Defining climatic parameters for selecting winter maintenance strategies for roads

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ABSTRACT

The two main strategies for friction control today are salting and gritting, and in the latter years the method of warm wetted sand has been improved substantially. The strategies are usually selected due to the vehicle mileage or the importance of the roads, but very seldom on the local climatic conditions. The aims of the presentation are to show that the climate should be an important factor and to establish climatic parameters that may be helpful in making those decisions. The accident and the road condition recordings assembled by VTI are compared to self-defined climatic parameters, which describe the severity, stability and instability of the winter climate in the regions investigated. The parameters are assumed to describe whether salting or the warm wetted sand method is favourable/unfavourable for friction control. The paper recommends that salting should be avoided in areas and in periods when the frequency of road surface temperatures below -8^0 C exceeds 20 %. In such climates the warm wetted sand method is probably more favourable for friction control. Warm wetted sand is also favourable on roads with traffic less than AADT 2000 and in periods with stable winter conditions, but have minor effects at road surface temperatures above -1^o C.

Keywords: climatic parameters, winter maintenance, salting, gritting and accidents

1. INTRODUCTION

Friction control of winter roads is a major task to assure safety and accessibility to the road users in cold climates. Traditionally, there are two main strategies for friction control in use today, salting and gritting of roads. Salting is mainly used on roads having high traffic volumes and gritting mainly on the secondary road network having less traffic. Both strategies have their advantages and disadvantages due to improvements of the friction, durability of the actions, effectiveness in different climatic conditions and impact on the environment. The aims of the presentation are to establish climatic parameters that may be helpful to make decisions for selecting the strategy for friction control in the winters and further to discuss the efficiency of the different strategies on the safety and accessibility due to the climatic conditions and to present recommendations how to use the climatic parameters in practice.

The analyses presented are mainly based on data assembled for the “The Winter Model Project” carried out by the Swedish Road and Transport Research Institute (VTI) in the years 2001-2005, Wallman (2006) and Wallman et al (2006). The present report is based on further analysis of the data assembled for the Winter Model Project by comparing accident data, operation standards for winter maintenance and climatic conditions in the different regions of Sweden. A more detailed presentation of the analyses is found in Norem (2008)

2. SCANDINAVIAN GUIDELINES FOR FRICTION CONTROL

All Scandinavian countries have established guidelines for defining strategies and methods for assuring acceptable standards for the road conditions in the winter period. An overview of the standards is presented in the report of the EU-project “Roadex,” Norem and Thordarson (2001). Generally, the guidelines and the routines for selecting standards for the winter operations of roads are based on the traffic volumes and the importance of the roads. All countries practice a certain limit for the traffic load to offer regularly use of salt. Usually this limit is within the range of AADT 2000-3000. None of the Scandinavian countries has defined climatic conditions to the guidelines for selecting salting or gritting. However, there is a practice in Finland, Sweden and Norway to avoid use of salt in the coldest areas of the countries.

Roads that are salted are assumed to be free of snow or ice the whole winter, except for periods with heavy snowfalls. The time for establishing sufficient driving conditions after a storm event is dependent on the selected standard for the road service. This lap time is an important part of the standard offered to the road users and is a main factor for the cost of winter maintenance and the consumption of salt.

3. METHODS FOR FRICTION CONTROL OF ROADS

3.1 Salting

Salt is used to avoid the formation of compacted snow and ice on the roads. Use of salt has three aims, either to melt snow and ice on the road, to prevent moisture to freeze on the roads or to take the advantage of the effect of the salt to reduce the bonds between the snow grains. When these bonds are reduced by the salt, it is impossible to compact the snow, and the snow hardly sticks to the road surface. The snow covers then change to a loose snow structure, slush.

The use of salt has important limitations in harsh climates. At temperatures below -8^{o} C it is difficult to keep high enough salt concentrations to avoid formation of ice films, and the Scandinavian guidelines operates with a lower limit for using salt (NaCl) of -6 to -8^{o} C. Spreading of salt in very low temperatures should thus be avoided.

