Effects of Winter Road Maintenance
State-of-the-Art
Carl-Gustaf Wallman, Peter Wretling and Gudrun Öberg
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State-of-the-Art

Carl-Gustaf Wallman, Peter Wretling and Gudrun Öberg
The study constitutes the basis for the model to be used as a guideline for determining winter road standards within the framework of the public economy.

Driving speeds vary widely on winter roads. However, it is estimated that passenger cars travel at 75–90% of the speeds they normally travel at on bare roads. In order to maintain a consistent stopping distance, speeds should virtually be halved. The appearance of the road has a greater affect on the reduction in speed than friction/road traction. Precipitation entails a much greater reduction than slippery road surfaces alone.

Accident rates on winter roads vary greatly. However, studies based on the observation of road conditions and traffic measurements show an increased risk on icy/snowy roads. The more unusual these conditions, the greater the risk. Aggregated studies do not support the presumption of increased risk in winter.

Statistics from the Swedish Motor Vehicle Inspection Co. were analysed as a result of notations of rust defects that caused cars to fail inspection. In Västervik, where roads are salted, cars fail inspection 2–4 times more often than on Gotland, where salt is not used. Experts estimate that the life expectancy of cars would increase by 25% if roads were not salted. Corrosion costs will continue to be high since new corrosion problems occur in conjunction with the effects on electronic equipment.

Many breaches of knowledge are identified.
Foreword
This documentary study is the first step in the research that will lead to a winter road maintenance standard (WMS) which determines the standard for winter road maintenance according to socioeconomic calculations. The project has been carried out on behalf of the Swedish National Road Administration. The assignment was previously commissioned by the Operational section via Hans Danielsson, Lennart Axelsson and Östen Johansson (the contact person). For the past year, Magnus Ljungberg from the Road division has acted as the contact person.

This literary study does not cover environmental effects for the simple reason that they are part of a study that is already being carried out on behalf of the Swedish National Road Administration. This literary study will be published as a VTI announcement by Göran Blomqvist.

Each of the authors has contributed to the majority of the chapters in this report. The Swedish sections were primarily compiled by Gudrun and the non-Nordic sections by Carl-Gustaf Wallman. The authors have all contributed, in relatively equal proportions, to the abstract material relating to the Nordic countries. In chapter 6, Carl-Gustaf Wallman has written about "Fuel consumption" and Gudrun Öberg has written about "Corrosion". Chapter 8 was written by Carl-Gustaf Wallman and the Summary and Abstract section are written by Gudrun Öberg. The report was edited by Annette Karlsson and Siv-Britt Franke.

The literary study began in 1994 but was interrupted by the Swedish National Road Administration at the beginning of March 1996 in connection with their review of R&D costs. The project was renewed at the end of November 1996. This means that additional investigations was completed during the interruption, the most important of which is accounted for in chapter 11.

The Swedish National Road Administration held a seminar on March 19, 1996 (with both central and regional representatives), which was largely based on the concept of this report.

Jan Ifver and Håkan Wennerström were the lecturers at the publication seminar held on May 29, 1997. Both are representatives of the Swedish National Road Administration.

Valuable viewpoints, consisting primarily of additional information or explanations, were presented at both seminars.

I would like to express my heartfelt thanks to those mentioned above and to all who have contributed to the implementation of the project and this report.

Linköping, September 1997

Gudrun Öberg
Project Manager
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Effects of Winter Road Maintenance
State of the Art
by Carl-Gustaf Wallman, Peter Wretling and Gudrun Öberg
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SE-581 95 Linköping, Sweden

Summary
This report is an account of a documentary study concerning the effects of various weather and road conditions (friction) and winter road maintenance measures. Environmental impact and the costs of road maintenance are not discussed here.

A joint decision was made with the Swedish National Road Administration, who commissioned the report, to emphasize Swedish studies and thereafter, to a successively lesser extent, Nordic studies and those carried out in other countries because winter traffic conditions vary so widely. The studies reported here are classified according to various connections and countries as shown in the table below.

Number of References

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<td><strong>66</strong></td>
<td><strong>40</strong></td>
<td><strong>16</strong></td>
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A number of reports occur several times in the table above. A total of 115 references are included. The emphasis is on accident investigations.

Ice and snow on streets and roads create problems for those who use them. To minimize these problems, road maintenance personnel undertake operative measures such as snow removal and measures to counteract slippery roads (salting and sanding). These operative measures greatly affect safety, accessibility, vehicle costs and the environment and are very costly for road maintenance organizations. Therefore, the development of effective strategies and methods for operative measures is a matter of some urgency, as is the gathering of knowledge about the effects and costs that different winter standards entail for road users and road maintenance organisations. It is also vital to develop methods for the efficient measurement of achieved standards, e.g. described as smoothness, friction and road conditions.
The documentary study yielded the following results:

**Speed** on winter roads varies greatly. However, it is estimated that passenger cars travel at 75–90% of the speeds they normally travel when the roads are bare. To maintain a consistent stopping distance, speed should essentially be reduced to half. It is the state of the road (its appearance) that determines speed reduction rather than friction and road operation standards. Drivers have difficulty judging friction levels and these difficulties increase as the road becomes more slippery. Precipitation entails much greater speed reduction than does a slippery road surface alone.

**Fuel consumption** increases significantly in fresh snow for both passenger cars and heavy vehicles. As vehicles are driven in the tracks left by those ahead of them, this increase diminishes quickly. The increase in fuel consumption caused by poor road conditions can, if conditions are not too bad, be counterbalanced by the reduction in fuel consumption brought about by a reduction in speed.

Road salt contributes to **corrosion** in two ways. In part because the road surface remains wet longer and in part because the presence of chlorides increases conductivity and thereby hastens the process of corrosion. Statistics from the Swedish Motor Vehicle Inspection Co. were analysed in light of demerits given for rust defects serious enough to cause cars to fail inspection. In the Västervik area, where roads are salted, cars fail inspection 2–4 times more often than on Gotland, where salt is not used. Experts estimate that the life expectancy of cars would increase by 25% if roads were not salted. New corrosion problems arise in that electronic devices are affected; thus, the assessment of experts is that corrosion costs will continue to be considerable even if metal corrosion is reduced.

**Accident rates allocated according to road conditions and the source of accident reports.**

<table>
<thead>
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<th>Condition</th>
<th>Accidents reported by the police</th>
<th>Accidents reported to insurance companies</th>
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<td>Bare road</td>
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<td>1</td>
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<tr>
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Thus there are great differences depending on road conditions and sources.

**Accident risks for pedestrians and bicyclists**

A rather rough estimate of the risk of accidents for pedestrians when roads are icy and snowy is that they increase by 5–10 times in comparison to bare conditions.
Accident risks related to the type of tyres used
In rural areas, studded tyres reduce the risk of accidents on slippery roads by approximately 40% compared with summer tyres. The reduction with non-studded snow tyres is approximately 25%. The effect is expected to be less in urban areas.

Problems related to various accident investigations
The great variations noted in accident rates on winter roads are obvious. There are significant regional differences but most importantly, "icy and snowy road conditions" is an extremely heterogeneous concept. Attempts to employ more refined classifications do not yield a noticeable reduction in the variations. However, those studies which are based upon observations of road conditions and traffic measurements show a clear increase in the risk of accident when road conditions are icy and snowy. The risk level varies throughout the season. It is higher during early winter and later stabilizes at a lower level when winter road conditions remain constant. The risk also increases when there are fewer occasions of icy and snowy road conditions during the season. Certain results indicate that the risk level is at the maximum when winter road conditions prevail approximately 15% of the winter. The risk decreases when the incidence of icy and snowy road conditions become less frequent and probably also when more frequent.

Aggregated studies do not support the presumption of an increased accident during the winter, at least not with regard to accidents involving personal injury.

The studies analyse winter problems during long periods. It is thus imaginable that many other factors are involved, such as the introduction of general speed limits, increased use of safety belts, safer vehicles, increased use of studded tyres, different methods of reporting accidents, etc. These effects should however be encompassed by the trend factor.

The collection of fundamental data is associated with a number of problems.

Weather reports for the season have most often been taken from SMHI (The Swedish Meteorological and Hydrological Institute) statistics or the equivalent.

Road conditions at the time of the accident are most often retrieved from the police report. It seems likely that trained observers of road conditions would, in many cases, have described conditions differently from the way the police did.

Sources of the accident report: The police, insurance companies and hospitals do not report the same types of accidents and the reports vary in quality.

The level of reporting varies but rises according to the severity of the accident. One can safely assume that nearly one hundred per cent of fatal accidents are reported by the police. The percentage of serious personal injuries reported is only 59% and only 32% of accidents involving minor personal injuries are reported. Property damage is reported most often to the insurance companies. Property damage is reported most often to the insurance companies; during severe traffic conditions it is likely that police reports in these cases become even more underrepresented. Reports from hospitals are the best source of information regarding single-vehicle accidents involving pedestrians and bicyclists.

Exposure (the flow of traffic) is a critical factor. In the best case, flow measurements are taken at the time of the investigation. However, ADT is often used with standard corrections for season and time distributions. Rougher estimates have also been employed. Of course, weather and road conditions
change rapidly and standards for winter road maintenance are (at least on the larger roads) very good. An increased risk of accidents during relatively brief periods of poor road conditions and the subsequent lower exposure can never be revealed in comprehensive studies.

In cases where the investigation covers large regions, we see the same problems as for exposure. The description is at the macro-level where local variations in weather, road conditions, flow, etc., cannot be studied.

Few studies are made at such a detailed level that they are related to the winter road maintenance measures that actually exist. It is reasonable to expect that these measures should have a noticeable impact on traffic flow and the risk of accidents, at least from a short-term perspective.

It is also seems likely that a certain risk compensation arises. Speeds generally decrease slightly during the winter and more so when weather and road conditions are poor. This has effects, in particular upon the severity of accidents because kinetic energy (the braking distance), personal injury accidents and fatal accidents are proportional to the second, third and fourth power of the speed. Thus, if speed is reduced from 100 to 90 km/h (10 %), braking distance is reduced by 19 %, accidents involving personal injury by 27 % and fatal accidents by 34 % when circumstances are otherwise the same. Another way of compensating for the increased risk is to heighten attention and yet another is to improve the vehicle’s equipment, e.g. by mounting studded tyres.

It is also probable that plough banks and snow in the ditches alleviate the effects of accidents.

Attempts to study the relations between weather, road conditions, maintenance measures and accidents are frequently made directly without considering the variables affected by the outside factors of flow, speed and the risk of accidents. It is likely that when conditions cause increased risk, speed and flow are reduced and vice versa. This compensation means that the number of accidents could essentially remain unchanged.

Many Swedish studies are more than 20 years old, which implies the existence of breaches of knowledge.

There are breaches of knowledge regarding:
– the distribution in time and space of road conditions and friction levels;
– the relation between speed, road class and road conditions;
– the dependency of capacity upon road conditions;
– corrosion of electronic equipment in vehicles;
– the variation in the risk of accidents during the winter season dependent upon the share of icy/snowy road conditions and type of road conditions. It is especially important to evaluate the risk for unprotected road users and to develop methods for studying the safety of unprotected road users;
– the consequences of different strategies on the socioeconomy, i.e. a winter model should be constructed in order to discover the “right” winter road maintenance standard.
1 Methodology

The national and international literature on which this report is based was traced using five different search methods:

- in VTI’s (Road & Transport Research Institute) own production
- in VTI’s library
- in literature procured through personal contacts
- in databases (IRRD, Roadline)
- by using search tools on the Internet.

Some of the information is based on second-hand reports, which could not be completely verified. In a few of the reports, only the summaries have been written in an international language (e.g. English, German or French).
2 Definitions and explanations

The report contains a large number of technical terms and concepts, which for safety’s sake are explained below.

**The headway** between two vehicles is the time that separates the passing of the fronts of two vehicles over a specific point in the road. The standard measurement unit is seconds.

**The flow** is the number of vehicles that pass a certain point per unit of time. The standard unit of measurement is vehicles per hour.

**Density** is the number of vehicles on a segment of road at any given time. The standard unit of measurement is vehicles per km.

**The capacity** is the maximum flow on a given segment of road.

The median value and 85-percentile (i.e. 85% of vehicles drive below this speed) which is denoted as $V_{50}$ and $V_{85}$ respectively, are usually specified when summarising speed measurements.

The term **percent occupancy time** (%) is sometimes used instead of density (f/km). The percent occupancy time is the amount of time that vehicles covers a certain point on the road.

**Friction measurements** on roads can be carried out in different ways. In Sweden, it is standard for research purposes to measure the friction forces according to the Skiddometer principle, i.e. on a braked measurement wheel, which rotates slower than a free-spinning wheel. The principle of a strongly braked wheel is also used in commercially available equipment such as Digislope. Another method is to measure the forces on a free-spinning wheel with an oblique wheel (e.g. 8° from the direction of motion). This method is standard in Norway.

A third method is to measure the forces on a locked wheel. This method is standard in the USA.

A fourth method is to calculate the friction rate using a pendulum mounted in a vehicle. The amplitude of the pendulum swing when braking is in proportion to the frictional force.

In the USA, friction measurements are carried out according to a standard test method, ASTM E274, with a locked measurement wheel on a wet road surface. The measurement result is given as a skid number (SN) at different speeds, e.g. SN$_{40}$ at 40 mph. In principle, the SN is the friction rate multiplied by a factor of 100. SN varies with speed $V$ mph according to:

$$Sn_{V} = SN_0 \times \exp((-PNG/100) \times V)$$

where $SN_0$ is the gliding ratio at speed 0 (a function of the micro-texture) and PNG is the percentage of the normalised gradient (a function of the macro-texture). In this summary, the terms *gliding ratio* and *gliding resistance* translations of the terms *skid number* and *skid resistance*, because friction measurements are not carried out in the same way in Sweden as they are in the USA.
In addition to the properties of the road surface, the friction rate depends on the following:

- The speed of the measurement vehicle.
- The gliding speed (the relative speed between the contact surface of the tyres and the road surface, i.e. the degree of braking).
- Any skid forces, i.e. if the measurement wheel rotates at an angle $\neq 0$ in relation to the direction of travel.
- The dimensions of the test tyres, the rubber mixture, pattern, tyre pressure, load, etc.
- The depth of the water.

The first four parameters mentioned here and, to a certain degree, the depth of the water, normally have a great effect on the friction rate. Since different friction meters are based on different measurement principles, where the aforementioned parameters are often totally different, it is only logical that the measurements are incomparable. In reality it is meaningless to compare friction rates that are not obtained using the same family of measurement devices and the same test parameters as described above.

However, for Swedish conditions it is safe to say that the BV11, Saab Friction Tester and BV14 belong to the same family of meters where the same measurement principle, and to a large degree the same apparatus, are used. Measurements obtained using these apparatus are comparable and should (ideally) often produce identical results, at least when testing with the same amount of water and at the same speed. However, when comparisons are to be made with, for example, SCRIM or one of the many locked-wheel measurement vehicles, one is really treading on thin ice.

