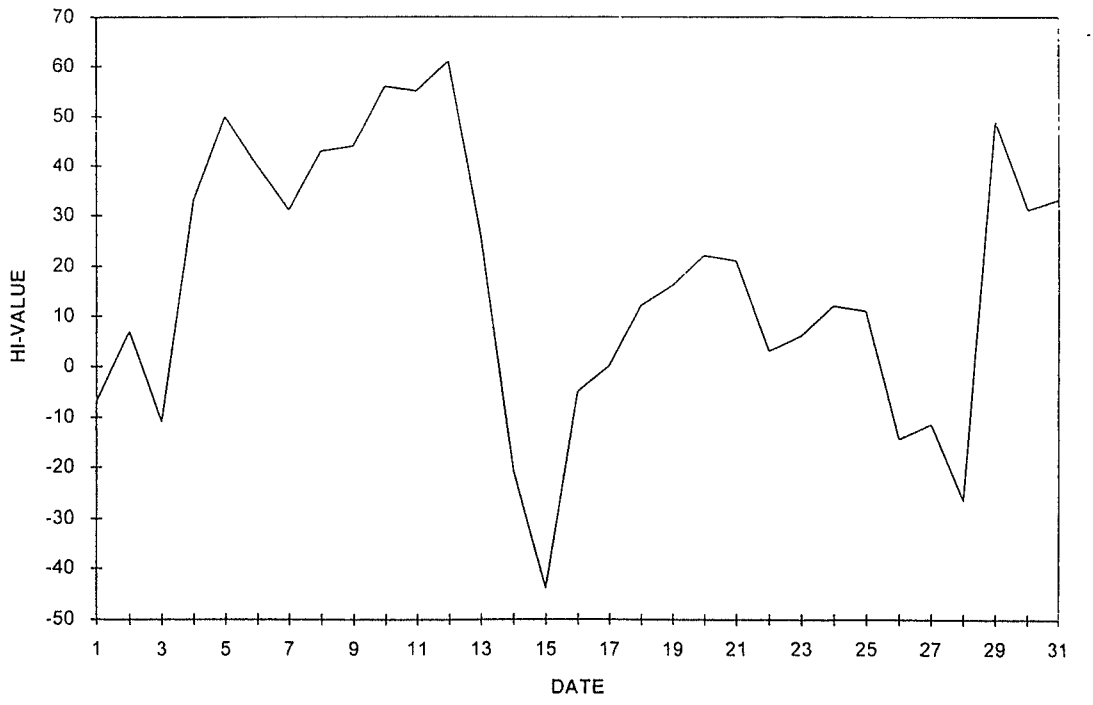

Figure 2. Calculated Hulme index for December 1994.

4 The Hulme index

An index for the estimation of winter weather variability was introduced by Hulme (1982). This index has been used by Thornes (1992) to compare different indices. The modified Hulme winter index (HI) is given by

$$HI = 10 * T_{max} - N_{frost} - 18.5(N_{snow})^{1/3} \qquad (1)$$

where T_{max} is the mean maximum winter road surface temperature, N_{frost} is the number of days with ground frost and N_{snow} is the number of days with snow lying at 09 LST.

4.1 Index calculation

The Hulme index was not developed to show the day by day variation but rather the summarised situation for the whole winter season. However, by calculating the daily values it is possible to analyse the influence of each factor in the formula.The results of these calculation are shown in Figure 2. The index values exhibits high variability during the test period, from a maximum value of +60 to a minimum of -44. High index values are closely related to days with a high surface temperature and low index values correspond to low surface temperatures. The occurrences of frost do not have a large effect on the index value as no weighting factor is applied to this parameter. Snow incidence, on the other hand, has a great influence on the daily values. One day with snow leads to a N_{snow} factor of -18.5. A total number of 4 days with snow gives an index value of 29.4. This value may be compared with the frost parameter which only records the value 11 despite the fact that frost occurred nearly three times as often as snow. If the accumulated values for the different parameters are used in equation 1 a HI for the whole period is equal to -21.2.

4.2 Analysis of the index

The modified Hulme index is best used if it is compared with other Hulme index calculation. This is due to the fact that the index value is not directly related to the number of slippery occasions. Maximum temperature is figured prominently in the index despite the fact that it does not affect directly a slippery event. Snow and frost events are not treated in a similar manner; and the index does not explicitly register a drop in temperature from above to below freezing, an event related to

a high risk of ice coating not dealt with in the index summation. The index is therefore lacking in that it does not cover all the necessary events.