3.2 Gritting and the warm wetted sand method

Sand or crushed rock has traditionally been spread out on ice and compacted snow surfaces to improve the road friction. The effect of dry sand is limited, the improvement of the friction coefficient is usually considered to be 0.05 to 0.1 and the improved friction is lasting for a limited time. On roads with traffic speeds 80 km/h and high percentage of trucks the improved friction will only last for approximately 50 cars, (Vaa 2006).

The last ten years there has been a rapid development of the warm wetted sand method, and the method is in use on a regular basis for the winter maintenance of roads and airfields in Norway, Vaa (2006). The equipment used today are spreaders that may use both salt and sand and the spreaders are equipped with water tanks that make it possible to heat the water to 95^{o} C and the hot water is mixed with the sand at the spreading disc. Best results have been documented by having water temperatures above 90^{o} C, water content of 30 % in weight and sand having relatively high contents of fines

The warm wetted sand method need to have road surface temperatures below 0^{o} C to have the sand grains to freeze to the ice or the compacted snow. When the climatic conditions are preferably, the effect of the gritting has been recorded up to one week with an AADT exceeding 1000, Vaa (2006). In those cases, there has been used 200 g/ m^{2} sand, and the road surface temperatures have been well below 0^{o} C and no precipitation.

Warm wetted sand may be used during light snowfalls, up to snow falling intensities of approximately 0.5 mm WE/h. For snow fall intensities up to that limit the turbulence generated by the traffic is shown by Wallman et al (2006) to remove most of the snow. For higher intensities a snow cover will be allowed to form and no friction control will be made during the snow fall. Special attention has to be made to road surface temperatures between 0^{o} and -1^{o} C, as the warm wetted sand method offer no better efficiency than dry sand in such weather situations.

When comparing the weather situations favourable for salting and the warm wetted sand method one will see that both methods have a well documented effect on the cold weather situations that are most frequent in the winters, road surface temperatures between -1 and -8^{o} C and no or only light falling snow. Warm wetted sand is probably the only method that works well for temperatures below -8^{o} C, and is thus most favourable in areas with very low winter temperatures. Snow/ice layers having temperatures between 0 and -1^{o} C are relatively frequent in some areas, and salt spread out to assure that the ice on the roads is melted, is today the only practical method to obtain the necessary friction at road surface temperatures close to 0^{o} C.

4. CLIMATIC PARAMETERS FOR SELECTING FRICTION CONTROL STRATEGIES

4.1 Requirements for the climatic parameters

To perform analyses for studying the effects of the climate on the efficiency, durability and safety of the different friction control methods there is necessary to define parameters that characterize the climatic conditions in a proper way. Ideally, the parameters should fulfil several needs and be useful to:

- Analyse the effects on both accidents, friction and accessibility
- Estimate the number of hours the winter maintenance standard will be below the required standards
- Estimate the number of actions and the consumption of salt or sand needed to fulfil the required level

- Cover a wide range of climatic types

The climatic parameters developed should preferable include all meteorological parameters that are important for selecting the strategies for the winter operation of roads. However, the further analyses are mainly based on analyses of the road surface temperature, and to a lesser degree on snow precipitation. The other parameters like wind, moisture and probability for freezing rain are not included.

4.2 Definition of the climatic parameters

The self-defined parameters are assumed to describe the climatic conditions that are favourable/non-favourable for use of salt or warm wetted sand in accordance with the assumptions presented in chapter 3. The parameter values are mainly presented on a monthly basis, but are both independent of the periodic length and they are dimensionless. The parameters are supposed to describe the severity, the stability and the instability of the winters at each location studied:

- Winter Severity Index,
- Winter Stability Index,
- Winter Instability Index,

Winter Severity Index, W_{sev}

The Winter Severity Index is the number of hours with recorded road surface temperatures below -8^0 C divided by the total hours in the period investigated. For instance, W_{sev} =0.1 means that 10 % of the recordings are below -8^0 C. W_{sev} tells the ratio of time when salting with NaCl is no alternative for friction control, if slippery roads develop.

