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UNITED STATES-SWEDEN-CANADA JOINT PROGRAM ON WINTER MAINTENANCE,
PART 1
(Par 2, Session 104)
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Winter Maintenance Policies, Lars Bergfalk, National Swedish Road Administration

Materials, Equipment, and Procedures for Deicing, Kent Gustafson, Swedish Road and Traffic Research Institute

Snowplow Design, Ingemar Olofsson, Sweroad/National Swedish Road Administration

Weather Information Systems, Ingemar Olofsson

Experiment with Unsalted Roads, Gudrun Oberg, Swedish Road and Traffic Research Institute
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Materials, Equipment, and Procedures for Deicing,
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1. Introduction

Winter maintenance is one of the most important tasks for the road administrators in Sweden and the other Scandinavian countries due to the severe climate in winter time. The demands from society are high regarding traffic safety and traffic flow day and night all the year and necessitate effective snow and ice control measures. Highway snow and ice control in Sweden differs to some extent between different parts of the long stretched country owing to variations in a.o. climate and traffic. A common policy is although to have a bare pavement on the more heavily used road networks. This is accomplished by chemical deicing with NaCl. The use of salt is a very discussed matter due to the negative effects. Salt increases the speed of corrosion and a Swedish calculation estimate the car corrosion to be appr SEK 5-6 thousand millions per year and appr. SEK 1-2 thousand millions are due to salt spread in winter maintenance. This corresponds to appr. 5-10 times the cost of the chemical deicing. Salt also has an effect on concrete bridges and the environment. The relationship between chemical deicing and traffic safety has been investigated but is still uncertain and sometimes questioned. Studies with the aim of clarifying this relationship are in progress in Sweden.

Because of the side effects from salting efforts are made by the road keepers to reduce the use of salt. In my presentation I will describe the prewet method and mention trials with spreading of brine that are in progress. Tests with prewetted salt have shown to be effective and the method is successively introduced in winter maintenance practices.

Another way of reducing the use of NaCl could be the use of an alternative which is effective and economic but doesn't have any adverse effects. Some results from the studies with CMA, Calcium Magnesium Acetate will be described.

Highway snow and ice control by road surface means has been tested by studying the susceptibility to icing of various pavements and the influence of the wearing course on deicing measures. A special interest has been shown to RUBIT, rubber asphalt and Verglimit, asphalt mixed with saltpellets and their effect on the skid resistance in winter. Tests in progress will be presented.
2. Winter maintenance procedures

Winter maintenance measures can be divided into the following categories: snow removal, chemical deicing with salt and mechanical deicing with sand or with graders and scrapers.

**Snow removal:**

Start criteria, snow depth in cm, and performance time, in hours, are set out depending on road class. There is some tolerance in the starting criteria depending on traffic, type of snow and snow plough plans. The main goal is however that the roads should be trafficable to vehicles with normal winter driving equipment. In very extreme weather situations this cannot be fulfilled, but it's very seldom that roads or road sections must be closed because of safety reasons. The start criteria varies between 3 cm of snow on priority 1 roads and 8 cm on the low priority roads. The performance time varies between 2 and 7 hours.

The snow removal of pedestrian and bicycle paths has got more attention the last years because a.o the fact that a lot of accidents happen on these paths by slipping, tripping or collisions. The paths are maintained with respect to traffic safety and driving conditions to the unprotected road users. The standard is said to be such that cyclists and pedestrians would not be tempted to use the road-way.

**Chemical deicing:**

The chemical deicing means spreading of salt, NaCl. Salt is used for spreading on the heavily trafficked roads and to mix into sand for the low volume roads. The salt is to prevent the sand from freezing and to make the material adhere better to the road. The Swedish National Road Administration is responsible for the winter maintenance of about 100,000 km of roads, which are principally divided into the following categories.

<table>
<thead>
<tr>
<th>Road class</th>
<th>Traffic volume ADT (km)</th>
<th>Total roadlength (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-salt</td>
<td>1500-</td>
<td>18700</td>
</tr>
<tr>
<td>B-salt</td>
<td>800-1500</td>
<td>11000</td>
</tr>
<tr>
<td>Sand</td>
<td>0-800</td>
<td>67300</td>
</tr>
</tbody>
</table>

On the high volume roads, with an ADT (Average Daily Traffic) of more than 1500 vehicles and called A-salt roads, the aim is to have a bare pavement. This is accomplished by chemical deicing with salt. In the standard criteria's time of action and total time (between ice formation and finished deicing measure) are set out. Roads with ADT between 800 and 1500
vehicles are salted only during the initial period with icy conditions in the autumn when conditions are unexpected to the drivers. Later during the winter, with more stable weather conditions, ice control is performed only with mechanical deicing. Roads with an ADT of less than 800 vehicles receive only mechanical deicing.

Salt is used mainly for preventive actions which means the prevention of ice formation and the bonding between snow and ice and the surface. The importance of working preventive, as early as possible in connection with snow fall or ice formation, is pointed out. This requires only small salt application rates and these varies between 5 and 25 g/m². The melting action is minor and removal of snow and slush by ploughing is therefore necessary. Salt is used in the temperature range 0 - -6°C. Prewetted salt is used to somewhat lower temperatures. NaCl is used almost exclusively.

All the spreaders are with spinner plate and normal spreading widths are between 4 and 8 meter. The last winters the use of pre-wetted salt has increased and this has led to new spreaders and equipment. The method is described in more detail later on in the presentation.

The total use of salt on the state roads in Sweden is appr. 150,000 tons per winter. The consumption of salt in the municipalities was of the same order a few years ago. However, depending on a.o the salt debate many cities have during the last winters changed their winter maintenance practices to the use of more mechanical deicing with sand treatment. The consumption of salt is therefore only about a third of what it used to be, or appr. 50000 tons per winter.