5 The Cost 309 winter index

In the framework of the European Co-operation in the Field of Scientific and Technical Research (COST) a winter index has been developed which use data from the RWIS (Knudsen, 1994). The COST index is based upon a summation of the days during a winter season with four types of slippery conditions: frost formation, temperature fall from plus to minus degrees, snowfall and snowdrift. The formula used for the calculation of the index value is

$$\mathbf{WI = a*(b + c + d + e) + a} \qquad (2)$$

where **a** is "1" if the road surface temperature is below 0,5°C at any moment within the 24 hour period, otherwise a = 0. The **b** term is used for the number of occasions with frost during the period, i.e. the dew point temperature is higher than the surface temperature and the surface temperature is below 0°C. The frost events must extend for at least 3 hours and the frost event must be separated by an interval of at least 12 hours. This implies that b can vary between 0, 1 and 2. If a data point records a drop in surface temperature below zero degrees, from at least +0.5°C to -0.5°C, the **c** term is increased by one. If a snowfall of at least 10 mm is observed during the 24 hour period the **d** term is given the value 1 otherwise it is set to zero. The **e** term is related to the occurrences of "noteworthy" snowdrift and is given the value 1 if this is the case, otherwise it is set to 0. The **WI** values are further summarised for the whole winter season to achieve a measure of the total need for maintenance activity.

5.1 Index calculation

The day by day variation of the COST index is shown in Figure 3. A zero value is recorded during the days with temperature over +0,5°C, i.e. the period from 5 to 12 December and during 4 other days in the month. An index equal to 1 occurs for situations with only the surface temperature below +0,5°C but no occurrences of the conditions resulting in slipperiness is recorded In other words, term b, c, d and e in equation 2 do not register as events. An increasing index value in Figure 3 indicates that more complex situations have occurred. A value of 6 indicates that all

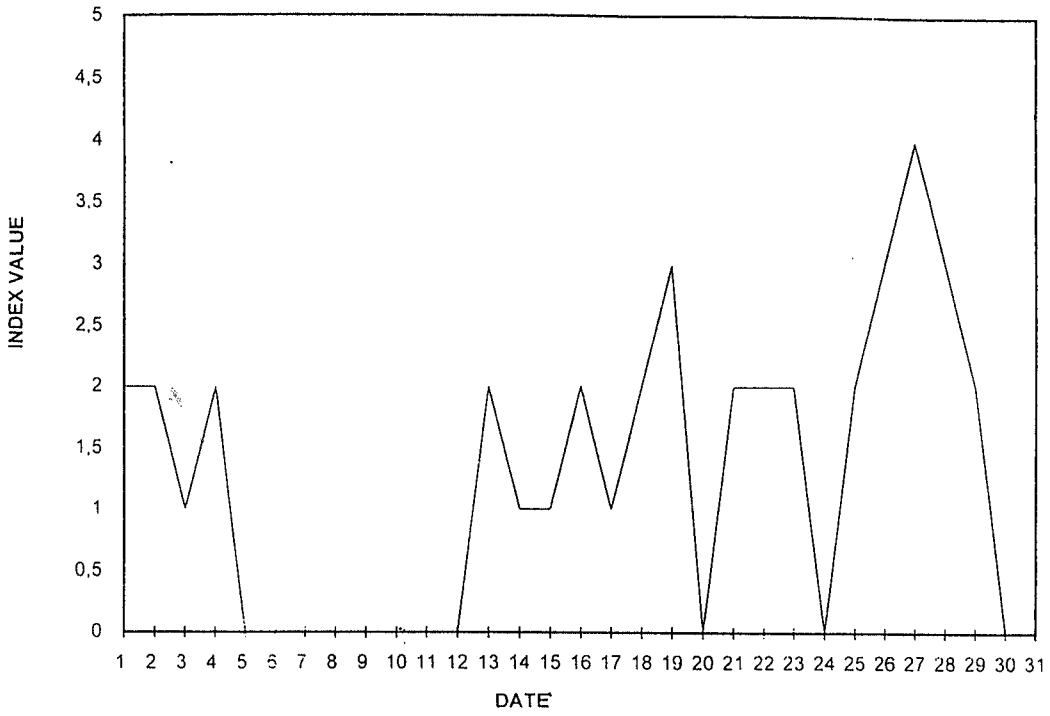

Figure 3. Calculated COST index for December 1994.