Winter Stability Index, W_{stab}

The Winter Stability Index, W_{stab}, describes the frequency of periods favourable for use of the warm wetted sand method. A period favourable for warm wetted sand is defined as a period lasting for 24 hours where the road surface temperatures in the whole period have been below -1^o C and the precipitation is less than 3 mm within a six hours period. The Winter Stability Index is then defined as the ratio of the number of favourable 24 hour periods divided by the numbers of days. W_{stab} = 1 means that all road surface temperatures in the given period is below -1^o C and there is only light snowfalls.

The calculation of the Winter Stability Index is explained in more detail by Fig 1. The first 15 hours the road surface temperatures have been below -1^o C and the accumulated precipitation is less than 3 mm WE in a six hour period. During the next period the road surface temperature has been below -1^o C all time, but the precipitation exceeded 3 mm WE within a 4 hours precipitation period and 8 hours after the start of the cold period.

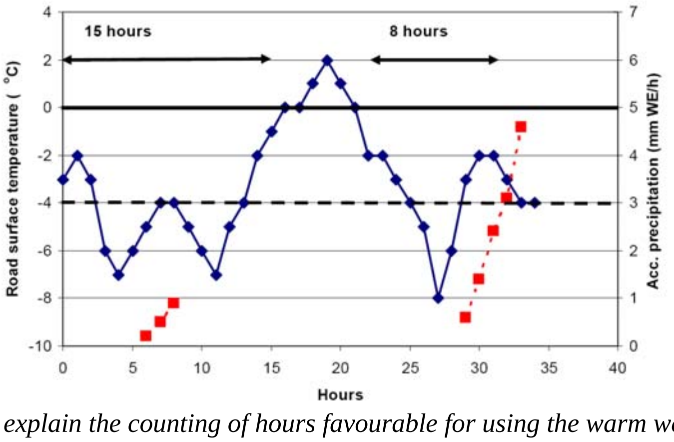

Figure 1. Figure to explain the counting of hours favourable for using the warm wetted sand method.

Winter Instability Index, W_{inst}

The Winter Instability Index, W_{inst}, is defined as the number of fluctuations around 0^o C divided by the number of days. For instance, if the road surface temperatures every day have one period with temperatures above 0^o C and one period below 0^o C, W_{inst} will be equal 2. When W_{inst} is 0, the road surface temperatures might have been either above or below 0^o C the whole period. W_{inst} thus does not describe if it has been a warm or cold period, but only the frequency of fluctuations around 0^o C.

4.3 Characteristic climates defined by the parameters

To give a better understanding of what kind of climates that belongs to the different combinations of the winter indexes some characteristic climates is presented in a diagram with the Winter Stability and the Instability Indexes as the two axes, Fig 2.

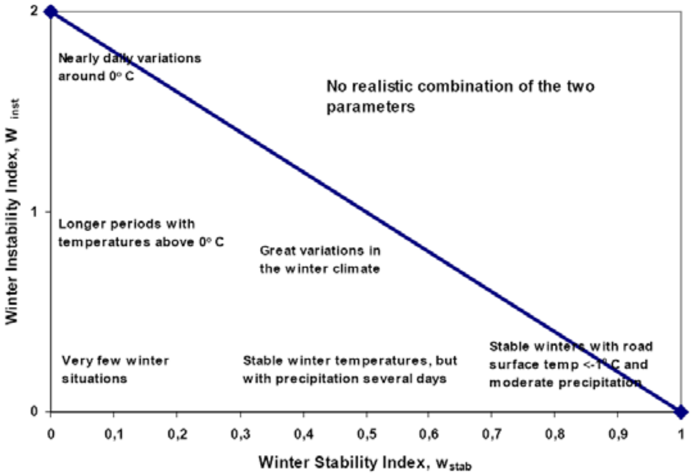

Figure 2. Characteristic climatic types presented in a diagram having the Winter Stability and the Winter Instability Indexes as axes.