Mechanical deicing:

Mechanical deicing involves spreading of abrasives, in most cases sand. Sand spreading is carried out in order to achieve a relatively rapid improvement in skid resistance. Sanding is used primarily on the low volume roads but the use in cities etc has also increased as stated above.

The particle size of the sand is recommended to be between 0.25-4 mm and with a maximum of 8 mm. The sand is normally mixed with salt in the proportion 50 kg salt per m³ of sand.

The use of alternative abrasive materials has increased the last winters. The reason for this is efforts to minimize the use of salt and shortage of natural gravel and sand. Crushed stone aggregate is commonly used and normal particle sizes are 3-6 mm or 4-8 mm. Many cities has changed to using crushed material totally or on parts of their street network, esp. on pedestrian and bicycle paths. The crushed material without fine particles (dust) does not need the mixing with salt and the spreading makes streets etc less dirty. Some-
times there has been some complaints about damaged wind shields but this has mostly been actual when coarse particles, 8 mm or more, have been spread on roads with higher speed limits.

Trials with other abrasives are also carried out. A lime stone product, porous and containing quartz (SiO$_2$) and lime (CaO), has been tested, both for direct spreading instead of sand and mixed with sand as a replacement for salt. Other tested abrasives are crushed lime stone and slag, but none of the materials mentioned have so far been used to any larger extent.

3. Prewetted salt and spreading of brine

To start melting snow and ice salt must be in solution. When spreading dry salt, a certain time always elapses before the salt begins to act on the road surface, since a salt solution must first be formed. This time can be reduced by adding the moisture before spreading takes place. The moisture added to the salt may be water alone or a suitable chemical solution such as NaCl or CaCl$_2$ solution. The dry salt is prewetted so that a thin film of solution covers the particles and the melting effect starts very rapidly. When spreading dry salt a relatively large part is scattered or blown off the road by traffic before it has had time to act.

By prewetting the salt adhesion to the road surface is improved and only a small part blows away. Prewetting also makes the spreading pattern more homogenous. A smaller quantity of prewetted salt can be spread to achieve the same level of maintenance as with dry salt. The method of prewetted salt were tested in Sweden for four winters in the beginning of the 80’ies, and it’s now widely used.

Prewetting of the salt can principally be carried out in two ways. The solution can be sprayed on top of the salt in connection with loading the truck. The other way, and the way used in Sweden is to prewet during saltspreading. The salt-spreader are generally made of:

- a conventional spreader with its distribution system;
- one or two tanks, glassfiber or metal, usually about 2m$^3$ for the storage of the brine and with a prewetting system (nozzles, pump, electronic equipment). (Figure 1)

Depending on the various models, the prewetting of the salt can be performed:

- on screw-machines, in the exit tunnel of the screw or on the spinner plate
- on belt-machines, either along the belt or at the end of the belt.
The spreaders give a homogenous mixture and more or less sophisticated electronic equipment ensures that the proportion of solution to dry salt is maintained at the correct level. Common is 20-30% of brine to the dry weight and at the same time a reduction of the dry salt by 30%. This means an actual reduction, saving on salt with about 20%.

The equipment for mixing the brine varies and all the range from very simple and inexpensive equipment to very much advanced, costsome and fully automatic mixing constructions have been developed. For road purposes NaCl- and CaCl₂-solution has been tested, but today NaCl is used almost exclusively. In the tests little or no noticeable difference with regard to effectiveness was found between the two solutions in the temperature range (0 - -6°C) where salting is performed. This together with the fact that CaCl₂ has a chemical effect on cement concrete has made the use of CaCl₂ very restricted.

The trials showed that a reduction in salt could be made with wet salt spreading and at the same time having the same or better effect of the salt. The spreaders used had an automatic reduction of dry salt by 30% by weight. Since a great part of the solution is water the actual reduction of salt is about 20%. During the trials the effectiveness of the method was followed by measurements of the skid resistance. In many cases a more rapid melting effect and faster increase in skid resistance could be monitored on sections with prewetted salt. This was especially pronounced on "hard" surface conditions such as hoarfrost and black ice. However also during snowy conditions the prewetted salt was found to work as good as or even better than the dry salt.

The experiences from the use of prewetted salt have shown these advantages and disadvantages.

**Advantages**

- Prewetted salt adhere better to the road surface which means a more homogeneous spreading pattern and less wastage outside the road.

- Faster melting reaction.

- Can be used at somewhat lower temperatures, with NaCl-solution down to app. -10°C.

- Prewetted salt create better conditions for preventive applications.

- Less salt can be spread to maintain the desired road standard which will mean less negative effects from the chemical use.

- The salting can be performed at higher speed.
Disadvantages

- More investments in spreaders and equipment for making the brine.

- The equipment is more complex.

One obstacle for the introduction of the prewet method into winter maintenance production has been the cost of investments, esp. for the brine mixing equipment. This has among other things led to a search for an inexpensive and more simple method of prewetting. During last winter a method of this kind was tested on a small scale. The prewetting was performed with water, about 5% to the dry salt, by spraying it over the salt load with a hand held simple spreader. The sprayer has a water meter to ensure the right amount of water. In order to have all the salt wetted it was found that only about 2 m³ of salt could be used and this is of course a major limitation. The simple method was used almost exclusively in connection with preventive actions and with small application rates.

Spreading of salt in liquid form has been used in some European countries, i.e. Italy and France, for many years but not to any larger extent depending on the limitations of the method. Since last winter liquid spreading is also tested in Sweden. During the winter 1987/88 two maintenance areas tested liquid spreaders and this winter five more areas participate in the tests. The spreaders are "cistern-trucks", which are equipped with a spraying system under low pressure and fed by a pump for the liquid chemical. Two types of spreaders are in use. One type is with a spray bar and a number of nozzles and the other is with spinner plates.