The large variations caused by different apparatus and test parameters can be illustrated by a few of the measurements taken in connection with the international PIARC experiments in Belgium and Spain a few years ago. These measurements were carried out at the same speed (60 km/h) and over the same stretch of road (75 m), yet there was a major difference in the friction coefficients, which were 0.90 using one measurement device and 0.33 using another. On another 75 m stretch of road, a friction coefficient of 0.90 was obtained using one measurement device and 0.44 using another. With one of the measurement devices, measurement distance no. 1 produced a friction coefficient of 0.90 while measurement distance no. 6 produced a coefficient of 0.53. In other words, distance no. 6 was much worse than no. 1. However, when another measurement device was used, the friction coefficient for distance no. 1 was 0.83 and for no. 6 it was 0.90. In other words, the friction coefficient for distance no. 6 was somewhat better using this particular device.

Consequently, it is possible to obtain just about any result, depending upon the apparatus and measurement parameters, and comparisons of measurements and limit values are almost worthless. In reality, this was the main reason for the international PIARC experiment. The purpose was partly to clarify the relationships between measurement apparatus and the reason for the variations and partly to attempt to develop some form of normalising the friction measurement values for a uniform standard.

The aforementioned experiment, in which VTI participated with a BV11 and a laser profilometer, also resulted in the development of a standard for measuring
friction, namely the IFI – International Friction Index. One might say that this value is a form of mean value for (almost) all friction meters. With the aid of the measurements carried out for the apparatus included in the experiment, it is possible to convert the measured friction values to IFI. However, in doing so, both a friction measurement and a measurement of the macro-texture are required for normalisation. In the latter case, a so-called "Mean Profile Depth" (MPD) according to ISO 13473-1 is used. Friction values measured with BV11 and the Saab Friction Tester can now be converted into IFI to facilitate international comparisons.

The aforementioned experiment is a major, important step on the way to achieving an acceptable equivalence between different friction measurement apparatus. However, the normalisation still does not produce small enough faults when extreme precision is desired. It is worth mentioning that CEN/TC 227/WG 5 has the matter on its agenda and is expected to give it high priority over the next few years.

Translation of relevant terms
Both French and German terms are used from time to time in this report. Therefore, we feel that it is worthwhile to list the relevant terms.

**French**
Weather:
- Sec – dry; pluie faible – drizzle; pluie moyenne – median rain; pluie forte – downpour.

**German**
Miscellaneous:
- anhaltend – long-term; Witterung – precipitation.

Road conditions:
- trocken – dry; nass – wet; Schneeglätte – snowy road, consisting of both a loose and a hard layer; Eisglätte – icy road, divided into Glatteis – thick ice, Reifglätte – frost, and überfrorene Nässe – thin ice.

Road maintenance:
- Räumen – ploughing; Salzstreuung – salting; Splittstreuung – spreading of crushed gravel; abstumpfen – deicing with friction materials.
3 Distribution of road conditions
3.1 Swedish investigations

The occurrence of ice-/snow-covered roads/streets in winter varies greatly throughout Sweden, both between different parts of the country and between roads of different sizes.

3.1.1 Public roads

Möller (1995)

The distribution of the vehicle mileage for different road conditions during the winter of 1993–1994, a fairly normal winter, has been calculated for the public road network. In the mid-winter period (December, January and February), the percentage of roads covered with ice and/or snow varied from 9% in southern Sweden to 51% in northern Sweden on roads of standard class A1–A4 (i.e. roads that are free of ice and snow). During the period March–April, the percentage of ice and/or snow-covered roads was 2% in central Sweden and 6% in northern Sweden. During the middle of winter, the percentage of public roads of standard class B1−B2 (snow-covered roads) covered with ice and/or snow varied from 43% in southern Sweden to 96% in northern Sweden. During the period March–April, the percentage of roads covered with ice and/or snow was 6% in central Sweden and 26% in northern Sweden.

3.1.2 Municipal streets and roads

The distribution of the road conditions for municipal roads and streets varies according to the time of year.

Möller, Wallman, Gregersen (1991)

The effects of winter road maintenance in urban areas were studied during the winters of 1986/87–1989/90. In Göteborg, the main roads were clear for 90–100% of the time. Streets in residential areas, bus-stops-pedestrian areas and footpaths/bicycle tracks were clear 60–90% of the time. In Borås, a four-lane national highway was clear 90–100% of the time. Footpaths/bicycle tracks roads in Mjölby were clear 40–70% of the time. Streets in residential areas of Skellefteå were clear 0–40% of the time, but most often only a few percent were clear.

Öberg (1994)

In urban areas, there are also major variations between different types of surfaces as illustrated by the results from Linköping at the end of the ‘80s. Similar trends can also be seen in other urban areas. The winter of 1986/87 was cold and there was not much precipitation. During this time bus-stops, footpaths, bicycle tracks and small residential streets were covered with ice and/or snow about 60% of the time. Larger residential streets and public-transport lanes on major arterial roads were covered with ice and/or snow 40% of the time while the major arterial roads themselves were covered with ice and/or snow 20% of the time. The winter of 1988/89 was mild and there was little precipitation. During this period, arterial roads were covered with ice and/or snow 5% of the time and the bus stops and footpaths/bicycle tracks 25–30% of the time. The percentages above apply for the entire winter (November–March).
Öberg et al. (1997)
During the winter of 1993/94, weather as a whole were normal. Timewise, the distribution of road conditions during the winter shows that footpaths and bicycle tracks in eastern Göteborg were only clear for half the winter. The roads in eastern Göteborg were only clear for 80% of the winter and a few percent were clear most of the time. In Umeå, footpaths and cycle tracks were clear 25% of the time, while heated footpaths were clear 85% of the time.
4 Friction

4.1 Swedish investigations

Öberg (1978a)
Slippery conditions are controlled chemically in part by means of salting to prevent these conditions and in part by salting surfaces that are already slippery. In the first case, if the action is carried out properly, the surface shall not become slippery. In the latter case, the time required for the road to clear once the salt is distributed varies. This depends on the amount of the ice and/or snow on the road, the degree of traffic and how the salt was distributed (dry, moist or in a solution and the amount that was spread). Salt works fast. There could be an improvement in friction after as little as 10 minutes in the wheel tracks where the salt has been processed by the wheels. Salted roads are often 10% clearer than unsalted roads of the same standard. This is most often wet/moist snowless ground.

Öberg (1978b)
On median, sanding improves friction on icy/snowy roads by 0.1 units. However, this may vary a great deal. The friction in the wheel track area sinks to the original level after approximately 300 vehicles. Outside the tracks, the improved friction may last longer.

Öberg (1981)
The friction (road grip) may vary depending on the condition of the road. It may depend on the condition of the road itself but also on the temperature, local climate or the fact that some surfaces cool down quicker than others.

The median friction in icy/snowy conditions often varies between 0.15 and 0.25. Friction may be as low as 0.05 when frozen rain and wet, thin ice. Friction levels on bare ground are often between 0.8 and 0.9.

If there is a thin layer of ice/snow, the difference between a rough and a smooth surface can often be approx. 0.1 friction units, but sometimes the differences may be as great as the differences between a covering of ice/snow and bare ground.

Figure 4.1.1 shows the friction levels for different ice/snow and bare ground conditions. When there is loose snow, the depth is so shallow that the surface dressing affects the level of friction. If the snow is deeper or the surface is smooth, the friction level would have been lower.

If, for example, the 15 percentile in the distribution of friction is 0.2, it means that the friction coefficient has been lower than 0.2 on 15% of the measured stretch.
Figure 4.1.1 Friction in different road conditions. The mean values and 95% confidence interval are indicated by bars for the 15 and 50 percentiles (f_{15} and f_{50} respectively).


After planing and ploughing, there is often ice/snow left on the road, which means that bare ground friction is not obtained. After planing with flat steel, there may be less friction than before planing as a result of the smooth surface that is created. This phenomenon does not occur when planing with a toothed planing bit.

The type of road surface in icy/snowy conditions may have a major impact, primarily if this covering is thin. Figure 4.1.2 illustrates one of the largest differences recorded. The condition of the road appears to be the same on either side of the surface joint with approx. 1 cm wet snow. On the rough surface dressing, there is "bare-ground friction", while on the smooth asphalt/concrete surface there is "ice/snow friction". More normal differences are 0.1.

Figure 4.1.2 Friction measurements on two types of surfaces. Wet snow, 1 cm, air temperature +2°C. Mean friction values over the last 300 m passed are specified at the peaks of the friction strip.
Öberg, Gregersen (1991)
It is sometimes said that friction on icy/snowy roads is greater at lower temperatures. This assertion could not be confirmed in this investigation.

Öberg et al. (1997)
There were no major differences in friction between the different types of surfaces on footpaths and bicycle tracks that were covered with ice and/or snow. The friction levels were, however, noticeably lower on bare ground coated with sand than on non-sanded bare ground.

4.2 Nordic investigations
Ruud (1981)
The conditions that we wished to illustrate in the investigation were, among other things, the variation in speed during the day for different levels of friction. See Table 4.2.1.

Table 4.2.1 Median speed and friction in different road conditions on salted and unsalted roads.

<table>
<thead>
<tr>
<th>Road no.</th>
<th>Ice and packed snow</th>
<th>Road condition</th>
<th>Clear road surface</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median friction</td>
<td>Packed snow, slush, wet asphalt</td>
<td></td>
</tr>
<tr>
<td>E 18 salted</td>
<td>0.25</td>
<td>0.40</td>
<td>0.65</td>
</tr>
<tr>
<td>Median speed (km/h)</td>
<td>73.5</td>
<td>76.1</td>
<td>80.9</td>
</tr>
<tr>
<td>Highway 312 + 153 unsalted</td>
<td>0.26</td>
<td>0.39</td>
<td>0.70</td>
</tr>
<tr>
<td>Median speed (km/h)</td>
<td>68.7</td>
<td>70.7</td>
<td>76.1</td>
</tr>
</tbody>
</table>

Sistonen, Seise, (1990)
The friction was measured with Skidding Tester ST-1 with an oblique wheel (8° angle) on the roads listed in Table 4.2.2 below.
Table 4.2.2  Flow of traffic and winter road maintenance (number of precautionary measures) on the sections that were measured.

<table>
<thead>
<tr>
<th>Road Section</th>
<th>Traffic volume vehicles/day</th>
<th>Ploughing</th>
<th>Planing</th>
<th>Salting</th>
<th>Sanding</th>
<th>Slush-removing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Highway 3</td>
<td>7 900</td>
<td>55</td>
<td>10</td>
<td>47</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>2. Local road 2834</td>
<td>500</td>
<td>53</td>
<td>16</td>
<td>0</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>3. Highway 54</td>
<td>2 000</td>
<td>53</td>
<td>12</td>
<td>28</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>4. Highway 54 (one winter period)</td>
<td>4 800</td>
<td>21</td>
<td>3</td>
<td>7</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 4.2.1 illustrates the distribution of friction coefficient during the winter on the roads listed above.

![Distribution of friction coefficient, %](image)

Figure 4.2.1  Distribution of friction during the winter.

Road no. 2, with the least amount of traffic, is the one with the lowest friction in comparison with the other roads. They also investigated how much extra friction there was with studded tyres at different levels of friction and with different numbers of studs in the tyres. Figure 4.2.2 shows that the relative friction increment is considerable at low friction.
Figure 4.2.2  Increase in friction with different numbers of studs.

Kallberg (1993)
A two-year test was carried out in Kuopio using less salt. On the roads tested, friction levels of less than 0.3 were twice as common as on salted roads. Less than 3% of the vehicle mileage was carried out at friction levels below 0.2.
4.3 Investigations made outside the Nordic countries

Dahir, Henry (1979)

In Pennsylvania, the friction of road surfaces seems to vary both in the short-term and from season to season. These variations make it difficult to establish a maintenance program in which friction is an essential factor. Day to day changes, caused by weather are superimposed on an annual variation cycle. The variations for five different asphalt surfaces and one concrete surface were studied in this project. The conclusions are as follows:

- Significant variations in friction from one season to another (15–30 units in SN), especially from early to late autumn and early to late spring. The SN₀ value is highest in early spring, then gradually sinks to a stable value from the middle of July to late November. This indicates that the surfaces are polished to a stable level in July.
- No matter what the season, there can be daily or weekly variations in friction of up to 25% caused by rain. After a downpour, there is always a lot of friction.
- Short-term variations in temperature – within 30 hours – seem to have little or no effect on friction.
- With regard to the stone used in the surface coating, sandstone gives small variations in friction, while limestone and dolomite, which are easily polished, produce quick changes that are also affected by precipitation.

Elkin, Kercher, Gulen (1980)

The friction properties of fifteen different asphalt surfaces were tested at speeds of 40, 50 and 60 mph, in order to identify the types of surfaces that retain satisfactory friction regardless of speed, season and climate factors such as rain and temperature. The results included the following:

- Friction coefficient SN₄₀ for the different surfaces varied from 23.8 to 61.8.
- Friction improves when the stone material contains slag.
- Friction is almost always greatest in the spring and least in the summer.
- Friction seems to be a function of temperature. However, the exact correlation has not been defined.

Hill, Henry (1981)

Measurements of the friction on road surfaces show that there are variations both in the short-term and from season to season. The short-term variations seem to be highly dependent on precipitation and temperature. Different tests indicate that friction may vary as much as 25% in the same week. The size of the friction coefficient SN₀ at a random time t can be expressed as:

\[ SN₀ = SN₉₀R + SN₉₀L + SN₉₀F \]

where \( SN₉₀R \) is the short-term variation, \( SN₉₀L \) is the long-term variation and \( SN₉₀F \) is a measurement of \( SN₀ \) irrespective of the superimposed variations.
\[ SN_{0L} = \Delta SN_0 \times \exp(-t/\tau) \]

where

\[ \Delta SN_0 = \text{the change in } SN_0 \text{ during the season measured, a function of the stone material’s polishing properties.} \]

\[ \tau = \text{polishing rate, a function of ADT.} \]

The following factors were introduced for the short-term variations:

1. For rain: dry-spell factor (DSF), \( DSF = \ln(t_R + 1) \), where \( t_R \) is the number of days since there was at least 2.5 mm of rain, but not more than 7 days.

2. For temperature: the temperature of the surface \( T_p \) (°C).

Multiple regression analysis produced the following correlation for two different regions (in Pennsylvania, and North Carolina and Tennessee):

\[ SN_{0R} = 3.79 - 1.17 \times DSF - 0.104 \times T_p, \ (r = 0.35) \]

and

\[ SN_{0R} = 1.88 - 0.77 \times DSF - 0.15 \times T_p, \ (r = 0.57). \]

The following conclusions are worth mentioning:

- Major variations in friction occur systematically during short periods, (from day to day or week to week).
- The mechanisms behind these variations seem complex. Rain and temperature seem to be the most significant causes of short-term variations.
- One important cause of the apparent variations in friction is errors in measurement, especially with regard to the measurements wheel’s lateral position. The error could be as great as 4 SN at 64 km/h.