The diagram in Fig. 6 needs a further explanation:

1 The three corners represent the following extremes of the climate.
- W_{inst}=0 and W_{stab}=0, represents climates where the road surface temperatures are always higher than 0^o C, and there are thus no winter situations
- W_{inst}=0 and W_{stab}=1; represents climates where the road surface temperatures are always below -1^o C, and the snow precipitation rates are never higher than 3 mm WE within 6 hrs.
- W_{inst}=2 and W_{stab}=0; represents climates where the average road surface temperatures fluctuate around 0^o C every day, and for such situations the Stability Index needs to be zero

2. Any combinations of the two parameters in the upper, right part of the diagram represent unrealistic combinations as the two parameters cannot both have high values.
3. A move along the X-axis from W_{stab}=1 towards the origin represents stable low temperatures, but with increasing frequency of snow precipitation
4. A move along the Y-axis from W_{inst}=0 to W_{inst}=2 represents mild winter conditions but with increasing frequency of frost at night.

5. GEOGRAPHICAL VARIATIONS OF THE PARAMETER VALUES

5.1 Assembling climatic data

The recordings of accidents and road surface conditions assembled for the “Winter Model” were grouped into four climatic regions, Fig. 3:

- Southern Sweden (SS); situated along the coast in Southern Sweden and characterized by fairly mild and short winters, and temperatures are often varying between +/- 0^o C in the midwinter.
- Central Sweden (CS); consisting of the inland part of southern Sweden. The area is characterized by modest precipitation and the winter temperatures are usually below 0^o C in the midwinter.
- Lower Northern Sweden (LNS); which is found approximately between 60 and 63^o northern latitude. The area has normally stable winters with modest precipitation and temperatures well below 0^o C in the mid-winter.
- Upper Northern Sweden (UNS); which cover the far northern part of Sweden. The area has usually very cold winters, and the precipitation in the winters is low.

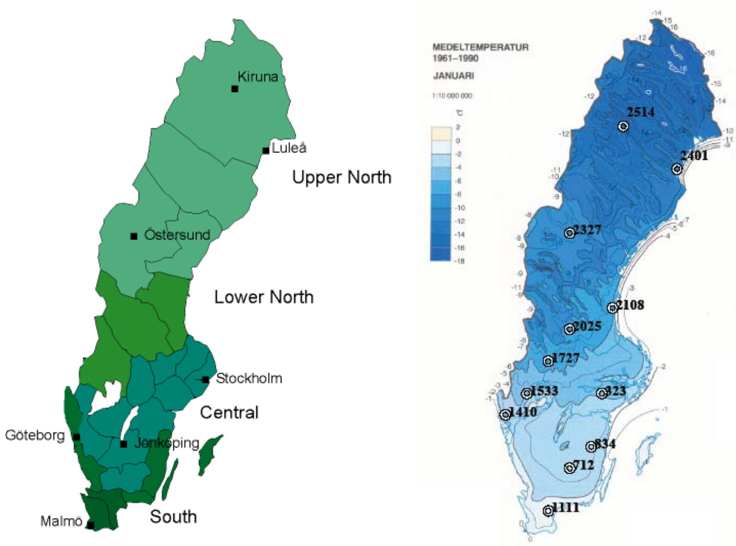

Figure 3. Maps of Sweden showing the subdivision of the country into four climatic regions, (left) and the average temperatures in January, (right). The location of the RWIS stations used for the analysis is presented in the right figure. (Raab and Vedin 1995)

In order to characterise the average of the climate in the four different climatic regions, recordings from three different Road Weather Information Stations (RWIS) in each climatic region and for four years has been assembled. The recordings used for the analysis were road surface temperatures and precipitation intensity and type. The locations of the stations are shown in the right hand figure in Fig. 3. The figure is made for the National Atlas of Sweden, Raab and Vedin (1995) and presents the variation of the average temperature in January in Sweden. The figure shows that the average temperature in January is close to 0^{o} C along the coast in Southern Sweden and -2 to -4^{0} C in the region that has been defined as Central Sweden. In Upper Northern Sweden the respective numbers are -8 to -16^{0} C.