Only NaCl brine is used for spreading and the method is primarily used for preventive actions but is also used more generally. The application rates are about the same as with spreading of dry salt, which means a reduction in the amount of salt spread. The purpose of the test the first winter was to investigate if the method was applicable to Swedish conditions, which are in many cases more severe than in the middle and south of Europe. The result was promising and positive reactions as - less salt consumption - higher spreading speed and - better long term effect were noted.

The test with spreading of NaCl brine continues this winter and the investigations will try to give answers to:

- In what road way conditions could the method be used?

- The risk of refreezing?

- Application rates?
Driving speed of spreading trucks?

etc.

4. Alternatives to sodium chloride

The negative effects from road salt have led to intensive efforts being made to find alternative chemicals which are non-corrosive or non-damaging to the environment while being suitable for winter road maintenance from cost and efficiency aspect. The list of chemicals tested can be made very long but there are only very few ones that have been used to any extent.

Calcium chloride, \( CaCl_2 \), has earlier been used, esp. at lower temperatures, but the use is now very restricted. In summertime although \( CaCl_2 \) is still in use for dust prevention on gravel roads, \( CaCl_2 \) can be effective at lower temperatures and it melts snow and ice more rapidly than road salt, but the side effects are as serious or even worse than for sodium chloride. It's hygroscopic, which tends to keep the road surface wet longer, corrosive and affects the environment negative. The principal reasons for not using \( CaCl_2 \) is however the higher direct cost and the negative impact on concrete structures. Urea, \( CO(NH_2)_2 \), are used on airports because it’s less corrosive than sodium chloride, but it has no use on roads. The use of Urea on airports are however today widely questioned because of the environmental effect from it. Urea has been tested on roads, although only on very short sections, such as bridges, as early as in the 1960’s. It was found that urea is less effective than road salt, it could in practice only be used at temperatures above about \(-3^\circ C\) and it requires twice as much urea as sodium chloride for the same deicing effect.

The most recent and thorough study of alternatives, made in USA in the late 1970’s, identified calcium magnesium acetate (CMA) as a potential deicer for roads and airports. In Sweden and at VTI CMA has been tested intensively for some years. CMA obtained from acetic acid and dolomitic limestone has been investigated primarily in laboratory but a field test with 50 tons has also been carried out.

The investigations carried out so far in Sweden is:

1) Deicing effect in laboratory.
2) Corrosion to steel, aluminium and magnesium.
3) Effect on cement concrete.
4) Field test.
Deicing effect of CMA

The freezing point depression of CMA varies between app. -10°C and -28°C depending a.o. on the Ca/Mg ratio, compared to -21,1°C for NaCl. The melting effect however varies less depending on the ratio and more on the grain size, density, hydration etc. Pelletized CMA has in the tests shown to be less effective than road salt but compared to urea its melting capacity is better. In general CMA can be used in the same temperature range as road salt but it doesn’t melt ice and snow as rapidly. (See figure 2).

Corrosion to steel, aluminium and magnesium

Corrosion tests with CMA on car body steel showed that CMA is much less corrosive than NaCl and CaCl₂, see figure 3. The weight loss on steel plates, which were covered with a mix of mud and the deicer for 100 days where after the test period considerable less for CMA compared to the other deicing chemicals in the test. Immersion test with aluminium plates also showed promising results for CMA, which were less corroding than NaCl, CaCl₂ and urea. The difference in speed of corrosion was however not so marked as with steel.

The corroding effect of CMA on magnesium alloy plates has also been tested, while magnesium alloy sometimes can be used in aircrafts. The immersion test compared CMA with Urea and showed that CMA was the most corrosive of the two deicers. The result indicate that to avoid the corrosive effect some kind of surface treatment of the magnesium metal must be accomplished or a corrosion inhibitor be mixed with the CMA.

Effect on cement concrete

The effect of CMA on cement concrete has been investigated in some different ways. Standard freeze/thaw tests, an immersion test to see the chemical effect, both in laboratory, and a more practical field test have been carried out.

The freeze/thaw test comprised CMA solution of different concentrations 3-25 % by weight, NaCl, CaCl₂ and MgCl₂ all 3 % by weight in concentration. The result is summerized in figure 4. The trends for the chloride salts, which were only tested for one concentration, have been drawn from the report by Verbeck & Klieger, 1957. According to the tests chloride salts, esp. NaCl and CaCl₂, have a marked peak in scaling by app. 3 % concentration. The scaling effect then decreases for sodium chloride while it increases very much for calcium and magnesium chloride with higher concentration. The scaling from CMA are somewhat different from the chloride salts. CMA has no similar peak but has a linear increase in scaling with concentration to the same maximum level as for NaCl. This can mean that if a concentrated oversaturated solution is induced
in the concrete, in cracks etc, due to the evaporation of "salted" water the scaling effect can be severe.

Cement concrete can also be affected chemically by deicing agents. This chemical effect has been studied in a test at Lund Technical University, Sweden. The immersion test with specimens in saturated CMA, Ca, NaCl and CaCl₂ solutions ran for more than a year. The specimens in NaCl-solution were very little damaged, while the effect on the cement concrete in CMA was considerable. Some of the specimens had more or less fallen apart, esp. the "poor quality" cement concrete in saturated solution at +20°C. Samples in CaCl₂ solution were also heavily damaged and perhaps even faster than with CMA.