**Kulakowski, Meyer (1989)**

The purpose of this study was to compare the friction of road surfaces on straight stretches of road and adjoining curves. The need for friction is greater in curves, because of the lateral forces that occur. At the same time, these lateral forces lead to the stone material being polished more in curves than on straight stretches of road, which probably leads to a reduction in friction.

The investigation was carried out in the state of New York and in Texas. Friction was measured with both worn tyres and tyres with good tread. The friction coefficient for the worn tyres was lower in curves than on straight stretches of road both in New York and in Texas. In Texas, the same conditions applied to the tyres with good tread. However, in New York there were no differences in the measurements taken on the straight stretches compared with those taken in the curves. This is probably due to the fact that winter affects the micro-texture of the surface in such a way that friction is improved.
5 Speed – stopping distances
5.1 Swedish investigations

It is not always possible to gauge the effects of traffic safety by studying accidents. Therefore, it is sometimes necessary to use indirect methods, for example, calculating the stopping and braking distances based on measured vehicle speeds and the friction between the tyres and road surface. Just because the braking distance is the same, it does not necessarily follow that the risk of accident or injury is the same since the reaction margins are greater at lower speeds and consequently any injuries incurred would be milder. Calculated stopping distances and accident rates have the same ranking when split into two types of road conditions (ice/snow and bare ground) and two types of tyres (cars with studded tyres and those without).

Öberg (1978b)

In this study, which was carried out in February 1977, both traffic and friction studies were carried out in northern Dalarna to investigate the increase in friction caused by spreading sand, the duration of the increase in friction and the way road users reacted with regard to variations in speed. The measurements were performed on stretches of road that are normally sanded, i.e. stretches of road with a flow of traffic less than 1,500 vehicles per day. The measurement data was used to calculate different indirect safety measurements such as stopping distances. It is important to be careful when making a safety-related interpretation of these indirect safety dimensions.

The sanding of the roads has resulted in the following changes on the test stretches between the period before the road was sanded until just after it was sanded. The summary below has taken these changes into account.

1. The change in the median friction on the road surface varied from a 0.03 reduction to a 0.18 increase in friction. The median was a 0.09 increase in friction.
2. The change in the median speed varied from a reduction of approx. 4 km/h to an increase of 11 km/h. The median was an increase of 2.4 km/h.
3. The change in the calculated median stopping distance varied from an 8 m increase to a 19 m reduction. The median was a reduction of 8 m.
4. The difference between the accessible side friction and the calculated, utilised side friction when driving in horizontal curves was greater. However, the calculated percentage of utilised side friction is approximately the same before sanding as it is after sanding.

If studies are carried out a longer time period after sanding, the following conclusions can be drawn:

1. The increase in friction as a result of sanding decreased gradually and after 300 vehicles had passed was completely nullified. However, there was a significant variation in duration between different stretches of road.
2. The increase in speed that was ascertained after sanding was relatively short-lived.
The increase in speed does not seem rational, i.e. there is no correlation between the difference in friction and the difference in speed in the total material. Therefore, the increase in speed after the road is sanded can probably not be explained by the actual level of friction but rather by the expectation of good friction that a newly sanded road should provide.

A profit and loss calculation with regard to sanding suggests that sanding is profitable from a traffic economy point of view.

Öberg (1981)
During the winters of 1978/79 and 1979/80, journey speeds and friction were measured on 20 stretches of roads with different standards of winter road maintenance. The journey speeds were also measured during the summer between these two winter periods. The journey speed and friction were measured over long stretches (see table 5.1.1). Friction was measured with a Saab Friction Tester using unstudded tyres.

Table 5.1.1  List of areas where measurements were taken.

<table>
<thead>
<tr>
<th>Vägnummer</th>
<th>Del</th>
<th>Vägbredd (m)</th>
<th>Årsgenomsnitt</th>
<th>Betäckning</th>
<th>Vägallaktor</th>
<th>Vintervägsförhållningslång</th>
<th>Mätsträckans längd (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>04</td>
<td>1</td>
<td>12,0</td>
<td>13,180</td>
<td>80 HAB (71)</td>
<td>VFEd 32</td>
<td>A</td>
<td>1114</td>
</tr>
<tr>
<td>04</td>
<td>2</td>
<td>12,0</td>
<td>13,179</td>
<td>80 HAB (74)</td>
<td>VFEd 32</td>
<td>A</td>
<td>2701</td>
</tr>
<tr>
<td>36</td>
<td>1</td>
<td>9,0</td>
<td>3,340</td>
<td>Järlingstorp (71)</td>
<td>VFEd 19</td>
<td>A</td>
<td>5389</td>
</tr>
<tr>
<td>36</td>
<td>2</td>
<td>8,0</td>
<td>3,720</td>
<td>Järlingstorp (79)</td>
<td>VFEd 19</td>
<td>A</td>
<td>2603</td>
</tr>
<tr>
<td>36</td>
<td>3</td>
<td>8,0</td>
<td>2,240</td>
<td>Y1 (78)</td>
<td>VFEd 32</td>
<td>A</td>
<td>1270</td>
</tr>
<tr>
<td>36</td>
<td>4</td>
<td>6,3</td>
<td>2,800</td>
<td>Y1 (75)</td>
<td>VFEd 22</td>
<td>A</td>
<td>2223</td>
</tr>
<tr>
<td>206</td>
<td>1</td>
<td>7,0</td>
<td>2,910</td>
<td>Y1 (77)</td>
<td>VFEd 23</td>
<td>A</td>
<td>1363</td>
</tr>
<tr>
<td>366</td>
<td>1</td>
<td>13,0</td>
<td>6,000</td>
<td>80 HAB (71)</td>
<td>VFEd 23</td>
<td>A</td>
<td>927</td>
</tr>
<tr>
<td>796</td>
<td>1</td>
<td>13,0</td>
<td>2,850</td>
<td>60 HAB (71)</td>
<td>VFEd 32</td>
<td>A</td>
<td>936</td>
</tr>
<tr>
<td>687</td>
<td>1</td>
<td>5,5 - 6,7</td>
<td>1,200</td>
<td>Y1 (77)</td>
<td>VFEd 14</td>
<td>A</td>
<td>2137</td>
</tr>
<tr>
<td>687</td>
<td>2</td>
<td>5,5 - 6,0</td>
<td>920</td>
<td>Y1 (77)</td>
<td>VFEd 14</td>
<td>B</td>
<td>2702</td>
</tr>
<tr>
<td>716</td>
<td>1</td>
<td>6,7</td>
<td>2,090</td>
<td>Y1 (73)</td>
<td>VFEd 19</td>
<td>A</td>
<td>1129</td>
</tr>
<tr>
<td>761</td>
<td>1</td>
<td>6,3</td>
<td>1,250</td>
<td>Järlingstorp (75)</td>
<td>VFEd 32</td>
<td>B</td>
<td>1912</td>
</tr>
<tr>
<td>761</td>
<td>2</td>
<td>5,2</td>
<td>650</td>
<td>Y2 (65)</td>
<td>VFEd 32</td>
<td>B</td>
<td>1927</td>
</tr>
<tr>
<td>761</td>
<td>3</td>
<td>5,2</td>
<td>650</td>
<td>Y2 (65)</td>
<td>VFEd 32</td>
<td>C</td>
<td>626</td>
</tr>
</tbody>
</table>

Table 5.1.2 lists the speeds related to different road conditions. The measurements were taken at different times of day (5 a.m.–11 p.m.), which means that even daily variations in speed are included in the speed levels listed. Furthermore, the level of friction may vary a great deal even if the condition of the road remains the same. Consequently, the speeds are uncertain and are sometimes based on short measurement periods and must therefore be regarded more as indications of the changes in speed that could occur.
Table 5.1.2  The median speed of cars (km/h) in different road conditions (including light snowfall/driven snow on ice/snow-covered roads. The interval specifies the lowest and highest median speeds from different measurement periods.

<table>
<thead>
<tr>
<th>Road</th>
<th>Summer bare ground</th>
<th>Winter</th>
<th>Winter</th>
<th>Winter</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>dry</td>
<td>moist</td>
<td>wet</td>
<td>thin ice</td>
</tr>
<tr>
<td>E4-1</td>
<td>97</td>
<td>93-97</td>
<td>92</td>
<td>90-93</td>
<td>73</td>
</tr>
<tr>
<td>E4-2</td>
<td>91</td>
<td>89-90</td>
<td>81*</td>
<td>81-85</td>
<td>77-78</td>
</tr>
<tr>
<td>34-1</td>
<td>91</td>
<td>92</td>
<td>90</td>
<td>90</td>
<td>73</td>
</tr>
<tr>
<td>34-2</td>
<td>90</td>
<td>84-92</td>
<td>90</td>
<td>89-93</td>
<td>76-80</td>
</tr>
<tr>
<td>34-3</td>
<td>91</td>
<td>94</td>
<td>87</td>
<td>91</td>
<td>79-85</td>
</tr>
<tr>
<td>32-1</td>
<td>81</td>
<td>85</td>
<td></td>
<td></td>
<td>71</td>
</tr>
<tr>
<td>32-2</td>
<td>85</td>
<td>87</td>
<td></td>
<td></td>
<td>73</td>
</tr>
<tr>
<td>32-3</td>
<td>84</td>
<td>83-86</td>
<td>85</td>
<td>78</td>
<td>75</td>
</tr>
<tr>
<td>206</td>
<td>87</td>
<td>83</td>
<td></td>
<td>81-82</td>
<td>77</td>
</tr>
<tr>
<td>636</td>
<td>90</td>
<td>89</td>
<td>89</td>
<td>74-78</td>
<td>82-84</td>
</tr>
<tr>
<td>796</td>
<td>86</td>
<td>84-87</td>
<td></td>
<td>75-81</td>
<td>67-80</td>
</tr>
<tr>
<td>211-1</td>
<td>69</td>
<td>70-75</td>
<td></td>
<td>53-54</td>
<td>54-55</td>
</tr>
<tr>
<td>211-2</td>
<td>67</td>
<td></td>
<td></td>
<td>57-61</td>
<td>54-61</td>
</tr>
<tr>
<td>687-1</td>
<td>73</td>
<td>75</td>
<td></td>
<td>69-74</td>
<td></td>
</tr>
<tr>
<td>687-2</td>
<td>69</td>
<td>68-72</td>
<td>66-68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>741-1</td>
<td>84</td>
<td>79</td>
<td></td>
<td></td>
<td>69-73</td>
</tr>
<tr>
<td>741-2</td>
<td>85</td>
<td>82-84</td>
<td></td>
<td></td>
<td>68-79</td>
</tr>
<tr>
<td>716</td>
<td>82</td>
<td>83</td>
<td>79-83</td>
<td></td>
<td>70-75</td>
</tr>
<tr>
<td>761</td>
<td>88</td>
<td>85-86</td>
<td>84-86</td>
<td></td>
<td>73-76</td>
</tr>
</tbody>
</table>

* newly salted

A very rough estimate is that speeds on an icy/snowy road are 75–90% of those on bare ground.
Different snow depths were measured on two roads each with a speed limit of 90 km/h and a width of 13 m. When an interval is specified, it means that there are results from several different measurements.

**Table 5.1.3** The median speeds of cars with different depths of snow on the road.

<table>
<thead>
<tr>
<th></th>
<th>dry bare ground</th>
<th>thin ice swirling snow</th>
<th>snow depth (max. on road surface)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 cm</td>
</tr>
<tr>
<td>lv 636</td>
<td>89</td>
<td>82-84</td>
<td>80-82</td>
</tr>
<tr>
<td>lv 796</td>
<td>84-87</td>
<td></td>
<td>75-80</td>
</tr>
</tbody>
</table>

Speed levels are reduced quickly when the condition of the road changes from dry, bare ground to a thin layer of snow. When there is more than 1–2 cm of snow on the road, it seems that the median speed is reduced by just under 3 km/h for each additional cm of snow. See table 5.1.3.
There are also measurements that show the effects of different amounts of snow. The road is totally or partially covered with packed snow (PS) or just a thin layer of ice (TI). See table 5.1.4.

**Table 5.1.4** The effects of snowfall (SF) and snowdrift (SD) on the median speed of cars. L=light, M=medium and K=heavy.

<table>
<thead>
<tr>
<th></th>
<th>PS</th>
<th>+LSF</th>
<th>+LSF +LSD</th>
<th>+MSF</th>
<th>+MSF+LSD</th>
<th>+MSF+MSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>lv 741-1</td>
<td>73-74</td>
<td>68-74</td>
<td></td>
<td></td>
<td></td>
<td>58-68</td>
</tr>
<tr>
<td>lv 741-2</td>
<td>68-72</td>
<td>68-69</td>
<td>67-69</td>
<td>66-68</td>
<td>66-71</td>
<td>74</td>
</tr>
<tr>
<td>lv 796</td>
<td>72</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>63-65</td>
</tr>
<tr>
<td>lv 741-2</td>
<td>73-74</td>
<td>68-74</td>
<td></td>
<td></td>
<td></td>
<td>58-68</td>
</tr>
<tr>
<td>lv 741-2</td>
<td>68-72</td>
<td>68-69</td>
<td>67-69</td>
<td>66-68</td>
<td>66-71</td>
<td>74</td>
</tr>
<tr>
<td>lv 796</td>
<td>72</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>63-65</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>TI</th>
<th>+LSF</th>
<th>+MSF</th>
<th>+KSF</th>
<th>+MSF+LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>E4-2</td>
<td>77-78</td>
<td>78</td>
<td>76</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>lv 206</td>
<td>81-82</td>
<td>75 (+MSD)</td>
<td>81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>lv 636</td>
<td>74-78</td>
<td>76</td>
<td>78</td>
<td>70</td>
<td></td>
</tr>
</tbody>
</table>

Speeds are often reduced with increasing in the amounts of snow or snowdrifts. The greatest reductions in speed are approx. 15 km/h compared with the same road condition without snowfall and snowdrifts and another 10 km/h lower than when the ground is bare. When the surface of the road is slippery and the temperature rises above 0 °C there is less friction and speed is reduced.

The adaptation of speed to slippery roads (friction) is somewhat better on smaller roads than it is on larger ones because on the whole, the reduction in speed is similar on all types of roads.

When there is low friction, the lowest speeds have often been measured in connection with relatively heavy snowfall and the highest speeds are often measured when the snow first starts to fall, i.e. when the road users have not yet discovered that the conditions have become slippery (less friction). There are also occasions road users drive as if the road condition were wet, bare ground rather than wet, thin ice. On other occasions when "low" speeds are recorded at high, median friction, it may be due to the fact that there are sections with lower friction that are visible in the lower range of the distribution of friction (e.g. the 15 percentile), but which are not visible in the median. On E4-2, very low friction was recorded (0.05) and the median speed sank gradually to a standstill. The vehicles could not make it up the relatively small hills on that stretch of road. At this time there was a thin, brown film on the surface of the road and it almost looked like "slushy, wet, bare ground"

The difference between the 50 percentile (median) shown above and the 85 percentile in the distribution of speed is approx. 10 km/h on bare ground and 2–3 km/h greater when the road is covered with a layer of ice and/or snow. This applies if all data is taken into consideration. However, individual measurements can give different results.
The purpose of the study was to investigate how much more slippery the unsalted roads were and whether there were different levels of friction on salted and unsalted roads as well as to determine whether there was any difference in the adaptation of speeds depending on whether the road surface was salted or unsalted.