5.2 Winter Severity and Stability Indexes

The variation of the Winter Severity Index and the Winter Stability Index, W_{stab}, for the winter months and the regions are presented in fig 4. The left hand figure shows that the values of the severity index are relatively small for the three southern regions compared to the northernmost region. The highest values for the three southern regions are found in January, varying from 0.12 in Southern Sweden to 0.18 in Lower Northern Sweden compared to Upper Northern Sweden with 0.53. There is thus a dramatic climatic difference between Lower and Upper Northern Sweden concerning winter temperatures.

The values for the Winter Stability Index, W_{stab} also increase from south to north for every winter months, right hand figure. The highest number for the stability index is 0.71 in January in Upper Northern Sweden. That value is probably close to a practical upper limit for W_{stab}, since in the stable cold climates there will always be some days with snow precipitation exceeding 3 mm WE in 6 hours.

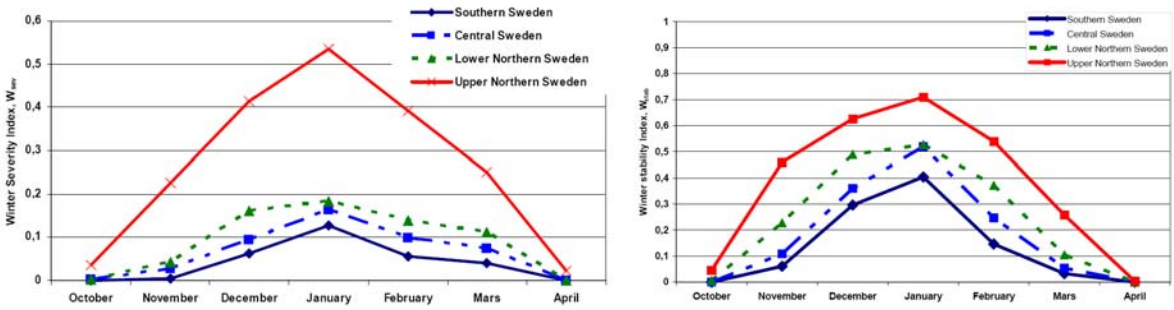

Figure 4. Calculated Winter Severity Indexes(left) and Winter Stability Indexes (right) for the winter months and the climatic regions. The calculations are based on RWIS-stations for the winters 2002/03-2005/06.

5.3 Winter Instability Indexes

The Winter Instability Index defines how often the road surface temperature varies around 0^o C. The calculated values of W_{inst} are presented in fig 5. In Southern Sweden, W_{inst} is almost constant in November to January and has a maximum in February, 1.4, which means that there is a variation between + and – degrees in average 70 % of the days in February. The Winter Instability Index for Central and Lower Sweden has its lowest values in January and the maximum in March. The highest value for both regions is 1.55. The Winter Instability Index for Upper Northern Sweden deviates considerably from the other three regions. The highest values are found in the start and the end of the winter, and it is as low as 0.01 in January, which means that the road surface temperatures are hardly above the freezing point in January.

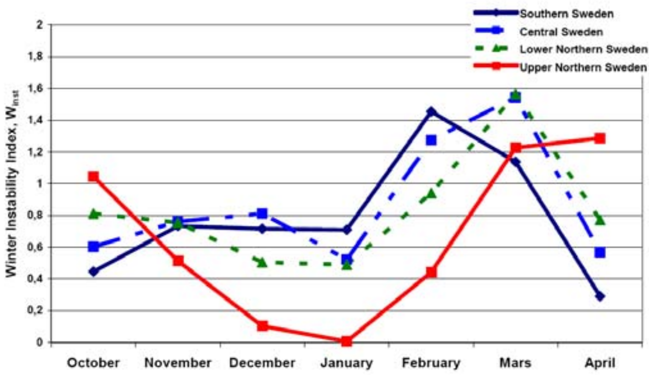

Figure 5. Winter Instability Index for the winter months and the climatic regions. The calculations are based on RWIS-stations for the winters 2002/03-2005/06.