These described tests are under laboratory conditions and the question is how the results can be transferred into the field. To get more information about this a more "realistic" field test is running, now for the third winter, at VTI. Cement concrete cubes of different quality are exposed under field conditions and sprayed with deicers every day when weather conditions call for salting. After the two first winters the specimens sprayed with chloride salts were very much damaged. The poor quality concrete, esp. those sprayed with NaCl and CaCl₂ solutions, had the largest weight loss while the high quality air-entrained cement concrete was nearly unaffected by the chemicals. Compared to the chloride sprayed cubes the specimens sprayed with CMA solution were much less affected and the most severe scaling took place on the poor quality concrete without air. To sum up after two years test the result indicates besides the minor effect from CMA, that the quality of the concrete is essential for the salt resistance and explains the need for air-entrained concrete under Swedish climatic conditions.

Field test

During the winter 1984/85 the Swedish Road Administration performed a preliminary field test with 50 tons of CMA. The CMA was very fine grained with low density and the material was at that time not enough developed for road purposes. The field trials showed that CMA could be used as a deicer but it was not as effective as road salt. Some handling and spreading problems occurred with the light material.

Summary CMA

The CMA research has led to these findings and conclusions:

- CMA can be used in the same temperature range as salt, but more CMA is needed for the same melting effect. CMA does not melt ice and compacted snow as rapidly as salt.

- CMA are much less corrosive to car body steel and aluminium than other used deicing salts. It is more corrosive to magnesium alloy than urea.
- The effect on concrete is complex. The scaling effect from weak solutions of CMA are less than from sodium or calcium chloride. CMA can however have a chemical effect, but the extent of this is not yet fully clarified.

After some years with interest in CMA, the intensity in research efforts now is lesser. The reason for this is primarily the price picture and the questions concerning the effect on concrete. During this year, 1989, the tests on cement concrete are finished and a final report will be written. During the time the road keepers wait and see what happens commercially and what comes out of the research in USA.

An alternative deicer on runways

Clearway 1 is a non-corrosive liquid-acetate solution that has been tested for airfield purposes as a replacement for urea and glycol. The acetate solution has a relatively low freezing point, appr. -40°C. A first and limited trial in Sweden with the deicer were accomplished at the airfield in Örnsköldsvik in early April 1988, (see figure 5). The purpose of the test was to get a first opinion about the applicability of the deicer compared to Urea. Three different spreading tests were made on hoar frost and black ice. The limited trials showed that the acetate solution had a good deicing and also anticing effect in the present conditions, thin ice and a few degrees Celsius below zero. The results also indicated that the deicer is an interesting alternative to Urea, but that it's still left to investigate the deicing effect in more severe winter conditions with thicker ice and lower temperatures and what application rates that are required. Further trials with Clearway 1 will be performed this winter 1988/89 in Sweden.

5. Wearing courses, ice-retardant overlays

The skid resistance of different wearing courses under summer conditions are relatively well known. The variation of the coefficient of friction with speed on dry or wet surfaces has been documented in many reports. The frictional characteristics of different surfaces in winter time has however not been studied to the same extent. The interest in winter skid resistance has been low in Sweden. One reason to this is the extensive use of studded tyres which has led both directly and indirectly to relatively good skid resistance values of pavement surfaces. About 80% of the Swedish private cars use studded tyres. The use of studded tyres does also, however create great problems due to the pavement wear. Especially on the high volume roads the rutting is serious regarding wet skid resistance because of the water that can be standing in the ruts. A lot of research work is carried out to find wearing courses which are resistant to pavement wear. The
development of improved wearing courses by studying different pavement types, aggregates, binders (modified) etc are continuously in progress.

With the aim of studying the frictional characteristics of different wearing courses in various winter conditions an investigation has been carried out by the VTI during the last winters. The following types of surfaces have been included: dense and open-graded asphalt, single and double surface dressings and special types such as rubber asphalt, Verglimit and Delugrip. One special interest was to study if there is a relationship between texture depth and the susceptibility to icing.

The texture of the surface-dressed sections differed owing to age and wear. In general, the measurements showed that a coarse texture is in many cases positive from the aspect of slipperiness in wintertime. This was particularly noticeable when the surface dressings were new and coarse. However, the positive effect diminished with increasing smoothness of texture and the characteristics were similar to dense graded asphalt.

Owing to its open structure, open graded or drain asphalt generally offers good friction properties in summer conditions, especially in rainy weather. However, the behaviour of drain asphalt, which is very often chosen because of its numerous positive properties, is a very discussed subject with regard to winter maintenance. Problems in wintertime have been noted by road keepers and some of the behaviour have been documented in the mentioned study. In general, the open graded asphalt shows a somewhat greater susceptibility to hoar frost and icy conditions early in winter because of its open structure that influence the surface temperature to be somewhat lower than on a dense asphalt. Also in connection with snowfall the behaviour of porous asphalt differs from the dense types. The porosity tends to keep the snow easier to the surface and cover the road with a slippery snow layer earlier than on a dense surface. Snow and ice also tends to stay longer on the drain asphalt. On salted roads the actions doesn’t have the same effect on open and dense asphalt. Many times the salting on a porous surface layer has an effect that disappers more rapidly because once the salt solution is formed on the surface this can be drained out to the road sides. If the snowfall continues there is no salt at the surface and the snow can stick to it and be compacted. On a dense surface on the contrary, the salt solution remains longer and the deicing effect therefore is lasting a longer time. This means that the drain asphalt often requires more salt and more frequently salting. This behavior of the open graded layers is most pronounced on roads with lower traffic.
Studies of special wearing courses less susceptible to icing so-called "ice-retardant surfaces" have been carried out in Sweden. Rubber asphalt, with rubber particles and Verglimit, with salt pellets, have been investigated. Studies with these special surfaces have been performed for many years, but no clear conclusions have been drawn. Various results regarding slipperiness, wear and economy has been noted. A special field test started in 1987 with the aim of studying the effect of rubber asphalt and Verglimit compared to conventional asphalt concrete. Three test sections, 1 km each, were laid and the investigations include skid resistance in winter conditions, wear and economy. This is the second test winter and the plans are to continue for a third and last winter. The initial cost for the two ice-retardant overlays were about two times the cost of the conventional asphalt concrete. The wear after one winter season were least on the asphalt concrete, a little bit more on Rubber asphalt and most on Verglimit. The amount of wear were however not very much on either of the three surfacings. In the light of earlier experience it was a little bit surprising that Rubber asphalt had more wear that asphalt concrete, but this can probably be explained by some fault in the composition of the rubber asphalt mass. Materials tests showed that the content of fine aggregates, less than appr. 4 mm, were too little.