During the winter of 1980/81, two roads in Östergötland that were previously salted were kept free from salt.

The conditions of these roads were studied five days a week during five months of the winter. The investigations showed that these test stretches were covered with ice and/or snow for 30% and 41% of the time respectively. The corresponding measurements for the control stretches were 19 and 28% respectively.

Whenever there was a good chance that the road would be covered with ice and/or snow, friction and speed measurements were carried out. These measurements continued until one of the roads became bare. The results of the friction measurements indicate low friction values both on the test stretches and the control stretches. There was no difference between the test and control stretches when the variations in longitudinal and transverse friction were studied.

It is difficult for the road user to adapt the speed to the condition of the road/friction. The following function is used to study this

\[
v = v_B f^{\frac{1}{n}}
\]

where

\[
v = \text{speed on a slippery road}
\]
\[
v_B = \text{speed on dry, bare ground in the summer}
\]
\[
f = \text{the road friction on a slippery road measured with the Saab Friction Tester, tyres without studs}
\]
\[
n = \text{a figure that indicates how the road users adapts to the friction of the road.}
\]

The lower the number, the better the adjustment made by the driver. If the speed is adjusted so that \( n = 2 \), it means that the calculated braking distance would be equally as long at all levels of friction, assuming that the friction = 1 when the ground is bare.

In connection with the calculations, the 50 percentiles were used in the distribution of speed and friction. The \( n \) values varied between 5.5 and 12.5 and seem to be slightly lower on the smaller roads. However, there is a great deal of uncertainty surrounding these numbers.

If braking distances are calculated, the results show that they do not increase very much from bare ground friction (0.8–0.9) down to friction levels around 0.4. The reason for this is that the road user does a good job of adjusting the speed to the friction. However, at friction levels of less than 0.2, the braking distance increases rapidly with the reduction in friction, i.e. the road user is not very good at adjusting the speed of the vehicle.

On certain types of roads, the vehicle maintains the same speed for the same conditions regardless of whether the road is salted or not. Road users did not even reduce their speeds when the roads were not salted and signs were placed along
the side of the road. Consequently, it is the road conditions of the road itself that determines the speed not the type of winter road maintenance that is performed on the road.

Öberg, Gregersen (1991)
As part of the MINSALT project, the spot speed was recorded on E4 in the County of Västerbotten during the winters of 1986/87 and 1987/88. At this point, E4 is 9 m wide and the median daily traffic, on an annual basis, is approx. 4,000 vehicles per day. The speed limit on E4 is 90 km/h. Speeds were recorded all winter long (during both of these seasons) and the condition of the road was studied at least once every weekday. The median daily speed is attributed to the road conditions observed. Consequently, it is possible that the condition of the road could have been different from that which is presented here. Friction was measured with BV11 and tyres without studs. The measurement points were on straight, flat sections of the road. See table 5.1.5.

### Table 5.1.5
The friction of the road surface and the median speeds of the cars (km/h) in different conditions on E4 in Västerbotten.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Speed</th>
<th>Friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry, bare ground</td>
<td>99,0</td>
<td>0,93</td>
</tr>
<tr>
<td>Moist/wet, bare ground</td>
<td>95,3</td>
<td>0,80</td>
</tr>
<tr>
<td>Spots/traces of bare ground</td>
<td>95,2</td>
<td>0,9-0,15</td>
</tr>
<tr>
<td>Spots/traces of thin ice</td>
<td>92,0</td>
<td>0,11</td>
</tr>
<tr>
<td>Hard snow and/or ice</td>
<td>93,1</td>
<td>0,27</td>
</tr>
<tr>
<td>Loose snow and/or ice</td>
<td>93,0</td>
<td>0,16</td>
</tr>
</tbody>
</table>

The median speed of passenger cars on dry bare ground is slightly higher than indicated by VTI's measurements, primarily those from Gotland. The speeds recorded in all conditions were above the applicable speed limit. When there was a lot of snow "smoke", the median speed often dropped to 75 km/h. The same daily, median speed was maintained over one 24-hour period in which there was 24 mm of rain and this was the lowest daily median speed recorded. This indicates that the driver's visibility is more important than the condition of the road or friction with regard to speed.

The first time the road is covered with ice or snow in the autumn, it seems as if speeds are lower than when the same conditions recur later in the winter. However, there is less traffic in the middle of winter than there is in the beginning and in the end. This in itself could have an effect on the speed levels. However, something that could affect these levels even more is if the "careful" drivers are the ones that do less driving in the winter.
Öberg et al. (1991)
As part of the MINSALT project, the spot speed was measured on streets and roads on Gotland in different weather and with different road conditions. The measurements were carried out during the winters of 1985/86 and 1986/87. The median speed on Gotland is lower than that on the mainland. The median speed on country roads between 6 and 7 metres wide, with a speed limit of 90 km/h varies between 75 and 81 km/h when the road is bare. There is a median reduction in speed of 6.5 km/h when the roads are covered with ice and/or snow. The lower percentiles drop slightly more than the higher ones. During a snowfall or when snowdrifts are forming, the speed can be 20 km/h lower than on bare ground. In Visby, measurements were carried out on Visbyleden (speed limit 70 km/h, 11 metres wide) and Färjeleden (speed limit 50 km/h, 10 metres wide). Median speeds of approx. 67 km/h and 56.5 km/h were measured on Visbyleden and Färjeleden respectively when the ground was bare. There is only a slight reduction in speed (a couple of km/h) when the roads are covered with ice and/or snow.

Möller, Wallman, Gregersen (1991)
Measurements taken in Göteborg indicate that speeds are reduced from 55 km/h on dry, bare ground to less than 41 km/h (at which point measurements were no longer taken) when it had snowed in the morning and the night before. In addition to a reduction in median speed, it seems as if there was also less variation in the speed distribution. At the time the measurements were taken, the road conditions were very slippery with friction levels of 0.10–0.15 (measured with the Saab Friction Tester (SFT) and tyres without studs).

Öberg (1994a)
In one Nordic project, SPORADIC salting tests were carried out in the centre of Linköping and speeds were measured for different road conditions. The speed limit on each of the streets where measurements were taken was 50 km/h and the median annual daily traffic varied from 2,000–20,000. On wet but bare roads, the median value of the hourly medians varied from 52 to 58 km/h for different streets (measured at a point between intersections). Just before intersections at which the traffic only turned, the corresponding speed is 27–28 km/h. When the roads were covered with snow and/or ice there was a slight reduction in speed (a couple of km/h). The difference in the hours with the highest and lowest median speeds is approx. 10 km/h. The friction (median value over the longer stretches; measured with SFT and tyres without studs) varied from 0.20 to 0.85 with the different measurements. In Køge, a suburb of Copenhagen, reductions in speed of up to 15 km/h were measured in connection with winter conditions, regardless of whether the bare ground speed was 60, 70 or 80 km/h. Only 5% of Køge’s residents use studded tyres (i.e. the snow/ice is not rough) and this could cause the conditions to be more slippery there. Furthermore, the bare ground speed is higher than in Linköping, which may explain the greater reduction in speed.
In measurements carried out in northern Sweden, on roads with speed limits of 110 and 90 km/h respectively, median speeds were reduced by 8±5 km/h and 6±2 km/h with the transition from bare ground to icy/snowy conditions. On the whole, these figures correspond with those for icy/snowy roads when little or no snow is falling. When snowfall is moderate, however, the reduction in speed was 12 km/h and 24 km/h when it was heavy. These figures are for roads with 90 km/h speed limits. The corresponding reduction for roads with speed limits of 110 km/h were slightly higher. There is a great deal of uncertainty connected with these figures because they are based on a small number of measurements.

Since the condition of the road was described in fairly good detail, this information has been used in a regression analysis to obtain indications of how, for example, a central strip affects speeds. Here, as well, three hours of speed data concerning the road conditions.

The model does not include information about the total flow of vehicles or of trucks, nor does it include information about daylight or darkness. This means that the correlation coefficient is not as good as it should be in the following models.

Model APPROACH: \[ Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_i X_i + \varepsilon \]

Dependent variable Y is the median speed of cars without trailers (PUV). Independent variables \( X_1, X_2, \ldots, X_i \) are:

- **HAST** = 1 if the speed limit is 110 km/h, otherwise 0 (90 km/h)
- **VB89** = 1 if the road is 8 or 9 metres wide, otherwise 0 (13 metres)
- **VLAG** = 1 if the road is covered with ice and/or snow, otherwise 0 (bare ground/dry, moist and wet/)
- **LS** = 1 if loose snow on the road, otherwise 0
- **MITT** = 1 if there is a central strip, otherwise 0
- **VK** = 1 if there is a side strip, otherwise 0
- **NED** = 1 if there is precipitation, otherwise 0

\( \alpha \) and \( \beta_i \) are regression coefficients that are determined in the regression analysis.

\( \varepsilon \) is the residual, i.e. the random variation that is not explained by the regression equations.

If data from the winters of 94/95 and 95/96 is used, the following models are obtained:

**Northern Region**

PUV=95.3-0.8*HAST-1.3*VB89-2.1*VLAG-4.2*MITT-2.6*LS+1.5*VK-2.1*NED

All the coefficients, except VK, are significant at a 5% risk level. Correlation coefficient (\( R^2=0.42 \)) means that the model clarifies approx. 42% of the variation in the dependent variable.

The regression model shows that if there is ice and/or snow on the road, the median speed is reduced by just over 2 km/h compared with speeds when the road
is bare. If there is a central strip of ice and/or snow, speeds are reduced by a further 4 km/h. And if there is loose snow on the road, the speed is reduced by a further 2-3 km/h. The total effect of all these conditions is a reduction of almost 9 km/h. Precipitation (= reduced visibility) causes a further reduction in speed of approx. 2 km/h, i.e. a total reduction of 11 km/h.

The difference between wide and normal roads (8–9 m) is just over 1 km/h. A somewhat surprising result is obtained on roads with the different speed limits. The speeds on roads with speed limits of 110 km/h is almost 1 km/h lower than that on roads with speed limits of 90 km/h. There could be a common variation between the variables which means, for example, that the effects of the road conditions are, instead, attributed to the type of road in question.

Central Region

$$PUV=94,6-4,5*V_{B89}-2,5*V_{LAG}-3,6*M_{ITT}-3,8*LS-1,9*V_{K}-2,2*NED$$

All the coefficients is significant at a 5 % risk level. $$R^2=0,48$$

The effects of roads covered with ice and/or snow, central strip of snow and precipitation are the same in both regions. In the central region, the total effect is approx. 12 km/h. In the central region, the coefficients for a string of ice/snow on the edge of the road differs significantly from zero and these coefficients are also negative, which seems more reasonable. In the central region, there is only data from roads with speed limits of 110 km/h, which is why the variable "HAST" is missing here.

Öberg (1994b)

During 1994, the results of speed measurements were summarised and used to compile table 5.1.6 below. The measurements used in the different studies are listed without being converted to the same units. It is important to remember that these results are maximised and that some of them are poorly supported. The aim is to illustrate the variations that can occur.
**Table 5.1.6** Reductions in speed (km/h) based on different weather/road conditions in different studies.

<table>
<thead>
<tr>
<th>Differences in speed (km/h) in relation to different weather conditions in different studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB-IS</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>6.5</td>
</tr>
<tr>
<td>6.5</td>
</tr>
<tr>
<td>&lt;3</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>7-19</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Definitions:
TB = dry, bare ground, IS = ice/snow, SF = snowfall, SD = snowdrift, mv = mean value, 50p = median, res = travelling speed, point = spot speed. Numbers in brackets refer to individual values.

**Möller (1996)**
The aim of the project was to investigate the usefulness of considering the condition of the road when adding flow of traffic and speed data that was not included in the Swedish National Road Administration’s annual accounting points.

The data that was collected during the winter of 1991/92 included vehicle speed and observations of road conditions from 14 annual accounting points across the country. A regression analysis of the speeds dependency on the condition of the road was carried out based on this data. The result for passenger vehicles (without trailers) is shown in the table 5.1.7 on the following page.
Table 5.1.7  The spot speed (including confidence interval) on weekdays in the middle of winter with little traffic, daylight and dry, bare ground and the difference in speed (including confidence interval) in different road conditions. Vehicle group: Cars without trailers. An asterisk (*) means that there is a significant difference in speed compared with zero at a 5% risk level.

<table>
<thead>
<tr>
<th>Measuring location</th>
<th>Spot speed/diff. in speed (km/h) in different road conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry, bare ground</td>
</tr>
<tr>
<td>Nymö</td>
<td>81.8 ± 0.4</td>
</tr>
<tr>
<td>Knislinge</td>
<td>94.2 ± 1.0</td>
</tr>
<tr>
<td>Gistad</td>
<td>99.3 ± 0.8</td>
</tr>
<tr>
<td>Vimmerby</td>
<td>99.0 ± 1.5</td>
</tr>
<tr>
<td>Gödestad</td>
<td>95.4 ± 1.0</td>
</tr>
<tr>
<td>Ödeborg</td>
<td>89.2 ± 0.4</td>
</tr>
<tr>
<td>Karlsstad</td>
<td>103.6 ± 0.8</td>
</tr>
<tr>
<td>Falun</td>
<td>100.4 ± 0.9</td>
</tr>
<tr>
<td>Jordbro</td>
<td>82.9 ± 0.7</td>
</tr>
<tr>
<td>Handen</td>
<td>79.7 ± 1.2</td>
</tr>
<tr>
<td>Ramsele</td>
<td>82.8 ± 1.7</td>
</tr>
<tr>
<td>Svenstavik</td>
<td>96.8 ± 1.4</td>
</tr>
<tr>
<td>Boden</td>
<td>92.4 ± 2.1</td>
</tr>
<tr>
<td>Norrfjärden</td>
<td>96.7 ± 1.0</td>
</tr>
</tbody>
</table>

5.2 Nordic investigations

Ruud (1981)
The conditions that we wished to illuminate in the investigation were as follows:
- The variation in speed on salted and unsalted roads in relation to snowfall.
- The variation in speed with the condition of the road in more general terms.
- The variation in speed during the day according to different friction levels.

The measurements were carried out on two stretches of road in Akerhus and Vestfold respectively; E 18 (Holm) and Rv 153 (Tomter) and E 18 (Hemsenga) and Rv 312 (Semslinna). In both cases, E 18 was salted, while the national highways were unsalted. Examples of the results of the measurements are listed in tables 5.2.1 and 5.2.2.
Table 5.2.1  Data for the measurement stretches.

<table>
<thead>
<tr>
<th>Road</th>
<th>Speed limit</th>
<th>ADT (Annual Daily Traffic)</th>
<th>Road maintenance measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>E18 Holm</td>
<td>80</td>
<td>4 000</td>
<td>salt</td>
</tr>
<tr>
<td>E18 Hemsenga</td>
<td>80</td>
<td>3 300</td>
<td>salt</td>
</tr>
<tr>
<td>Rv 153 Tomter</td>
<td>80</td>
<td>6 500</td>
<td>no salt</td>
</tr>
<tr>
<td>Rv 312 Semslinna</td>
<td>80</td>
<td>8 000</td>
<td>no salt</td>
</tr>
</tbody>
</table>

Table 5.2.2 Median speeds for different road conditions on salted and unsalted roads.