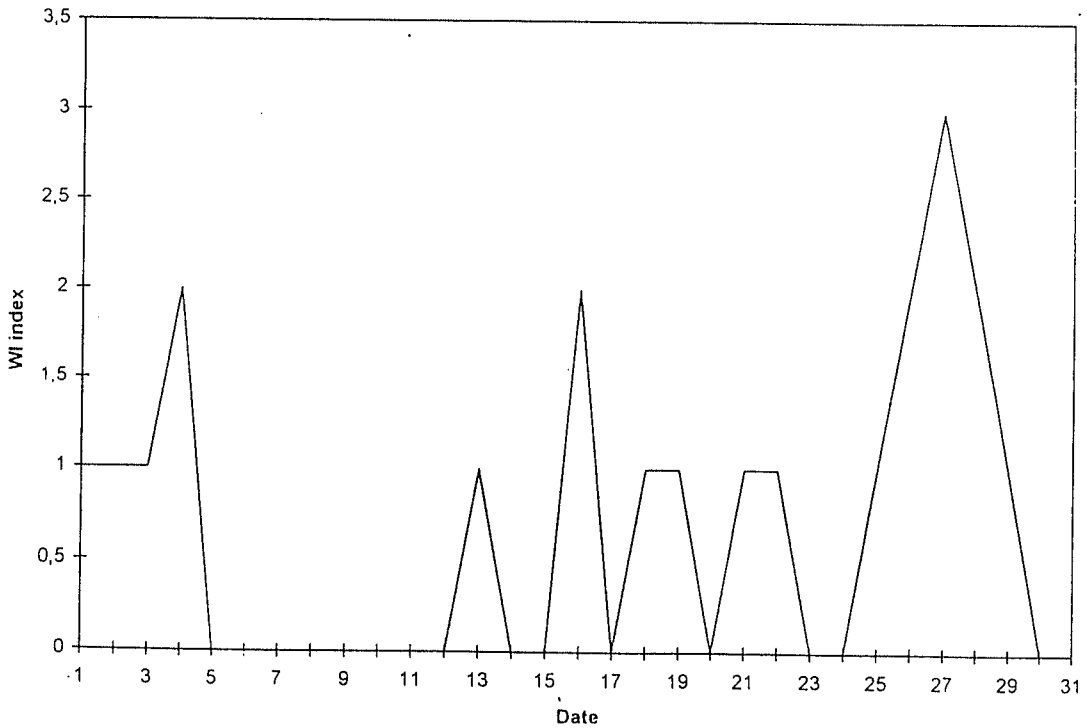

Figure 4. Calculated GAB index for December 1994.

conditions have been recorded. The highest value obtained during December 1994, for this station, was 4 which occurred during the 27th. During this 24 hour period both a rime occasion and a temperature fall was obtained as well as a snowfall exceeding 10 mm. Tree types of slippery conditions were recorded during the same day and together with the value of **a** equal to 1, the index calculation gave a four point value.

5.2 Analysis of the index

The index calculation includes the basic parameters which can give rise to road slipperiness according to the previous discussion. The summation also includes a term which not is directly related to road icing but is a necessary condition. If the surface temperature is not below 0°C, there could not be any formation of rime on the surface nor can any temperature fall be registered. However, the COST equation includes the a term twice, which perhaps may lead to over-representation. This gives furthermore that the index summation is not directly related to the need for maintenance activity as the a-criteria is not enough to call for action by itself.

Another feature of the COST index is that all the parameters are treated similarly, i.e. no weight function is included in the formula. The information from such a summation can be useful as it reveals the number of times that action needs to be taken, if the a dependence is reduced as discussed above. However, the temperature fall parameter needs more input information since not all temperature fall events equate with the need to salt roads.

6 The GAB index

The GAB index sums the same basic parameters as the COST index, namely occasions with snow, frost and black ice. According to the description of different types of road icing, these three types represent the different categories of road slipperiness which are possible to detect by use of a RWIS system. However there are differences from the COST index in the summation relationship (equation 3) as well as in the criteria used to specify the input parameters (snow, rime and black ice) in the formula

$$\mathbf{WI} = \sum \mathbf{A} * \mathbf{snow} + \mathbf{B} * \mathbf{rime} + \mathbf{C} * \mathbf{black\ ice} \qquad (3)$$

Snow - (or rain provided that the surface temperature is below 0°C), can be divided into subgroups depending on the amount of snow. 20 mm is the smallest amount which gives an increase in the index value. **Rime** - number of occasions with risk of rime formation, at least a 2 hour duration with a time interval of at least 4 hours. **Black ice** - number of occasion with temperature fall from plus to minus, the surface is not allowed to dry up which is checked against the humidity of the air and occurrences of precipitation. The temperature drop must be from at least +0.5 to -0.5° C.