The performance of the two "ice-retardant" surfaces during icy conditions has not yet been studied to any larger extent depending on a very warm first test winter. However, there was one occasion with hoar frost where the two overlays, esp. Verglimit, were better than the conventional overlay. At the time the air temperature was a few degrees below zero and the relative humidity was high. Hoar frost was formed, most on the asphalt concrete but not as much on the other two surfaces. This occasion showed that the two special overlays could have an effect on the skid resistance in connection with hoar frost and temperatures around zero degrees Celsius. There are also a few times with snowy conditions but in these cases there has not been any significant difference in surface standard between the studied overlays. It is therefore still uncertain to what extent these two so called ice-retardant overlays really can retard the formation of icy conditions. Further more it’s also left to clarify the total economy of these surfacings.

In another study rubber asphalt Rubit, in U.S. Plus Ride, is more intensively investigated esp. regarding economy, wear, traffic safety, winter maintenance and noise. During 1988 road sections were choosen for follow-up and the first measurements were made. New test sections for the study are planned to be laid during 1989-90.
Figure 1  Spreader for prewetted salt.

Figure 2  Melting effect on ice from NaCl, CMA and Urea at -6°C in laboratory tests.
Figure 3 Corrosion test according to Swedish standard SS 186039. Weight loss in mg/cm² on steel after 100 days.
Figure 4 Concrete-Frost Testing acc. SS 137236. Tests with 3 % solutions of NaCl, CaCl₂, MgCl₂, and 3-25 % solutions of CMA. Weight loss after 56 cycles. Trends for NaCl, CaCl₂ and MgCl₂ acc to Verbeck & Klieger, 1957.

Figure 5 Runway deicing. Skid resistance after deicing with Clearway 1 and Urea. Test at Örnsköldsviks airfield, Sweden in april 1988.
WINTER MAINTENANCE - SNOW PLOWS IN SWEDEN


The focal point of this presentation is the showing of pictures of many different pieces of equipment with a running commentary. In this summary only a few of the pictures have been copied.

Contents:

* History
* Modern plow technique (design)
* Plow types
* Choice of equipment
* Standards (road classes)
* Technique and equipment
* New technical solutions

History

In Sweden, we can trace our history of road plowing back to 1687, when the first regulation on winter maintenance was written (county governor's instructions). See Appendix 1.

In 1920, motorized plowing and the first one-way mold board plow was introduced.

Modern Plow Technique (design)

Modern plows came into use in 1960-70, when chemical ice control became common and new demands on flow plows were stressed. Factors that influence the design of modern plows were e.g. the decline of the number of snow fences used. Trucks became more powerful. Better materials were used to make snow plows and more durable wearing parts entered the market. Another important factor is, that today we have much higher demands on clear roads and road safety (industry - "just in time").
Plow Types

The plows used in Sweden are:

* V-type
* One-way
* Slush-plow
* Combination plow (one-way & wing)
* Combination plow reversible (steel & rubber)
* Snow-blower
* Loaders

Choice of equipment

Money can be saved by choosing the right equipment. About 35-40% of the total winter maintenance costs are for snow removal. The accident risk is 15-30 times higher on slushy, slippery or snow covered roads as compared with clear roads.

The Swedish National Road Administration has a big fleet of equipment for snow removal:

<table>
<thead>
<tr>
<th>Own Fleet</th>
<th>Contractors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trucks: 700</td>
<td>1,500</td>
</tr>
<tr>
<td>Graders: 400</td>
<td></td>
</tr>
<tr>
<td>Loaders: 600</td>
<td></td>
</tr>
</tbody>
</table>

Some of the factors which influence the choice of equipment are:

* Climate factors (geography)
* Road categories
* Type of tool carriers available
* Type of weather situation (forecasts and actual situation - snow type, wind, etc.)
* Timing (traffic situation, soil frost, etc.)

Standards (road classes)

Depending on road class, we have different start criteria and performance time. See Appendix 2.

Technique and Equipment

As mentioned earlier, we choose equipment depending on many factors. I will show you some situations and types of solutions we normally use. See Appendices 3-9.
New Technical Solutions

I would also like to point out some technical solutions we have made to increase the efficiency of snow and ice removal, e.g.:

* Quick front coupler
* Retaining gate
* Blades and mounting system
* System 2000 with carbide tool tips
* Constant pressure regulator for blades
* New mushroom shoe
* On spot snow chain (automatic)

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EDISH WINTER ROAD MAINTENANCE – THE HISTORY OF SNOWPLOWS

87 FIRST WRITTEN REGULATION ON WINTER MAINTENANCE
"COUNTY GOVERNOR'S INSTRUCTIONS"

34 ROYAL DECREES CALLED "INNKEEPERS REGULATIONS"

41 SNOWPLOWS ARE MENTIONED IN NOTES WRITTEN BY CARL VON LINNE

90 A CLEAR DISTINCTION IS MADE BETWEEN MAINTENANCE OF WINTER ROADS AND ROADS WITH NO SNOW. (PASSING OF THE "SNOW GAVEL").