<table>
<thead>
<tr>
<th>Road no.</th>
<th>Ice and packed snow</th>
<th>Road cond.</th>
<th>Bare ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>E 18</td>
<td>Median-speed (km/h)</td>
<td>73.5</td>
<td>76.1</td>
</tr>
<tr>
<td>Rv 312 + 153</td>
<td>Median-speed (km/h)</td>
<td>68.7</td>
<td>70.7</td>
</tr>
</tbody>
</table>

In summary, we can ascertain that:

- The speeds on the salted European highways varied less with the conditions of the road than they did on the unsalted national highways. On icy/snowy roads, there was a reduction in speed of 5.4–6.5 km/h on the European highways compared with 6.7–8.7 km/h on the national highways. (Based on the results of each partial stretch).
- On the whole, the speeds on very slippery roads were approx. the same as those on less slippery roads.

**SINTEF (1987)**

During the winter, slippery roads often cause disturbances in the flow of traffic. Steep inclines often cause the greatest problems. The purpose of this investigation was to study this problem. In 1986, two steep inclines were measured with regard to friction, speed, flow of traffic, headway and the number of vehicles in a "the queue".

According to the speed measurements, the median reduction in speed on winter roads is 10 km/h compared to summer roads. The headway between vehicles increases by approx. 0.6 seconds. Calculated stopping distances show that the reduction in speed on winter roads, from a traffic safety point of view, is insufficient to compensate for the reduction in friction.

"Vedlikeholdsstandarden for Statens Vegvesen" recommends sanding hills when the friction coefficient is less than 0.25.

Once the road is sanded, the friction coefficient increases to approx. 0.35. The speed is, on median, 8 km/h lower after sanding. This unexpected reduction in speed can be explained in part by the fact that only a short stretch of road was sanded and the road user "believes" the road is slippery because it was sanded.
The headway for vehicles in a "queue" is somewhat greater after sanding. According to the calculated stopping distances, the level of traffic safety after sanding is the same as it is in the summer.

According to a calculation of road user and road maintenance costs, it is possible to sand the road every weekday for two months for the same amount that a one-hour "stoppage" in traffic costs.

**Sistonen, Seise (1990)**

Friction (Skidding Tester ST-1 side friction 8° angle) was measured on a few roads. The friction was divided into four different groups:

\[
\begin{align*}
    f < 0.27 & \quad \text{very slippery} \\
    0.27 < f < 0.39 & \quad \text{slippery} \\
    0.39 < f < 0.50 & \quad \text{satisfactory grip} \\
    0.50 < f & \quad \text{good grip}
\end{align*}
\]

In a statistical analysis, friction was explained by temperature, winter road maintenance and rain. The correlation was high but the applicability was low since important factors were missing.

Free vehicles speed was measured. When the condition of the road changed from good to slippery there was only a slight reduction in speed, which means that the calculated stopping distance increased by approx. 30%. On very slippery roads, the stopping distance decreased in comparison with slippery roads. See table 5.2.3

**Table 5.2.3** Driving speed of cars and calculated stopping distances in different road conditions.

<table>
<thead>
<tr>
<th>Classification of slipperiness</th>
<th>1. Highway 3 speed limit 80 km/h</th>
<th>2. Local road 2834 speed limit 60 km/h</th>
<th>3. Highway 54 speed limit 100 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>speed km/h</td>
<td>stopping distance; m</td>
<td>speed km/h</td>
</tr>
<tr>
<td>Satisfactory - good grip μ &gt; 0.39</td>
<td>79.2</td>
<td>78.3</td>
<td>60.3</td>
</tr>
<tr>
<td>Slippery 0.27 &lt; μ ≤ 0.39</td>
<td>78.1</td>
<td>101.3</td>
<td>57.7</td>
</tr>
<tr>
<td>Very slippery μ ≤ 0.27</td>
<td>72.3</td>
<td>95.7</td>
<td>46.0</td>
</tr>
</tbody>
</table>

Vuni rapport 423A
Saastamoinen (1993)
Reducing the speed limit from 100 to 80 km/h meant a reduction in speed of less than 4 km/h. When there was good friction, 0.36–0.45, the speed was reduced by 0–3 km/h. When the conditions were fairly slippery (friction 0.26–0.35), speed was reduced by 3–6 km/h and by 4–7 km/h when the road was slippery (friction <0.26) compared with good conditions (friction >0.45). The winter conditions caused the faster drivers to reduce their speeds more than the slower drivers, which in turn reduced the distribution of the reduced speed.

Roine (1993)
The behaviour of the drivers when driving in queues and sharp curves was studied. Some of the vehicles were equipped with studded tyres and others were not. The measurements were performed on slippery roads. When the road conditions were slippery, the median speed in the curves was 6 km/h lower than when the road was dry or wet but bare. The safety margin was lower in the slippery conditions. Vehicles with studded tyres drove slightly faster in the curves, but there was little difference in the safety margin compared with the vehicles without studded tyres.

The vehicles with studded tyres drove slightly faster in the queues than those without studded tyres. However, there were no significant differences in the safety margins.

Approximately 20–30% of the drivers in queues leave such a small margin of safety that unexpected braking leads to a dangerous situation and possibly accidents.

Kalenoja, Mäntynen (1993)
In Kuopio, the unsalted roads lead to a very slight reduction in the median speed of heavy trucks. On the other hand, lower speeds (the 5th percentile) were reduced by 6–10%. Only a minor part of the risk of delay is caused by winter road conditions.

When the use of salt (the amount) was reduced, the median travel time increased by 1–5%. Unstudded tyres increased travel time by 2%. It is unclear as to whether this applies to heavy or light vehicles.

Gjæver (1993)
The aim of the investigation was to study the effects that the condition of the road had on flow, speed and headway. The measurements were carried out on three sections of E6; in Taraldrud south of Oslo and in Klettstigningen and Heimdal south of Trondheim. These sections have two lanes and a speed limit of 80 km/h. The ADT in Taraldrud is 20,000 and 16,000–17,000 vehicles for both of the other stretches. The results are presented in table 5.2.4.
Table 5.2.4  Median speeds in different weather and road conditions, between the hours of 06.00–10.00.

<table>
<thead>
<tr>
<th>Weather-/road conditions</th>
<th>Average speed km/h</th>
<th>Taraldrud</th>
<th>Heimdahl</th>
<th>Klettstigningen</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>North (rush hour)</td>
<td>South</td>
<td>North (rush hour)</td>
</tr>
<tr>
<td>Dry weather, dry bare road</td>
<td>63.9</td>
<td>80.3</td>
<td></td>
<td>68.4</td>
</tr>
<tr>
<td>Dry weather, wet bare road</td>
<td>55.6</td>
<td>78.3</td>
<td></td>
<td>67.2</td>
</tr>
<tr>
<td>Dry weather, snow-clad</td>
<td>45.6</td>
<td>72.8</td>
<td></td>
<td>64.7</td>
</tr>
<tr>
<td>Dry weather, tracks worn, dry</td>
<td>–</td>
<td>–</td>
<td></td>
<td>65.3</td>
</tr>
<tr>
<td>Dry weather, tracks worn, icy</td>
<td>–</td>
<td>–</td>
<td></td>
<td>62.7</td>
</tr>
<tr>
<td>Rain, wet bare road</td>
<td>46.9</td>
<td>(rain)</td>
<td>72.7</td>
<td>67.8</td>
</tr>
<tr>
<td>Rain, snow-clad</td>
<td>(rain)</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Snow, wet bare road</td>
<td>56.9</td>
<td>(snow)</td>
<td>79.0</td>
<td>60.5</td>
</tr>
<tr>
<td>Snow, tracks worn, dry</td>
<td>(snow)</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Snow, tracks worn, icy</td>
<td>55.8</td>
<td></td>
<td>64.3</td>
<td>61.8</td>
</tr>
<tr>
<td>Fog, dry bare road</td>
<td>51.0</td>
<td>(fog)</td>
<td>76.9</td>
<td>–</td>
</tr>
<tr>
<td>Fog, wet bare ground</td>
<td>(fog)</td>
<td>66.6</td>
<td>72.8</td>
<td>67.5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>62.1</td>
<td>79.8</td>
<td>66.2</td>
<td>73.0</td>
</tr>
</tbody>
</table>

Mäkinen et al. (1994)

The aim of this investigation was to study the changes in the behaviour of the drivers when they changed from studded tyres to tyres without studs on their own cars. The drivers recorded each of their trips. Two cars equipped with instruments (with and without studs) were also used to measure the different effects. The test drivers were allowed to drive with the same types of tyres as they use in private.

There was no change in the number or length of the trips when the drivers changed to unstudded tyres. During the first winter, there was an increase in the speed of the cars without studded tyres, especially on highways with good road conditions. The cars without studded tyres reduced their speeds in the curves more than those with studded tyres. The cars without studded tyres braked softer on slippery secondary roads. During the second winter, the drivers who did not have studded tyres drove pretty much the same as when they where using studded tyres. This winter, as well, they drove slower in the curves than the cars with studded tyres. The cars without studded tyres drove slower in densely populated areas than those with studded tyres. On median, cars without studded tyres remained 11 metres further behind the vehicle in front of them. The drivers who tried
driving without studded tyres were pleased and wanted to continue. Twenty five percent of those who drove with studded tyres considered changing to tyres without studs.

**Heinijoki (1994)**
The aim of this project was to determine how much consideration drivers give to slippery road conditions and the type or quality of the tyres they use. The friction was divided into four groups (>0.45; 0.35–0.45; 0.25–0.35; <0.25). In general, all of the drivers had a hard time judging the level of friction on the road. Less than 30% were able to judge it properly and 27% were 2-3 groups from the correct one. The error was greater the more slippery the road became. No difference in speed was recorded between the vehicles with and without studded tyres regardless of whether there was high or low friction.

The winter speed limit of 80 km/h was considered a guideline and a safe speed when driving on slippery roads. There were sections where the speed level was higher on slippery roads than on bare roads.

**Sakshaug, Vaa (1995)**
Two studies were carried out based on accidents that resulted in personal injury, and that were reported to the police:

**Part 1**
A before and after study of the accident effect of salting a previously unsalted road network.

**Part 2**
A comparative study of a salted and an unsalted road network. The study comprised sections of the main road network across the country. 839 km of road were salted while 540 km of the sections being studied were not.

The study also included speed measurements. The results are presented in Table 5.2.5.

**Table 5.2.5 Reduction in speed in relation to different weather and road conditions.**

<table>
<thead>
<tr>
<th>Road and weather conditions</th>
<th>Reduction in speed.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median speed on dry, bare ground: 72–84 km/h</td>
<td></td>
</tr>
<tr>
<td>Wet, bare ground and snowfall</td>
<td>-4.2</td>
</tr>
<tr>
<td>Slush and snowfall</td>
<td>-7.1</td>
</tr>
<tr>
<td>Loose snow and snowfall</td>
<td>-7.9</td>
</tr>
<tr>
<td>Packed snow and snowfall</td>
<td>-8.1</td>
</tr>
<tr>
<td>Ice and snowfall</td>
<td>-7.7</td>
</tr>
<tr>
<td>Bare in the tracks and snowfall</td>
<td>-4.9</td>
</tr>
<tr>
<td>Slippery in the tracks and snowfall</td>
<td>-6.0</td>
</tr>
<tr>
<td>Ice and rain</td>
<td>-11.7</td>
</tr>
</tbody>
</table>
5.3 Investigations made outside the Nordic countries
Durth, Hanke (1984)
The analysis was carried out on three typical, straight, horizontal sections of road: highway (Autobahn) A60, national highway (Bundesstraße) B 45 and national highway B 26, see Table 5.3.1.

The condition of the roads was divided into four classes; “dry”, “wet”, “slippery” and “salted”. There was no differentiation between the different types of slippery road surfaces. See Table 5.3.2.

**Table 5.3.1** Data for measurement sections.

<table>
<thead>
<tr>
<th>Road</th>
<th>Width</th>
<th>ADT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A60</td>
<td>29</td>
<td>40,000</td>
</tr>
<tr>
<td>B45</td>
<td>9.5</td>
<td>15,000</td>
</tr>
<tr>
<td>B26</td>
<td>7.5</td>
<td>9,000</td>
</tr>
</tbody>
</table>

**Table 5.3.2** Median speeds for the three sections with different road conditions.

<table>
<thead>
<tr>
<th>Road</th>
<th>Slippery</th>
<th>Salted</th>
<th>Wet</th>
<th>Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 60</td>
<td>63</td>
<td>85</td>
<td>91</td>
<td>112</td>
</tr>
<tr>
<td>B 45</td>
<td>37</td>
<td>77</td>
<td>86</td>
<td>90</td>
</tr>
<tr>
<td>B 26</td>
<td>34</td>
<td>61</td>
<td>70</td>
<td>71</td>
</tr>
</tbody>
</table>

Durth, Hanke, Levin (1989a)
The aim was to investigate the extent to which the ploughing and salting of public highways affects the accessibility and safety. The study was carried out on five sections of road in the vicinity of Darmstadt (Table 5.3.3).

The study comprised speed and flow measurements in connection with different road conditions, i.e. dry, wet and slippery and before and after maintenance. There was no differentiation between the different types of slippery road surfaces. Only on very few occasions were the conditions anything other than loose or packed snow (Table 5.3.4).

**Table 5.3.3** Data for the measurement sections.

<table>
<thead>
<tr>
<th>Road</th>
<th>Width</th>
<th>ADT</th>
</tr>
</thead>
<tbody>
<tr>
<td>B26</td>
<td>7.0</td>
<td>8 840</td>
</tr>
<tr>
<td>B45</td>
<td>8.5</td>
<td>14 148</td>
</tr>
<tr>
<td>L3094</td>
<td>7.5</td>
<td>7 162</td>
</tr>
<tr>
<td>L3106</td>
<td>5.2</td>
<td>1 240</td>
</tr>
<tr>
<td>K137/138</td>
<td>6.5</td>
<td>2 919</td>
</tr>
</tbody>
</table>
Table 5.3.4  Median speeds in connection with different road conditions.