6.1 Index calculation

All parameters in the index are given the value 1 if the criteria are fulfilled, otherwise they are 0. The summation is carried out daily and could be given for the whole winter season or a shorter time period if so required. A, B and C are weight functions which can be related to the cost of maintenance activity. In Figure 3 the values for the GAB-index is given for the test period. The index values varies between zero and up to 3. On the 27 th of December one situation with snowfall and two with risk for black ice formation was recorded which in the summation gave the highest value during the test period. A difference between the GAB-index and the other two indices is that rain on a cold surface, with a road surface temperature below 0°C, is included in the summation. This results in the index recording more "snow" events than the other two.

6.2 Analysis of the index

The time interval for rime occasion, as well as for black ice is set to four hours in the definition of the parameters in the index. This is based on studies which show how long salting effects may last on a road. The decline of salt amounts on the road has been shown to be related to weather, state of the road surface, traffic, etc. In theory, four different rime situations may occur in a 24 hour period, and a total of six temperature drops from above to below freezing. The snow criteria relates to the amount of snow and at least 20 mm must be recorded before action must be taken. As a result, the snow-parameter may occur several times during each day. Another aspect with the snow parameter is that snowfall often requires a number of salting and plowing operations to keep the roads free from snow, and therefore this fact must be accounted for in a fully developed index. This can, for example, be achived by giving the snow event a higher ranking compared to the other events.

7 Maintenance activity

The three examined indices were analysed against reports of salting activity. These reports give information about the time when salting was carried out along the road stretch near the RWIS station. Furthermore, the type of situation is noted in the report, i.e. if the salting was carried out due to road icing or snowfall. By comparing the recorded road icing conditions with the salt activity report it is possible to examine how well a winter index matches the maintenance activity. It is also possible to conclude if the indices include all the necessary parameters to describe the severity of a winter with respect to the need for salting etc.

In Table 1 all occasions with a risk of road icing are listed based on the recordings from the RWIS station. The table also includes information about concurrent salting activity. A division into three groups was done: A= a salting was carried out in accordance with the information from the RWIS-station, B= the RWIS-station gave information that a risk of slipperiness but no salting was carried out, and C= salting was carried out despite the RWIS not indicating road icing conditions. From the table it is also possible to conclude that if the summation is carried out on a daily based a higher number of occasions will be recorded compared to the summation being carried out for individual events. For example, if a rime situation starts during the evening and continues until the next day, it will be counted as two separate situations if a daily summation is used. This is made even more complicated if one should take the duration of the effect of salting into account. These aspects are, however, probably best taken care of by addressing how the winter index should be used.

A total of 30 events was recorded during December 1994. During 15 of these (A=50%) salting was carried out. The B-situation occurred during 11 occasions (37%) and the C-situation during 4 (13%). Of the 30 recorded events, 24 were flagged by the RWIS, 2 by synoptic information, 3 could be due to incorrect prognosis of slippery risk and 1 was probably due to snow accumulation on the road during a prolonged snowfall.

Table 1. Slipperiness indication from RWIS versus salting action.

Date	Time	Type of situation	Indication	Action	Comments
1	12	Rime	RWIS	B	
2	16	Temp. fall	RWIS	B	
3	10	Rime	RWIS	B	Short duration
4	01	Rime	RWIS	B	Warming
9	17	-	-	C	
13	03	-	-	C	
14	01	Snow	RWIS	A	
16	07 20	Rime Rain, Rst<0°	RWIS RWIS	A B	
17	01 14 18	Rime Temp. fall Snow	RWIS RWIS Syn	A B A*	
18	05	Rime	RWIS	B	
19	01 05 07	Temp. fall Rime Snow/rain	RWIS RWIS RWIS	B A A	
21	01 20	Snow Temp. fall	syn RWIS	A* A	
22	05	Temp. fall	RWIS	B	
23	05	-	-	C	
25	15	Temp. fall	RWIS	A	
26	04 07 19	Snow Rime -	RWIS RWIS -	A A C	One salting at 05
27	05 06 18	Temp. fall snow Temp. fall	RWIS RWIS RWIS	A A B	One salting at 06
28	03 18	Rime Snow	RWIS RWIS	A B	Rst=0°
29	00	Rime	RWIS	A	Started on 28th

A= salting based on climate information
B= indication of road icing, no salting
C= salting not matched with RWIS-recording