71 THE FIRST STATE LAW FOR ROADS. "WINTER ROADS ARE TO BE KEPT OPEN AT REQUIRED WIDTH AND WHERE IT IS NECESSARY MARKED BY THE RESPECTIVE PLOWING-TEAMS.

10 MOTORIZED PLOWING AND THE FIRST ONE-WAY MOLD BOARD PLOW ARE INTRODUCED.

0 SANDING OF ROADS. CONFLICT WITH SLEIGHS.

0 MOTORIZED AND AUTOMATIC SANDING. SAND MAGAZINES. EXPERIMENTS WITH SALT
TIME FOR EXECUTION

Snow removal

Road class

5-6
3-4
3
2
2
1

Start criteria

Performance time

(mgmmfimrz)

Camamowg

Precipitation

CONSUMPTION

Heavy snowfall

CONDITIONS
Background - History

Even though the two Swedes, Anders Celsius and Carl von Linné, created the Celsius Scale with 0 degrees for freezing of water and 100 degrees C for boiling water in the 18th century, we cannot take credit for being the first country using road weather stations. However, we started early and now have the most number of stations - more than 420 - in operation.

In the early 1970's we began to test some systems available commercially. We had a feeling, that some changes had to be made to the somewhat conservative and old fashioned winter maintenance operations. Many general changes in the road and traffic situation had taken place and there was a certain need for having a tool to help the supervisor of winter road maintenance in his very difficult task of keeping the roads open and safe during the winter season.

Some major reasons for having a system and its advantages are:

- Maintenance areas getting larger in most counties (fewer maintenance areas)
- Increased traffic volumes every year
- Increased demands from public and industry on road safety and on roads to always be kept open and in good condition
- Increased environmental awareness (e.g. less salt usage)
- Better work environment thanks to the system (less stress)
- Possibilities of better information to the road users
The first system to be tested did not exactly meet our demands but proved, that the idea of electronic information systems for checking the road conditions would be of great help. A period followed, when a very sophisticated system with many sensors at the road side submitting radio communication signals to a special central was developed. Different alarm criterias were calculated from the values received. This whole system never really worked because it was too advanced for the technique available at that time (mid 1970). The Swedish Road and Traffic Research Institute (VTI) took up the challenge to develop a simple and fairly cheap electronic system to measure temperatures (road and air) and the air humidity. These readings had to be easily available to the roadmaster. A prototype series of ten stations connected to the ordinary telephone network and with each fieldstation containing a very cheap and simple speechsyntheziser, was installed and became an immediate success. In fact a few of these 12 year-old stations are still in operation. The next step was to organize mass production of measuring stations. A high technology firm was awarded the responsibility to develop the next generation. The main outline of that prototype looks pretty much the same today even though the technique has improved a lot thanks to modern computer technology and new communication systems (e.g. videotex). See Appendix 1.

Fieldstations and Central Units

The fieldstations are design to operate in extreme climatic enviornment. They are equipped with a micro processor and have capabilities for a variety of input and output, e.g.:

* Road surface temperature
* Air temperature
* Air humidity
* Wind speed and direction
* Precipitation

Some stations also have sensors for road conditions such as dry, wet and salt concentration. Other sensors are instruments for checking snow and frost depth, traffic volumes and air pollution. Up to 32 sensors can be connected. The values normally obtained from each station are current values, trends and estimated dew—point temperature. The dew-point is one of the most interesting values and is compared with the road surface temperature to check the risk of ice-formation.

The central units, which are located in the road maintenance centre, call the field stations every half hour and collect current data via modems. The basis of the central unit is an ordinary IBM-compatible PC.

The central computer calculates an one-hour forecast. If this indicates a risk of slippery conditions or if a field station calls, an alert is given at the central unit. If the central unit is unmanned the computer calls the roadmaster at his home telephone number or his pocket paging receiver.
The roadmaster can communicate with any station via the central unit by means of radio or telephone. The information he receives is given in plain language via the speech-synthesiser. Furthermore, all stored values and possible warnings can be read off the screen of the computer at the central unit or via teletex (videotex) anywhere. The communication and transmission of data can be made in both directions by radio or telephone and will increase the possibilities for a speedy alert signal when special situations occur.

Road Climate Surveying

When planning a system for road weather information in Sweden, we made a careful study of the best location of the stations from the very beginning. Infrared camera technique with airborne registrations gave a good picture of ground temperatures but was a very expensive method. Parallel to that technique a specially equipped vehicle was developed with instruments for registration of road temperature and air temperature at different levels as well as air humidity. Today we have three cars in service and they are storing data for every 5 metres of road in a computer. The measuring is made at an average speed of 50 km/h. Registrations such as fog, ice on the road, location of bridges, rock cuts, etc. can be done manually by push buttons.

The information gained from these studies are not only important when choosing the best location of the field stations for an early warning but will also supply valuable information for other purposes, e.g. producing special road climate maps. The weather situation can also be calculated between field stations to a certain degree. See Appendix 2.

Information and Management Centers

In some counties we have special information and management centers. These centers are normally manned around the clock during the winter season. The centers are equipped with PC's with telephone modems and telefax as well as the normal road weather information system with e.g. graphical colour presentation of temperature curves. They receive weather radar picture as well as satellite images from the Swedish Meteorological Institute. Special forecast models are used to combine all the information to get as high a prediction accuracy of the road condition as possible. These centers will reduce the number of roadmasters required to be on duty in the different districts. See Appendix 3.
Research and Development (R & D)
A major problem when trying to obtain a perfect road weather information system is to find an accurate road condition sensor. It is not very difficult to check if the surface is wet or dry but it is harder to measure how much salt there is on the surface under different circumstances (e.g. on a dry surface). One quite promising sensor is the type that measures the freezing point and it is normally equipped with a built-in Peltier element.