<table>
<thead>
<tr>
<th>Measurement point</th>
<th>Slippery</th>
<th>Road conditions</th>
<th>Wet</th>
<th>Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>B26</td>
<td>45.4</td>
<td>60.0</td>
<td>61.4</td>
<td>68.0</td>
</tr>
<tr>
<td>B45</td>
<td>41.8</td>
<td>56.7</td>
<td>77.6</td>
<td>81.5</td>
</tr>
<tr>
<td>L3094</td>
<td>45.8</td>
<td>59.3</td>
<td>74.7</td>
<td>77.7</td>
</tr>
<tr>
<td>L3106 direction 1</td>
<td>47.6</td>
<td>56.3</td>
<td>69.0</td>
<td>70.6</td>
</tr>
<tr>
<td>L3106 direction 2</td>
<td>40.4</td>
<td>52.3</td>
<td>67.5</td>
<td>68.1</td>
</tr>
<tr>
<td>K137</td>
<td>49.1</td>
<td>56.7</td>
<td>77.9</td>
<td>85.6</td>
</tr>
<tr>
<td>K138</td>
<td>45.1</td>
<td>56.7</td>
<td>67.6</td>
<td>79.6</td>
</tr>
</tbody>
</table>

Durth, Hanke, Levin (1989b)

Up till now, salt has been regarded as an irreplaceable method of skid control on German highways. In an attempt to achieve a sensible compromise between traffic safety and environmental requirements, some road maintenance authorities have tried reducing the amount of salt they use. Certain sections in these “white nets” – with little traffic and few accidents – were selected, where fine gravel is normally used instead of salt or where ploughing is the only method of road maintenance (see Table 5.3.5). The aim of this project was to study the effects that this kind of limited winter road maintenance would have road on accessibility and on traffic safety.

The tests were carried out in Bavaria and Hessen. In Bavaria, crushed stone sand was used instead of salt while in Hessen no action whatsoever was taken. However, this is a modified truth – when the roads became very slippery, they were salted (in both states) to avoid catastrophic traffic safety situations. The median speeds in connection with different road conditions are listed in Tables 5.3.6 and 5.3.7.

Table 5.3.5  Data for measurement sections.

<table>
<thead>
<tr>
<th>Road</th>
<th>Width</th>
<th>ADT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bavaria</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B307</td>
<td>8.5</td>
<td>3,978</td>
</tr>
<tr>
<td>St2075</td>
<td>6.5</td>
<td>988</td>
</tr>
<tr>
<td>St2368</td>
<td>5.5</td>
<td>1,391</td>
</tr>
<tr>
<td>M11</td>
<td>6.0</td>
<td>2,229</td>
</tr>
<tr>
<td>Hessen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L3006</td>
<td>5.0</td>
<td>2,214</td>
</tr>
<tr>
<td>K461</td>
<td>5.0</td>
<td>910</td>
</tr>
<tr>
<td>K478</td>
<td>5.0</td>
<td>150</td>
</tr>
</tbody>
</table>
### Table 5.3.6  Bavaria. Median speeds with different road conditions.

<table>
<thead>
<tr>
<th>Measured sect.</th>
<th>Dry</th>
<th>Wet</th>
<th>Ice/snow</th>
<th>Ice/snow</th>
<th>Dry snow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>Wet</td>
<td>Gravel</td>
<td>track wear</td>
<td>patches</td>
</tr>
<tr>
<td>B307</td>
<td>86.9</td>
<td>-</td>
<td>55.7</td>
<td>65.7</td>
<td>84.9</td>
</tr>
<tr>
<td>St2075</td>
<td>75.2</td>
<td>-</td>
<td>47.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>St2368</td>
<td>77.2</td>
<td>79.3</td>
<td>50.5</td>
<td>59.9</td>
<td>68.6</td>
</tr>
<tr>
<td>M11</td>
<td>88.3</td>
<td>-</td>
<td>65.4</td>
<td>72.0</td>
<td>89.8</td>
</tr>
</tbody>
</table>

### Table 5.3.7  Hessen. Median speeds with different road conditions.

<table>
<thead>
<tr>
<th>Measured sect.</th>
<th>Dry</th>
<th>Wet</th>
<th>Ice/snow</th>
<th>Ploughed</th>
<th>Frost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>Wet</td>
<td>Ice/snow</td>
<td>Ploughed</td>
<td>Frost</td>
</tr>
<tr>
<td>L3006</td>
<td>60.7</td>
<td>56.0</td>
<td>35.0</td>
<td>45.3</td>
<td>-</td>
</tr>
<tr>
<td>K461</td>
<td>89.0</td>
<td>76.8</td>
<td>42.4</td>
<td>45.4</td>
<td>82.4</td>
</tr>
<tr>
<td>K478</td>
<td>63.0</td>
<td>62.6</td>
<td>41.4</td>
<td>47.9</td>
<td>52.8</td>
</tr>
</tbody>
</table>
6 Headway, capacity, flow, density

6.1 Swedish investigations

Öberg, Gregersen (1991)
On E4 in Västerbotten, the amount of traffic is about the same when there is bare ground as it is when the road is covered with ice and/or snow if the same winter period is studied. On the other hand, there are major variations depending upon the time of day, week and year. There were approx. 30% fewer passenger cars in the middle of winter than at the beginning and end of winter.

Möller, Wallman, Gregersen (1991)
Neither weather nor the condition of the roads has a great affect on the daily flow of passenger cars on the roads in central Skellefteå. There were 3−5% fewer passenger cars in the middle of winter, in both Göteborg and Skellefteå, than there were at the beginning and end of winter. In Göteborg, morning traffic was studied in 10 minute intervals. The two peaks in the flow, before 7am and 8am respectively, just about always occurred within the same 10-minute interval. It was also ascertained that the peaks in Borås had nothing to do with the weather or the condition of the road.

Öberg (1994)
On a street in Linköping with a speed limit of 50 km/h, a study was carried out to determine whether the percentage of short headways decreased when the conditions of the roads deteriorated. Only headways < 10 seconds were studied.

Figure 6.1.1 below illustrates that there is a slight difference between different road conditions. There are more drivers with the shortest headway the better the road conditions with the three divisions listed below.

![Figure 6.1.1 Distribution of headway (<10 s) for all vehicles in both directions.](image)
In order to clarify the figure, the percentage of vehicles with the shortest headway are listed in table 6.1.1. On the whole, the results are the same if only passenger cars are studied.

**Table 6.1.1** Percentage of vehicles with the shortest headway in connection with different road conditions.

<table>
<thead>
<tr>
<th></th>
<th>Number of vehicles with less headway than</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 sec.</td>
</tr>
<tr>
<td>Dry, bare ground</td>
<td>3.6</td>
</tr>
<tr>
<td>Wet, bare ground</td>
<td>2.4</td>
</tr>
<tr>
<td>Ice/snow</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Öberg et al. (1997)

It was not possible to ascertain any major differences in the amount of pedestrian traffic between when the ground was bare and when conditions were mixed during the winter. On the other hand, when there was ice and/or snow on the ground there were only about 75% as many pedestrians as when the ground was bare. There is a greater variation with regard to the number of cyclists. During the winter, with mixed road conditions, the number of cyclists is approx. 60% and when there is ice and/or snow on the ground approximately half the number of cyclists compared to when the ground is dry during the winter.

When the temperature is below 0 °C, the number of pedestrians decreases by 10–15% for every 5 °C reduction in temperature. This reduction applies primarily to children and elderly people. On the other hand, precipitation does not have any considerable affect on the amount of pedestrian traffic.

The main reason for the reduction in the number of cyclists is that it is winter. Precipitation reduces these numbers even further.

### 6.2 Nordic investigations

**Ragnøy (1984)**

In Oslo, elderly people were asked whether they had any problems getting out during the winter. Each of the people surveyed was over 67 years of age and lived at home. They were asked how often they go out during the summer and winter.

72% of those surveyed said they go out less often in the winter than they do in the summer. The percentage was greater for the oldest people and lower for the youngest.

The participants were also asked to specify why they went out less often in the winter than in the summer. The results are presented in Table 6.2.1 below.
Table 6.2.1  The reasons why people go out less in the winter.

<table>
<thead>
<tr>
<th>Reason</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total of all priorities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather, cold</td>
<td>63</td>
<td>81</td>
<td>14</td>
<td>4</td>
<td>1</td>
<td>163</td>
</tr>
<tr>
<td>Slippery sidewalks</td>
<td>180</td>
<td>77</td>
<td>25</td>
<td>1</td>
<td>0</td>
<td>283</td>
</tr>
<tr>
<td>High snowbanks</td>
<td>6</td>
<td>26</td>
<td>12</td>
<td>5</td>
<td>0</td>
<td>49</td>
</tr>
<tr>
<td>Health</td>
<td>95</td>
<td>43</td>
<td>12</td>
<td>4</td>
<td>1</td>
<td>155</td>
</tr>
<tr>
<td>Fear</td>
<td>6</td>
<td>18</td>
<td>18</td>
<td>4</td>
<td>2</td>
<td>48</td>
</tr>
<tr>
<td>Other</td>
<td>13</td>
<td>18</td>
<td>9</td>
<td>3</td>
<td>0</td>
<td>43</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>363</td>
<td>263</td>
<td>90</td>
<td>22</td>
<td>4</td>
<td>741</td>
</tr>
</tbody>
</table>

50 % of those who answered specify slippery sidewalks as the main reason (priority 1) they go out less in winter. 26% cited health reasons while 17% said it was because of the weather, cold, etc.

In other words, there are three main reasons that the elderly go out less during the winter. These are listed below in order of priority:

− the condition of the streets and sidewalks (slippery or high snow drifts)
− health reasons
− other reasons related to the time of the year (weather, cold, darkness, etc.).

Elolähde, Pursula (1984)

Pursula (1984)

Adjustable speed limits could be suitable in order to adapt the speed of traffic to different weather and light conditions. The aim of this study was to investigate the effects of speed limits of 80, 100 and 120 km/h on the traffic on Västerleden, which is a four-lane highway outside of Helsinki.

The analysis covered the correlation between the flow of traffic, density and median speed (the fundamental diagram), as well as the proportion of short (dangerous) headways and the dispersion in the distribution of speed. The limit for dangerous headway was defined using the relevant stopping distance at the current level of friction.

For good outdoor conditions, the results were obtained in accordance with Figures 6.2.1–6.2.2. For precipitation and darkness the results were obtained in accordance with Figures 6.2.3–6.2.4.
**Figure 6.2.1** The relationship between flow and speed and density at all measurement points in good conditions.

**Figure 6.2.2** Proportion of dangerous, short headways in good conditions at three measurement points according to density.
Figure 6.2.3 The relationship between the flow and speed and density in different weather conditions for measurement point 2. (On road lightning).

Figure 6.2.4 The effects of the weather and road condition on the proportion of dangerous, short headways.
Figure 6.2.4  The effects of the weather and road condition on the proportion of dangerous, short headways.

In summary, a reduction in the speed limit reduces the difference in speed between successive vehicles and between lanes. The number of dangerous, short headways also decreases

(Note: The result concerning the headways is not confirmed by other studies).

Blakstad (1992)
In practice, the capacity is defined here as the greatest amount of hourly traffic registered before a breakdown. The capacity is to be registered for one-hour periods. For shorter periods, it is possible to register a much greater intensity

The definition of capacity on sections of road means that the traffic breaks down because the flow is too high. In practice however, breakdowns are often caused by special circumstances (accidents, crash, illegal parking and, in particular, vehicles that are travelling too slowly). Since it is likely that events of this kind are more common in connection with slippery conditions or reduced visibility there is also reason to believe that they result in a reduction of capacity during the winter. Speeds in excess of 50–60 km/h do not affect the capacity. However, the headway between vehicles in “queues” does.

The investigation does not specify the degree to which capacity can be expected to be reduced in connection with different types of weather or road conditions. It suggests that the effect of normal winter driving conditions is a reduction of 10–20%. The author’s deduction is that the degree to which different weather and road conditions reduce traffic should be measured directly based on the capacity, since he does not know of any models that make it possible to calculate the effect using intermediate variables such as speed, headway or the overtaking frequency. A proposal for an experiment has been included in the Appendix.

Giæver (1993)
The purpose of the investigation was to study the effects of the road conditions on flow, speed and headway. The measurements were carried out at three locations; Taraldrud south of Oslo and in Kettstigningen and Heimdal south of Trondheim. Representative parts of the results are presented in figures 6.2.5 – 6.2.7 below. Queues are defined by the fact that the headway to the vehicle in front is less than 5 seconds.
Distribution of headway in different weather/road conditions

Heimdal 6-9 a.m., rush hour

Figure 6.2.5 Distribution of headways in morning traffic, Heimdal.

Figure 6.2.6 Relationship between flow and speed in dry weather on dry, bare ground. Heimdal, heavy morning traffic heading towards Trondheim.
In summary, speeds are reduced by up to 20 km/h when it is snowing. There is less reduction in speed when it is raining. The median headway in queues increases by 0.2–0.5 seconds when it snows in comparison with dry weather and dry, bare surface. Rain and snow can reduce capacity by as much as 20%, which is reflected by the fact that the relationship between flow and density is much more uneven than when the weather is dry.

Saastamoinen (1993)
The headway between vehicles did not change much in comparison with good summer conditions. The number of critical distances (<1.5 seconds) in queues fell from 38% in the summer to 25% in bad conditions.

Öberg (1994)
One Saturday afternoon in Køge outside Copenhagen, 2-4 cm of snow fell and the flow of traffic was 20% less than on a Saturday with bare roads.

6.3 Investigations made outside the Nordic countries
Durth, Hanke, Levin (1989a)
Slippery conditions cause changes in the flow of traffic with regard to both the number of vehicles and the distribution in time. This is illustrated in Figures 6.3.1 and 6.3.2. In figure 6.3.1, the reduction in flow is quite evenly divided during the day. It is likely that trips have either been cancelled or that travellers have chosen other modes of transportation. However, Figure 6.3.2 illustrates that there were delays and queues, which resulted in an increase in flow during the rush hours.
Figure 6.3.1 Hourly traffic flow in different weather conditions.

Figure 6.3.2 Hourly traffic flow with queues during rush hour.

Durth, Hanke, Levin (1989b)
On sex out of seven test sections, the flow was reduced by 28–53% on days when the roads were covered with ice and/or snow. The selection principle meant that alternative routes should exist. It seems that a large number of road users have chosen alternative routes; the reduction was greatest during peak traffic hours. The increase on the seventh section resulted from winter holiday traffic. On normal weekdays, there was a reduction in flow on that section as well. Figure 6.3.3 illustrates a typical flow chart.

Figure 6.3.3 The effect of weather on the flow of traffic.
The number of queues increases when the road conditions deteriorate, as does the number of vehicles in the queues. See Figure 6.3.4.

**Figure 6.3.4** The relationship between the formation of queues and flow and road conditions.

The mean headway (in queues) changes with the road conditions, but is less affected by the speed. See Figure 6.3.5.

**Figure 6.3.5** The mean headway as a function of road conditions and speed (in queues).
Seddiki (1992)

The purpose of the investigation was an attempt to establish the effects of different meteorological variables on traffic from a micro-, meso- and macroscopic point of view.

The traffic variables at the different levels were:
- **microscopic:**
  - headway (TIV)
  - distance (DIV)
  - spot speed
  - length of vehicle
- **macroscopic:**
  - flow (Q)
  - density (k)
  - percent occupancy time (T)
  - median speed.

In addition, there are mesoscopic variables, where vehicles are studied in queues (TIV ≤ 4.0 sec.). These variables are:
- the number of vehicles in a queue
- median speed
- median headway.