The average Winter Instability Indexes for the seven winter months for the four regions from south to north are 0.77, 0.75, 0.87 and 0.69. There are thus only small variations of the total number of fluctuations around 0^o C. However, on a monthly basis the Instability Index is a good indicator to characterize the climatic conditions.

6. ACCIDENTS VERSUS WINTER MAINTENANCE STANDARD AND CLIMATIC CONDITIONS

6.1 Assembling accident data

The basis for the data used in the present analyses is a comprehensive assembling of data for the winters 1993/94 to 96/97. The data included both all police recorded accidents on the state roads in Sweden in that period and data of road surface conditions recorded by the road authorities. The total number of accidents is 3271. The accident data are broken into:

- Types of accidents and severity of the accidents.
- Road conditions at the time of the accidents.
- Vehicle mileage on the different road conditions
- Maintenance standard for the roads.
- Climate zones.

The present analyses are only based on accidents causing fatalities and severely injuries since the quality of the data for the severe accidents are supposed to be higher than accidents with less consequences. The road conditions were originally classified in five categories, but to simplify the analyses only two groups of road conditions are specified, bare roads and snow/ice covered roads.

6.2. Analyses of the accident data

The accident analyses are made separately for the four climatic regions, and the winter maintenance standards are grouped in three, A1+A2 and A3+A4, which require salting and B1+B2, which is based on gritting. The accident rates are then calculated for each climatic region and maintenance class and for the five different types of road surface conditions. The calculation for one climatic region and one standard class may generally be presented as shown in fig. 6:

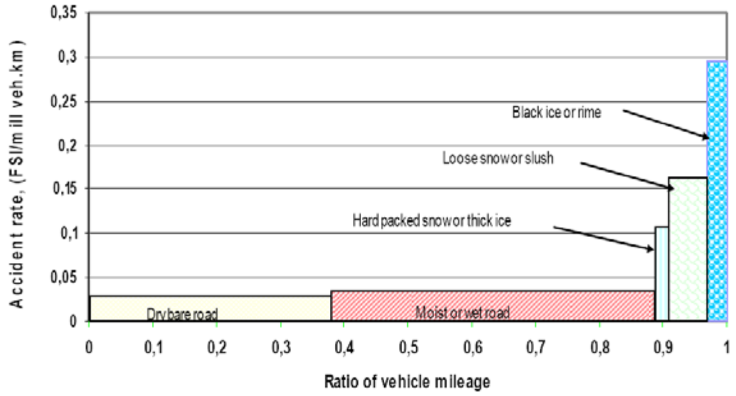

Figure 6. Representative figure for presenting ratios of vehicle mileage and the accident rates on specified road conditions. The example is for A3+A4 roads in Central Sweden.

Fig. 6 may be considered to be representative for the calculated accidents rates for the salted roads. Generally the vehicle mileage on bare road surfaces is 75-96 % of the total volume and the accident rates on bare roads are much lower compared to driving on snow or ice covered surfaces. Usually the accident rates are highest for driving on thin ice surfaces and a little less for loose snow or slush. Packed snow or thick ice has the lowest accident rates of the snow/ice covered surfaces. The accident rates shown in Fig 2 represent the probability for a driver to be involved in an accident in certain conditions. One should have in mind that the number of accidents on a road is the product of the accident rate and the vehicle mileage. To reduce the number of accidents one should preferably reduce both the accident rate for the different surface conditions and the ratio of the vehicle mileage for driving on conditions having the highest accident rates.