Most sensors can be improved, however there is an important cost factor regarding sensors in the road that have to be changed often due to wear by traffic especially in countries that allow studded tyres.

Improved prediction models for temperatures and more accurate weather forecasts by the use of weather radar and satellite pictures are very promising for the future. Still, the local conditions for the roads have to be checked by instruments on the road side and the importance of research to refine the use of the field stations and climate surveys cannot be overestimated.

Better possibilities to inform road users through a good Road Weather Information System will be one of the most exciting challenges in the future.

In Europe, we cooperate in a project on Road Weather Conditions called EUCO-COST 309 (European Co-operation in the Field of Scientific and Technical Research). The major task is to spread and exchange ideas in this field as well as to find some general standards when and where it is necessary. Sweden is in charge of testing different sensors and systems at a special test site outside Gothenburg.

Cost-benefit, etc.
To calculate the cost benefit of a road weather information system is very hard. Reduction of salt usage and increased road safety are important factors but not the only ones. Further studies will be undertaken but we know already, that the roadmasters who actually have to finance the system through their ordinary budget are very much in favour of it.

Looking back, here are some reasons why we have succeeded with our system. We developed the system together with the users (roadmasters) and some of the best experts in road climatology as well as some very good technicians. Numerous meetings with all the people involved have taken place from the very beginning and follow-up meetings are still held. The whole idea is to solve the roadmasters' problem, not to manifest the latest technique. The fact that top management fully understands the value of R & D in sound modern maintenance technique has certainly also contributed to the success of our RWIS.
Special courses for all involved personnel have taken place for many years. These courses are also repeated after the system has been in use for a season. The increase of the awareness and the knowledge of how the weather and the road interact is one of the major advantages of the implementation in accomplishing better winter maintenance of the roads.

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Road climate surveying

1. Cold air pool
2. Cold elevated section
3. Lakeside climate
4. Area subjected to precipitation
5. Stream of cold air flow
6. Strong wind
7. Area in shadow

Temperature Curves
EXPERIMENTS WITH UNSALTED ROADS


In an earlier presentation you heard about the rules and recommendations for Swedish winter road maintenance. A large project called MINSALT (minimum damage of road salt) was also mentioned. One part of that project is experiments with unsalted roads. The main reason for the project was the large costs of corrosion caused by winter road salt, and that we couldn't prove that it was safer to drive on salted roads.

The table below shows an example of an attempt to make an economic assessment of changes in costs on roads and streets when changing the winter road maintenance from using salt to not using salt. The costs are given for one year (1985) in million Swedish crowns. The calculations are mainly based on an experiment with unsalted roads in the early eighties and, to some extent, results from other studies and assessments made by various experts.

<table>
<thead>
<tr>
<th></th>
<th>National roads</th>
<th>Municipal roads and streets</th>
<th>All roads and streets in Sweden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accidents</td>
<td>-400</td>
<td>+600</td>
<td></td>
</tr>
<tr>
<td>Travel time</td>
<td>+ 30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standstills</td>
<td>+ 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cancelled journey</td>
<td>?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safe journey</td>
<td>?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle corrosion</td>
<td>-1000</td>
<td>-1000</td>
<td>-1700</td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>- 50</td>
<td>- 20</td>
<td>-160</td>
</tr>
<tr>
<td>Washing cars</td>
<td>- 80</td>
<td>-80</td>
<td>-160</td>
</tr>
<tr>
<td>Tyre</td>
<td>+ 75</td>
<td>+75</td>
<td>+150</td>
</tr>
<tr>
<td>Winter Road Maintenance</td>
<td>0</td>
<td>+300</td>
<td></td>
</tr>
<tr>
<td>Bridge repairs</td>
<td>- 100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pavement wear</td>
<td>- 11</td>
<td>- 5</td>
<td></td>
</tr>
<tr>
<td>Cleaning Delineator Posts</td>
<td>- 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ditch maintenance</td>
<td>+ 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweeping streets</td>
<td>?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cleaning Surface Water Pipes</td>
<td>?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lamp Posts Corrosion</td>
<td>?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental Impact</td>
<td>-100</td>
<td>-50</td>
<td>-170</td>
</tr>
<tr>
<td>Industry and Trade</td>
<td>?</td>
<td></td>
<td>-230</td>
</tr>
</tbody>
</table>

\[ \text{Total:} \quad -1632 -246 \]
Despite reservations on the magnitude of certain effects it is never the less of interest to compare different effects. Not all effects can be quantified economically. This applies especially to the ways in which the road user and the road administration view certain conditions.

It is not the absolute value that is most important it is the relation between values. The largest items are for accidents, vehicle corrosion and for winter road maintenance. Other effects are of relatively small significance.

The interval for accident costs ranges from an increase of 19 % to a decrease of 13 %. The first figure is from an earlier experiment with unsalted roads and the second figure is from expanding the salted road-network. This means that there was an increase in accidents when previously unsalted roads first were salted. This increase was not statistically significant (5 % risk level).

The earlier experiment with unsalted roads showed that the rust corrosion on test specimens of car body steel, both treated and untreated, were less than half as extensive on the unsalted roads as on salted roads.

The cost of winter road maintenance is an intelligent guess by road engineers: an increase between 0-50 % when changing to unsalted winter maintenance.

The MINSALT project will give us better information. This project is not finished yet but there are some results that can modify the figures above.