The measurements were carried out on a six lane city highway, A6a, an access road to Paris from the south. The measurements were split into categories according to the weather conditions; good weather (dry roads), light rain, median rain and downpour. No operational definition of the levels of intensity for the different types of precipitation was given.

A. Macroscopic measurements.

The following function was adapted to the measurement data for the relationship between flow (Q) and percent occupancy time (T) (the fundamental diagram):

\[ Q/T = a \times \exp(-b \times T) \]

where \( a \) and \( b \) are parameters whose values are determined by means of regression analysis. The parameter values differ with regard to lane and the intensity of the precipitation. The data in Table 6.3.1 refers to the left-hand lane (the fast lane).

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downpour</td>
<td>363,205</td>
<td>0.075</td>
</tr>
<tr>
<td>Median</td>
<td>362,582</td>
<td>0.069</td>
</tr>
<tr>
<td>Light rain</td>
<td>371,458</td>
<td>0.070</td>
</tr>
<tr>
<td>Dry road</td>
<td>360,828</td>
<td>0.060</td>
</tr>
</tbody>
</table>
The fundamental diagram of the above is illustrated in Figure 6.3.6 below.

![Fundamental diagram for the left-hand lane in different road conditions.](image)

**Figure 6.3.6** Fundamental diagram for the left-hand lane in different road conditions.

The capacity was reduced significantly when precipitation increased, as a result of lower speeds and greater headway. The capacity in connection with different types of precipitation is illustrated by Table 6.3.2.

**Table 6.3.2** The capacities in different lanes with different levels of precipitation.

<table>
<thead>
<tr>
<th></th>
<th>heavy</th>
<th>Rain median</th>
<th>light</th>
<th>Dry road</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left lane</td>
<td>1782</td>
<td>1933</td>
<td>1952</td>
<td>2213</td>
</tr>
<tr>
<td>Middle lane</td>
<td>1708</td>
<td>1824</td>
<td>1872</td>
<td>1989</td>
</tr>
<tr>
<td>Right lane</td>
<td>1246</td>
<td>1761</td>
<td>1712</td>
<td>1360</td>
</tr>
</tbody>
</table>

The reduction in capacity in heavy rain may be as much as 19% in comparison with dry conditions.

The capacity in the right lane is strongly affected by heavy traffic.

**B. Mesoscopic measurements.**
These measurements applied to queues. The results shown in figure 6.3.7 are median headways up to and including 4.0 seconds in connection with different levels of precipitation.
Figure 6.3.7 The distribution of headway in queues.

C. Microscopic measurements
There is no variation in the changes to the headway caused by precipitation, when a headway greater than 4.0 seconds is included. Therefore, these results have not been listed here. An example of how the distribution of speed changes in connection with different levels of precipitation is illustrated in Figure 6.3.8.

Figure 6.3.8 Distribution of speed in connection with different levels of precipitation. Left-hand lane.
The median speeds and headways for three lanes and different levels of precipitation are listed in tables 6.3.3 – 6.3.6.

**Table 6.3.3** Median speed and headway. Dry road.

<table>
<thead>
<tr>
<th>Lane</th>
<th>right</th>
<th>middle</th>
<th>left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median speed (km/h)</td>
<td>91.06</td>
<td>94.41</td>
<td>112.44</td>
</tr>
<tr>
<td>Median headway (1/10 s)</td>
<td>50.01</td>
<td>19.99</td>
<td>22.88</td>
</tr>
</tbody>
</table>

**Table 6.3.4** Median speed and headway. Light rain.

<table>
<thead>
<tr>
<th>Lane</th>
<th>right</th>
<th>middle</th>
<th>left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median speed (km/h)</td>
<td>46.40</td>
<td>73.31</td>
<td>112.83</td>
</tr>
<tr>
<td>Median headway (1/10 s)</td>
<td>17.80</td>
<td>17.31</td>
<td>22.30</td>
</tr>
</tbody>
</table>

**Table 6.3.5** Median speed and headway. Moderate rain.

<table>
<thead>
<tr>
<th>Lane</th>
<th>right</th>
<th>middle</th>
<th>left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median speed (km/h)</td>
<td>62.49</td>
<td>65.00</td>
<td>81.37</td>
</tr>
<tr>
<td>Median headway (1/10 s)</td>
<td>23.03</td>
<td>17.83</td>
<td>16.87</td>
</tr>
</tbody>
</table>

**Table 6.3.6** Median speed and headway. Heavy rain.

<table>
<thead>
<tr>
<th>Lane</th>
<th>right</th>
<th>middle</th>
<th>left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median speed (km/h)</td>
<td>67.21</td>
<td>68.41</td>
<td>76.04</td>
</tr>
<tr>
<td>Median headway (1/10 s)</td>
<td>41.72</td>
<td>19.08</td>
<td>19.49</td>
</tr>
</tbody>
</table>
7 Vehicle costs

7.1 Swedish investigations

7.1.1 Fuel consumption

**Hjelm, Sävenhed (1982)**

The purpose was to compare the fuel consumption when driving with studded snow tyres with the measurements made for summer tyres on dry asphalt. One tyre of each type was used. The measurements were carried out at a constant speed. Two return trips were measured at speeds of 60, 75 and 90 km/h. The results are summarised as follows: at 60 km/h 2% less fuel was consumed with studded tyres. At 75 km/h fuel consumption was 1% higher and at 90 km/h 2% higher with studded tyres than with summer tyres.

**Wallman (1985)**

**Heavy vehicles**

A Volvo F12 with a total weight of 18.1 tonnes was driven on return trips in the same lane at a constant speed. On dry ground, the fuel consumption was 3.0 l/10 km and 2.5 l/10 km at speeds of 50 and 70 km/h respectively.

In 8 cm of loose snow at a speed of 50 km/h, the fuel consumption was 5.5 l/10 km as long as the snow was untouched. The consumption then dropped gradually to a constant 3.6 l/10 km after approximately 8 passes.

In 5 cm of loose snow at a speed of 70 km/h the consumption was 5.0 l/10 km in untouched snow, after which it dropped gradually to a constant 3.6 l/10 km after approximately 8 passes.

**Passenger car**

A Volkswagen Golf was driven on different types of winter roads, from packed snow to 13 cm of loose snow. The tests were carried out on streets leading up to and through a residential area in actual traffic conditions. The aim was to establish the effect that the condition of the road has on fuel consumption in combination with changes in driver behaviour. The tests took place during and after snowfalls, during which there was normal traffic on the streets. A snowfall of 13 cm under these conditions meant a 25% increase in fuel consumption compared with packed snow. The driver reduced his median speed from 39–34 km/h. Furthermore, he had a tendency to reduce the variation in speed.

The report also indicates a relationship between fuel consumption, the depth of snow and the angle of the street.

**Sävenhed (1986)**

**Heavy vehicles on streets with little traffic**

A 16-tonne Scania G82M4x2 was driven at 70 km/h in 1 cm wet snow. Measurements were carried out on a taxiing runway with no traffic at a military air base outside of Strängnäs.

In the first track, the fuel consumption was measured as being 3.0 l/10 km after the first pass, while after the fourth, fifth and sixth passes it had dropped to as little as 2.4 l/10 km.

In the second track, the fuel consumption was measured as being 2.8 l/10 km after the first pass. This time it dropped to 2.4 l/10 km after the third pass.
After both of these series of measurements, the runway was ploughed. A measurement was then carried out on a very wet surface. The fuel consumption was 2.3 l/10 km. Consequently, 1 cm of wet snow meant a 30% increase in fuel consumption compared with a very wet road where it is quite likely that the fuel consumption is greater than it is on a dry road. During the second series of measurements, the increase in fuel consumption was 20% compared with the value measured on a very wet road.

The measurement procedure was repeated at a later date. This measurement was carried out with a Scania G82M6x2, 16-tonne truck with the support axle raised. On the first pass in 6.5 cm wet snow, the fuel consumption was measured as being 3.4 l/10 km. After the third pass, the fuel consumption was measured as being between 2.6 and 2.9 l/10 km. At the time the second measurement series was scheduled to begin the snow had become packed approx. 1 cm to 5.2 cm. The fuel consumption was measured as being 4.2 l/10 km after the first pass. The fuel consumption in connection with this measurement series also dropped quickly, to between 2.7 and 2.9 l/10 km. After both of these measurements series the track was ploughed. A fuel consumption of 2.5 l/10 km was then measured. The consumption was 36% more in the first pass with 6.5 cm wet snow. During the second measurement series with 5.2 cm wet snow, 68% more fuel was consumed when compared with the wet runway after it was ploughed. It is also worth noting, that the same amount of snow that is packed 1 cm more resulted in a 24% increase in fuel consumption.

**Passenger car on a road without traffic**
The same type of measurements were carried out with a passenger car at the same air base. The car was driven with the cruise control set at 50 km/h in 13 cm of cold, fine-grained, fresh snow. On the first pass, the car was not able to maintain the speed. The gearing had to be changed down and the car had to be driven manually. The fuel consumption was measured as being 2.13 l/10 km and the median speed was 22 km/h. A further 15 measurements were then carried out. The fuel consumption in connection with these measurements varied from 1.11 l/10 – 1.58 l/10 km, depending on how well the driver was able to stay in the tracks. During these passes, the speed varied between 39 and 50 km/h, despite the fact that the cruise control was set to 50 km/h.

The car was driven manually in 3rd gear in a new track. The fuel consumption was measured as being 2.07 l/10 km at an median speed of 33 km/h.

Following these measurements the snow was ploughed away and a couple of measurements were carried out on the clear runway. The fuel consumption was measured as being 0.75 l/10 km at an median speed of 50 km/h.

The increase in fuel consumption varied from 48–111% and was as much as 184% on the very first pass.

**Passenger car on road with traffic**
Measurements were carried out within a speed range of 50–85 km/h on a 2,160 meter stretch of road. Dry roads were compared with thin ice, wet roads and slush. Obviously, the surface cannot be homogeneous on such a long stretch of road. The measurements show an increase in fuel consumption of between 10 and 30% in different levels of slush, compared with a dry road.
Ragnarsson, Öberg (1986)
Whenever it snowed, the condition of the road was documented carefully with regard to the depth of the snow at different points across the road. Samples of snow were also taken in order to determine the level of moisture. The measurements spanned three winters. During the first two winters, six roads of varying standards were measured. During the third winter, two other roads were selected and the same measurements carried out. The vehicle’s spot speed and fuel consumption at different constant speeds were also measured on these roads.

The results of the measurements of fuel consumption and the median speed of the cars are illustrated in figure 7.1.1, which is not included in the report but was compiled from basic data.

![Figure 7.1.1](image.png)

*Figure 7.1.1* The median speed of passenger cars in connection with different road conditions is indicated by ● and the fuel consumption at different speeds is marked with an x.
Despite the fact that the test spanned three winters, there were relatively few measurements. The results are listed below:

- On roads with ADT > 1,000 there is seldom any loose snow in the tracks and seldom more than 2 cm of snow between the tracks. Roads with little traffic could have much more snow.
- The median speed of passenger cars is reduced by 10-15 km/h when it snows and there is little snow on the ground compared with the median speed in dry weather and bare ground.
- As long as the speed remains the same, fuel consumption is increased by 2–5% when there is 0.5 cm of loose snow compared with when there is no loose snow in the tracks. Fuel consumption increases by approx. 10% during a moderate snowfall compared with a light snowfall which in turn causes approx. 10% greater fuel consumption than in summer conditions.
- The increase in fuel consumption as a result of poor weather/road conditions can, if the conditions are not too bad, be compensated for by the reduction in fuel consumption generated by the reduction in speed.

**Wallman (1996)**

Speeds measured on Swedish roads since 1980 have been summarised and tables listing speeds on bare ground and reductions in speed in connection with various road conditions have been drawn up. The information was divided up according to region, type of road, standard operating class and specified speed limit.

The following model for calculating fuel consumption in different road conditions is based on new measurements of fuel consumption for passenger cars:

\[
q = 0.006 \times v + 0.24 \quad \text{dry, bare ground}
\]
\[
q = 0.006 \times v + 0.32 + 0.05 \times s \quad \text{miscellaneous conditions}
\]

where

- \(q\): fuel consumption in l/10 km
- \(v\): speed in km/h
- \(s\): snow depth in cm (on the road)

The equations apply for \(v \geq 60\) km/h. We can assume that fuel consumption is constant for \(50 \leq v \leq 60\) km/h.

### 7.1.2 Corrosion

**Ulfvarson, Johansson (1974)**

**Swedish National Road Administration (1975)**

The effects of using salt, (primarily sodium chloride) as a method of combating slippery conditions in the winter, and in the summer for dust-laying with calcium chloride, were studied on roads and streets in different parts of the country and on fixed and mobile stations. We were able to understand the correlation between corrosion, salt and dampness for each station. During the regression analyses, it was clear that one factor, namely a wet road, was significant with regard to corrosion on the mobile stations. This factor is correlated in a number of ways with salting and temperature. Consequently, it is difficult to say exactly what the wet road factor means and what we should conclude from its significance. Is it a result of salting or an independent factor. Spreading salt on roads is also an
important factor in the emergence of corrosion and with that the ions that are spread in connection with salting, namely sodium, calcium and chlorine.

Apart from the results from the west coast, salt is the reason for the entire difference, or almost the entire difference, in corrosion between fixed and mobile exposure.

One guarded deduction of the study is that salting the road contributes to about one third of the corrosion of the median Swedish car’s unprotected metal surfaces in rural areas and slightly less in environments where there is more traffic (e.g. large city and industrial environments) and almost not at all on the west coast.

**Jutengren (1983)**

The study was part of a test where roads were left unsalted in Östergötland. The study was carried out on two unsalted and two salted roads. Test bodies were exposed for 30 km on each road four days a week. The results indicate that, depending on the type of weather that is dominant during the season, the corrosion conditions on the road can vary greatly from one winter to another. Salting the road meant unprotected steel corroded at least twice as fast during a normal winter. In columns the rate increases three times. During a colder winter, there was considerably less corrosion, both on the salted and unsalted roads. However, in certain cases, the effects of salting the road increases simultaneously. During the winter of 1981/82, the rate of corrosion on unprotected steel (exposed surfaces) was 3–5 times higher on a salted road, while the corrosion in the slits was just over twice as high.

The road salt causes rust inhibitors and touch-up paint to break down faster while factory paint is only slightly affected by it.
When tabulating the results obtained in the study of unsalted roads, each of the effects was evaluated from a financial standpoint in order to weigh the advantages and disadvantages.

The depreciation that is blamed on corrosion is based on modified capital costs. If the vehicle’s median service life increases if the corrosion stops, the annual capital cost in the fleet will be reduced. The capital costs consist of interest and write-offs.

\[
K = \frac{P}{L} + \frac{P \cdot r}{2}
\]

\(K\) = capital costs SEK/year
\(P\) = new car price SEK
\(L\) = median service life
\(r\) = interest

In discussions with experts, we reached the conclusion that if roads were not salted, the service life of cars would increase by 25%. On the basis of this, the cost of corrosion caused by road salt was calculated as being 1.7 billion SEK or 12 öre per kilometer.