The number of accidents related to driving on snow and ice, given a vehicle mileage of one million vehicle kilometre, has been calculated and the results are presented in Figure 7. For the three southern regions the salted roads has the lowest number of accidents, and there seems to be a positive effect of the higher standard classes A1 and A2. The results from Upper Northern Sweden are quite opposite. The number of accidents is almost twice as high compared to the unsalted roads. This is probably a result of the high amounts of temperatures below -8^{o} C found in Upper Northern Sweden, and at which conditions salt may be to more harm than doing nothing.

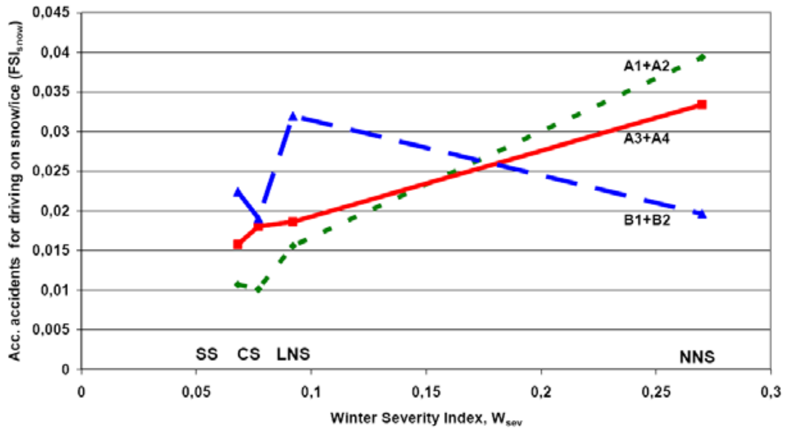

Figure 7. Number of accidents related to driving on snow and ice covered roads specified for winter maintenance standard classes, climatic regions and average hours with temperatures below -8^{o} C for each region, W_{sev}.

The accident rates for driving on snow/ice covered roads are dependent on the ratio of vehicle mileage and are increasing for lower ratios. The accident ratio for snow/ice to bare roads is as high as 8-10 % for vehicle ratios of approximately 0,05 and 2-3 for ratios exceeding 0,5. For instance is 30-40 % of the accidents recorded on the A1+A2 roads in Southern and Central Sweden occurring on the 4 % of the time the roads have been covered by snow or ice.

The data material makes it possible to calculate the total number of accidents as a function of the ratio of vehicle mileage on snow and ice (Norem 2008). The calculations indicate that there is a maximum in accidents for vehicle mileage ratios on snow and ice between 0.2 and 0.4, Fig. 8. If these indications are correct one should preferably introduce salting if the ratio of snow and ice on unsalted roads are 0,3-0,5 and the use of salt may reduce the ratio to less than 0.2. On the other hand, by introducing salt in climatic areas having ratios exceeding 0.5 and ending up with ratios close to 0.2-0.3 would probably increase the number of accidents.

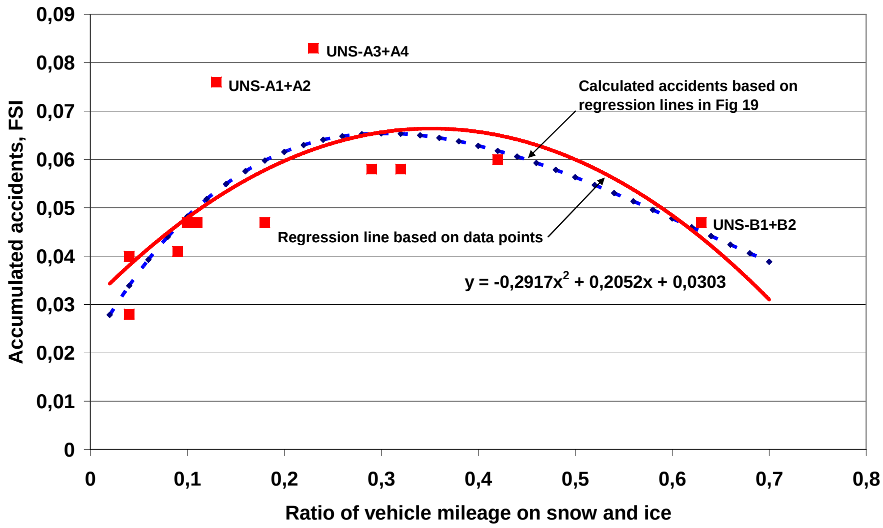

Figure 8. Regression line presenting number of fatalities and severely injuries as a function of the ratio of vehicle mileage of snow/ice covered roads. The dots represent data for different maintenance classes and climatic regions.