The experiment with unsalted roads in the MINSALT-project takes place in 3 different counties in Sweden shown in the figure on next page. The figure also shows where the earlier experiment with unsalted roads took place.
This experiment started in Gotland in the winter 86/87 and in Västerbotten and Dalarna in the winter 87/88. In Västerbotten and Dalarna the experiment only include rural roads but in Gotland also streets.

Because of the differences in winter weather it is not enough to do a before and-after-study. There is also a need for control roads, on which salt is used all the time, to neutralize for the different winter weather. The same studies are done on both experiment and control roads. All results are compared with the period before the experiment but also to changes on the control roads.

Often when doing experiments in the winter there is an unusual winter which makes it difficult to come to the right conclusion even when comparing with control roads. The first experiment winter in Gotland was very cold and with a lot of snow. The second experiment winter was warm and there was almost no snow until late February. In Dalarna the experiment winter was much warmer than usual and during the whole winter snowfalls were quite usual but there were some months with a lot of snowfalls and others with almost no snowfall. The winter in Västerbotten was much warmer than usual but with quite a lot of snow.
Västerbotten and Dalarna are usually rather cold in the winter which means that salt seldom can be used in midwinter because of the temperature, but the winter when the experiment took place was so much warmer than usual that if it hadn't been an experiment salt could have been used the whole winter. This made it more difficult to maintain the roads without salt than in an ordinary winter and where salt was used, almost twice as much as usual was needed.

The changes in accidents reported to the police on national roads during the experimental winters are shown below with a 95 % confidence interval.

<table>
<thead>
<tr>
<th>County</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Västerbotten</td>
<td>+14 ± 57%</td>
</tr>
<tr>
<td>Dalarna</td>
<td>+13 ± 11%</td>
</tr>
<tr>
<td>Gotland</td>
<td>+12 ± 36%</td>
</tr>
<tr>
<td>and on municipal streets in Gotland</td>
<td>-36 ± 22%</td>
</tr>
</tbody>
</table>

There has been more accidents on the national roads during the experiment winters than in the 5 winters before. Especially during the last winter because of the weather. For example in Västerbotten accidents increased by 70 % on the test road and by 50 % on the control road. But on the municipal streets the accidents have decreased during the unsalted winters.

The changes in road condition were different in different counties. In Västerbotten the percentage of ice and snow increased from 43 % to 48 % and in Dalarna from 17 % to 38 % on bigger roads but there were no changes on smaller roads. In Gotland the percentage of ice and snow increased by 10-20 % units on roads. The ice/snow conditions are not the same on unsalted roads as on salted ones. There is more packed snow or ice on the unsalted roads and more loose snow or slush on the salted roads.

Studies of dirt spray show that there was significantly more dirt spray on the salted roads. The mean difference over all measurement occasions was small but the number of days with severe dirt spray was only about half as many on the unsalted roads as on the salted ones.
The corrosion on untreated test specimens in Gotland has been approximately ten times less than on salted roads. This difference is much larger than in the earlier experiment in Östergötland where the corrosion was less than half the corrosion on salted roads. The police cars in Gotland and in a control area were tested and the corrosion on those cars were about 50% higher in the control area than in Gotland. It is important to know that the police cars were handled with much more care than cars used by ordinary people. Later on the results from the vehicle inspection centers will be used to get information about corrosion on ordinary people’s cars in Gotland and in the salted control area.

According to the survey drivers of private cars think that using salt is bad or rather bad: Gotland 90%, Dalarna 55-70% and Västerbotten about 80%. The drivers of heavy vehicles are almost as negative to salting: Gotland 80%, Dalarna 40% and Västerbotten 60%.

The costs for maintaining the roads (not including new equipments) have increased by 40% in Västerbotten, 14% in Dalarna and in Gotland by 32%.

The experiment continues this winter with almost the same winter maintenance as in the first experiment winter. There is one exception. In Dalarna salt can be used on some roads if it can be foreseen that this will have a long positive effect on the road condition. A small amount of salt in the sand is also used on the larger of the earlier unsalted roads.

Many towns in Sweden reduce their salt-usage by reducing the salted road net-work. There is also an experiment in a town in Sweden where the road administrator use salt only in junctions and just before junctions. This is an attempt to use salt only where the need of high friction is larger than else where. At the same time the trees along the streets are spared from salt. And we know from inquires that many road users want salt only at hazardous spots.

The largest street in this experiment has 2 lanes in each direction and an annual average daily traffic of 20 000. The environmental impact of chemical deicing has been studied along this street. The impact has been demonstrated by damage to vegetation and by high salt concentrations in soil and
vegetation before the experiment. After one experiment winter the salt concentrations in soils were much lower, but in the leaves there were almost the same concentrations as before.

The first experiment winter was quite warm and there were no long periods with effect on the road surface of "point salting". But the hours after a salting the friction could be as in the figure below, low between the junctions and quite high around the junctions.

The costs for maintaining these streets increased by 5 %.

Friction level at a street where only the junctions have been salted. Junction marked with +.
After this winter there will be a suggestion from the Minsalt-group with guidelines for when, where and how to use salt in winter road maintenance. These rules will be tested the next winter which is the last Minsalt winter.

Finally, I want to show you that ice and snow on the ground is a much bigger problem for pedestrians than for car drivers in Sweden. During the whole year in the county Östergötland 1/3 of the people coming to the hospital because of a traffic accident were pedestrians. But 2/3 of all injured in single, slippery accidents were pedestrians. For injured in slippery accidents the sickness/recovery period is on average 25 days for pedestrians and only 11 days for car occupants and in non-slippery accidents 20 days for both pedestrians and car occupants.

The above indicates strongly that concerning the winter maintenance, from safety point of view, pedestrians ought to be given priority.