7. RECOMMENDATIONS FOR SELECTING STRATEGIES FOR WINTER MAINTENANCE

7.1 Climatic limits for salting of roads

Fig.7 indicates that the number of accidents for the salted road network increase with a factor of 2-3 from Lower to Upper Northern Sweden. Upper Northern Sweden is the only area having W_{sev} indexes exceeding 0.2 in any month. The highest recorded value for Lower Northern Sweden in January is 0,18, while the respective numbers for Upper Northern Sweden from November to Mars are 0,23, 0,41, 0,53, 0,39 and 0,25 respectively, Fig 4.

It is thus assumed that salt should be used with great caution in periods where W_{sev} is exceeding 0,2 in the winter months. In practice this means that salt has no effect in 20 % of the period. In such areas the winter stability is usually very high and the warm wetted sand method represents a reasonable alternative to salt as a strategy for friction control.

3.1 Climatic limits for the warm wetted sand method

The recommendations for the feasibility of the warm-wetted sand method are presented in a W_{stab}-W_{inst} diagram, Fig.9.

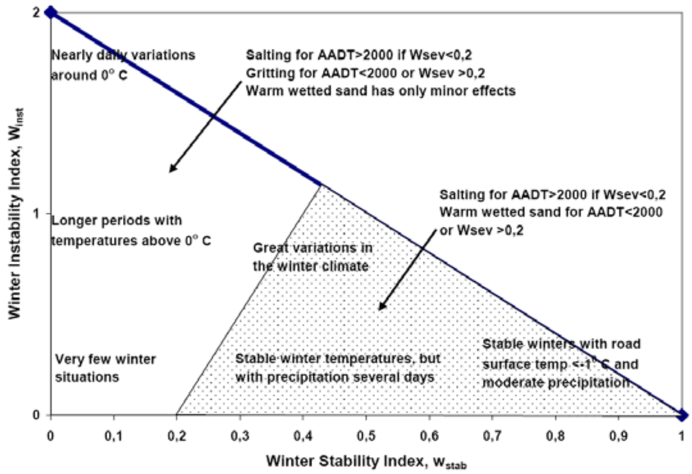

Figure 9. Recommendations for selecting winter maintenance strategies based on the climatic winter indexes.

The recommendations presented in Fig 9 are based on the following assumptions:

- Warm wetted sand is preferable when the probability for favourable conditions the next 24 hours is high. However, the extra cost of using the warm wetted sand method is not very high. Fairly low values for the probability to loose the effect of the warm wetted method due to climatic variations may thus be accepted
- The lower limit for the Winter Stability Index has been set to 0.2 when the Winter Instability Index is close to 0. Such climates are characterized with cold weather and snow falling frequently. The consumption of salt in such climates needs to be high, and one may justify using the warm wetted sand method even if the lasting effect is low.
- The maximum value for the Winter Instability Index for using warm wetted sand has been set to 1.2, which indicates that there are fluctuations around 0^o C 60 % of the days. The highest theoretical value for W_{stab} is 0.4 when W_{inst}=1.2. Climates represented by such values are characterized by warm days and cold nights and with few days with precipitation. This should indicate bare roads that might have thin ice during the nights. The warm wetted sand method has limited effect in such conditions, which should favour salting for higher values of W_{inst}.

The proposed recommendations for the climatic limits for using warm wetted sand should be open for discussion, and adjustments have to be made when more experience is gained with this method.

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