The following shows the costs resulting from corrosion on passenger cars in general and not only those caused by salting. Table 7.1.1 lists the costs calculated in 1982 and 1987. The cost of corrosion per car is estimated at approx. 2,600 SEK during 1987.

Table 7.1.1  Calculated costs 1982 and 1987.

<table>
<thead>
<tr>
<th></th>
<th>1982 SEK/car, year</th>
<th>1987 SEK/car, year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1982 prices</td>
<td>Converted to 1987 prices</td>
</tr>
<tr>
<td>Body</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depreciation</td>
<td>1,250</td>
<td>2,175</td>
</tr>
<tr>
<td>ML-treatment</td>
<td>160</td>
<td>220</td>
</tr>
<tr>
<td>Repairs</td>
<td>270</td>
<td>370</td>
</tr>
<tr>
<td>Exhaust system</td>
<td>250</td>
<td>345</td>
</tr>
<tr>
<td>Brake pipes</td>
<td>50</td>
<td>70</td>
</tr>
<tr>
<td>Radiator</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Inspection</td>
<td>55</td>
<td>75</td>
</tr>
<tr>
<td>Total, SEK/car, year</td>
<td>2,050</td>
<td>3,275</td>
</tr>
<tr>
<td>No. of cars on the road</td>
<td>2.94 milj</td>
<td>2.94 milj</td>
</tr>
<tr>
<td>Total no. of cars in Sweden billions of SEK/year</td>
<td>6.0</td>
<td>9.6</td>
</tr>
</tbody>
</table>
Swedish National Road Administration (1984)
The Swedish National Road Administration has made a very rough estimate of the percentage of vehicle corrosion that may be caused by the road environment. This calculation shows that approx. 2/3 of the corrosion can be traced to the condition of the road (mainly the use of salt by the road maintenance authority). The more salt that is spread the greater the amount of corrosion. See figure 7.1.2.

![Corrosion vs. Amount of Salt](image)

*Figure 7.1.2 The relationship, in theory, between the amount of salt and vehicular corrosion.*

The figure illustrates that the increase in corrosion decreases when the amount of salt is increased. This also means that road salt contributes less to corrosion in places where there is a high level of humidity and high salt content in the atmosphere than in areas where the air is cleaner.

Bridges, road signs, road dividers, fences and other road devices are also subject to corrosion.

Sodium chloride reduces the freezing point. This means that the surface is wet for a longer period, which in turn leads to increased corrosion. Furthermore, the presence of sodium and chloride ions increases corrosion. See figure 7.1.3.

![Corrosion vs. Time](image)

*Figure 7.1.3 The relationship, in theory, between vehicular corrosion and the duration of exposure to sodium chloride.*
The longer a surface is wet, the greater the number of frost cycles, which can influence the breakdown of cement structures. This refers primarily to bridges built prior to 1965 because they do not contain additives that create air holes.

Calcium chloride is very hygroscopic, i.e. it “sucks up” the water in the atmosphere. Consequently, gravel roads become moist and therefore less dusty. Vehicular corrosion is affected by both the presence of salt ions and by the fact that the road dirt that sticks to the car is always moist.

**Jutengren (1986)**
The calculations have been performed with regard to the distribution of the total corrosion on the road and in the atmosphere during winter and summer. The values were recorded in the early 1970s and have been revised to correspond with an median year. This revision is primarily based on the number of days during a one year period that the temperature exceeds –2 °C, i.e. when a corrosion process could be set in motion. See figure 7.1.4.

The calculations produced the following conclusions:

- Relatively speaking, the highest amount of corrosion was found in the region of Göteborg (100) and the lowest in upper Norrland (18).
- On the whole, the relative figures for corrosion correspond with the relative amounts of rust-related damage reported by the Swedish Motor Vehicle Inspection Co.
- The greatest amount of corrosion in the northern regions of Sweden occurs in the summer as a result of the gravel roads being sanded to reduce the amount of dust.
- On median, corrosion on cars as a result of salting the roads is estimated at close to two billion SEK, i.e. more than a quarter of the total cost of corrosion.
Figure 7.1.4 Estimated relative values for the corrosion and its distribution over the summer and winter seasons. The shaded sectors constitute the percentage of corrosion that can be affected by different methods of road maintenance. The other sectors constitute the percentage of corrosion that can result from atmospheric conditions. The map shows the different regions of Sweden.
"Råd & Rön” magazine (a consumer advice magazine) (1988)
Rust damage is common after the car has been driven 100,000–120,000 km. The exhaust system begins to show signs of weakness after 20,000 km and after 60,000–80,000 km, the exhaust systems on half of all cars must be repaired annually. The same applies to the brake linings. The electrical systems on one third of all cars must be repaired after they have been driven 100,000–120,000 km. Owners must be prepared to change spark plugs and breakers continuously. On the other hand, engines last for 370,000 km.

Jutengren (1989)
The test was carried out by exposing steel plating test bodies, fitted on vehicles in regular traffic on Gotland (test area) and in Västervik (control area). The atmospheric corrosion was measured by exposing the same type of test bodies on a fixed station within the respective areas. The test comprised both treated, untreated, anti-corrosive treated and painted test bodies.

The rates at which the exposed test bodies in both areas corroded were compared with each other during both a reference period when both areas were salted and a test period when only the roads within the control area were salted.

During the reference period (both areas were salted), the corrosion when mobile exposure was slightly greater in the Västervik area than on Gotland. This is probably due to the fact that more salt was used in the Västervik area.

The absence of salt on Gotland during the test period brought about a considerable reduction in the amount of corrosion on unprotected steel and reduced the effects on paint and anti-corrosive agents. There was an 80-90% reduction in corrosion on unprotected steel. Short-term exposure of unprotected test bodies showed that there is a strong link between corrosion and the frequency of using salt.
The atmospheric corrosion on Gotland was greater than in Västervik area during both the reference and test winters and it was not possible to prove any obvious correlation between the atmospheric corrosion and the arising from mobile exposure.

Hedlund, Rendahl (1990)
Corrosion measurements were made on fleets of police cars (model years 1984 and 1985) on Gotland and in Västervik. The study began during the last winter that salt was used on Gotland, i.e. the winter of 1985/86, and continued during the period when salt was no longer used.

- The annual inspection of these vehicles showed that there were half the number of new rust defects on the cars on Gotland compared with the cars in Västervik from the autumn of 1986 to the spring of 1989. See figure 7.1.6.
- The results of the exposure tests with unpainted sheet metal show that the corrosion had dropped to less than 1/10 during the winter since road maintenance authorities stopped using salt.
- On Gotland, when the roads are not salted during the winter, exposed metal plates rust twice as fast during the summer than in winter. In Västervik, with salted winter roads, there is 5–10 times more rust during the winter than in summer.
Painted metal plates with scratches down to the metal indicate an insignificant spread of corrosion on cars on Gotland after being exposed for 18 months. After the same period, there is a considerable spread of corrosion on the cars in Västervik.

Consequently, salting the roads in winter has a very strong influence on vehicular corrosion. Results indicate that corrosion could be more than halved if the roads were no longer salted.

**Figure 7.1.6** The number of rust defects/police car. Gotland salt-free beginning in the winter of 86/87. Västervik was salted during the entire period.

**Mattsson (1990)**

Damage to material and technical equipment, operational breakdowns and accidents caused by corrosion cost society an estimated 40–50 billion SEK annually.

The fundamental reason for corrosion is that the material is not chemically stable in its environment. In steel and most other metals there is a driving force that strives to transform them into stabler compounds. These compounds, i.e. the corrosion products, are often similar to the minerals from which the metals were once derived. Rust is basically the same as bog ore.

Chemically, the metal atoms may appear in different states, i.e. as crystals of pure metal, as free metal ions, as salts that do not dissolve easily, metal oxides or other compounds. The state that is most stable is totally dependent on the chemistry in the environment.

The relative humidity in the air varies a great deal. When it is below 60%, there is very little chance that steel will corrode.

Automotive rust is a problem that affects most car owners. In order to reduce the costs of vehicular corrosion, a paint system has been developed consisting of several layers of paint that protect the body and an anti-corrosive agent that is
sprayed into the cavities of the body. Brake pipes and exhaust systems are now made of harder metals, etc. This has resulted in a 20% reduction in the costs arising from automotive rust between 1982 and 1987. During 1989, corrosion on cars in Sweden cost approximately 10 billion SEK.

New corrosion problems occur as technology and society develop. Those who associate corrosion with rusty, old cars probably have trouble realising that the electronic equipment is also affected. While it is true that most electronic parts can be protected by encapsulating them, the areas connecting the circuits with the outside world are completely exposed. Studies have shown that even a thin layer of corrosion products can reduce their capacity to conduct currents.

Electronic equipment is often used to control other technical devices in, for example, cars. For this reason, there should be strict requirements with regard to the reliability of the electronic equipment. Already, electronic equipment is common in cars and will be even more so in the future. The environment on the streets and roads is highly polluted and chemically aggressive. This makes corrosion a problem that is difficult to handle.

**Hedlund (1993)**
The purpose of the project was to assess and compare the resistance to corrosion of different car models after 3 and 6 years of operation and evaluate the effects of the design, material and surface treatment.

Body parts from cars that have been in accidents were cut out for inspection of their spaces and cavities. This method means that it is possible to detect rust at an early stage, before it becomes visible from the outside.

The results indicate that a great deal of rust can be found on cars that are both 3 and 6 years old (1989 and 1986 models respectively). There are major and statistically significant differences between the car models. The design and whether or not the manufacturer applied an anti-corrosion agent have an affect on corrosion. With regard to the use of pre-coated sheet metal (e.g. zinc-coated), the results indicate that this is the single best factor for improving resistance to corrosion in clefts. However, there is a big difference between different types of zinc coatings. The thickness of the zinc coating seems to be the most significant factor with regard to protection from corrosion.

Certain car models should receive anti-corrosion treatment as soon as possible, while other models can wait 3–4 years.

**Hedlund (1995)**
Normally, roads are salted during the winter in southern Sweden, but on Gotland the roads have not been salted since 1985/86. This means that at the time of the study, there were cars on Gotland as old as 8 years that had never driven on salted roads.

Both inspections and analysis of statistics compiled by the Swedish Motor Vehicle Inspection Co. show major differences between Gotland and the mainland with regard to corrosion on cars. The inspections were performed on the Postal Service’s Opel Kadetts of model 1986. With regard to the Swedish Motor Vehicle Inspection Company’s statistics, it was difficult to find any corrosion-related problems on such new cars, even on the mainland. This is due to the fact that the Swedish Motor Vehicle Inspection Co. only finds fault if there is so much rust that
it can affect traffic safety. Therefore the Swedish Motor Vehicle Inspection Company’s statistics comprise the entire fleet, i.e. even older cars.

Inspection of rust damage on Opel Kadetts, models 1986-1988, shows that the vehicles driven on salted, winter roads had 2-3 times as much rust damage as the vehicles that were driven on Gotland. The difference varies depending upon the type of corrosion evaluated.

An analysis of the Swedish Motor Vehicle Inspection Company’s statistics concerning negative observations due to rust so extensive that the cars did not pass inspection, indicates that there are 2–4 times as many cars in Västervik that do not pass inspection as there are on Gotland. The difference is smallest for framework systems of these cars, and greatest for the brake pipes and spring discs.

In 1987, it was estimated that the cost of corrosion on passenger cars in Sweden was 2,600 SEK/car and year, i.e. 8.8 billion SEK per year. The results of the inspections and the Swedish Motor Vehicle Inspection Company’s statistics during that year indicate that road salt is the cause of at least half of the corrosion damage on cars driven on salted roads. If we roughly estimate the current costs as being 10 billion SEK, and consider the fact that most cars are driven on salted roads, we find that the cost of corrosion on cars as a result of salted roads is approximately 5 billion SEK/year.

The fact that the cost of corrosion would be halved if roads were no longer salted does not necessarily imply a savings equal to half the cost of corrosion. In 1987 when the cost of corrosion was calculated, it was assumed that half of all cars scrapped were scrapped because of rust damage. If there were a dramatic reduction in corrosion, the service life of cars would increase. However it is difficult to say how great this increase would be because it is likely that there would be an increase in the number of cars scrapped for other reasons.


There was one question directly related to rust on cars. There were also several questions concerning different types of repairs. The question asked here is as follows: Has the car been received anit-corrosion treatment or been subjected to an inspection of the rust protection during the past 12 months? This does not include the treatment of new cars prior to delivery.

29 % answered ”yes” and 69 % answered ”no”. Of those who answered ”yes”, 9 % had a rust protection warranty and had taken the car in for inspection, 4 % had taken the car in for anti-corrosion treatment, 3 % had performed a complete anti-rust treatment themselves and 13 % had touched up spots of rust themselves.

**7.2 Nordic investigations**

**7.2.1 Fuel consumption**

**Gabestad, Ragnøy (1982)**

Without referring to sources or other references, the following values are given for fuel consumption in passenger cars:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry, bare ground</td>
<td>D/l/10 km</td>
</tr>
<tr>
<td>Packed snow, moist bare ground</td>
<td>D + 0.05 l/10 km</td>
</tr>
<tr>
<td>3 cm loose snow</td>
<td>D + 0.14 l/10 km</td>
</tr>
<tr>
<td>10 cm loose snow</td>
<td>D + 0.35 l/10 km</td>
</tr>
</tbody>
</table>
In this work the following idealised correlation for the bare ground consumption is given D:

\[ D = a + \frac{b}{V} + c \times V^2 \]

D: l/10 km  
V: speed in km/h  
a: 0.281  
b: 22  
c: 0.000062

7.2.2 Corrosion

Thurmann-Moe, Ruud (1973)

The studies were mainly carried out outdoors in order to be able to register atmospheric corrosion. In laboratory tests, the effects of different means of combating slippery conditions were studied. None of the agents tested gave less corrosion than salt except urea. However, this compound is not as good a means of combating slippery conditions because it does not melt as well and it only works within a limited temperature range. 13 different inhibitors were tested, but none of them was very effective.

Figure 7.2.1 illustrates the seasonal variation for a 5% salt solution (max. corrosion at 3–5%), a water-based solution and the atmosphere. All three curves show a similar trajectory and indicate that the greatest amount of corrosion is found in the autumn and the least is seen in the summer. During the year that the measurements were carried out (1968) there was a great deal of precipitation and it was quite humid in the autumn while the rest of the year was relatively dry. Different climatic conditions may have produced a different result. In the outdoor tests, it is estimated that salt is responsible for 70–80% of the total corrosion. This cannot be completely transferred to the road surface but should be seen as a maximum effect. In tests on the road, the effect was approx. 50%. In other words, salt doubles the amount of corrosion. However, salt’s contribution to corrosion, spread over the year, is reduced.

![Figure 7.2.1](image_url)

*Figure 7.2.1 The seasonal variation in corrosion in laboratory tests outdoors, 1968.*
**Project "MINSALT" (1991)**
At the beginning and the end of the MINSALT project there was a trip to Åland to discuss experiences regarding a reduction in the amount of salt used on roads. In Mariehamn only a few very short, difficult-to-navigate sections of road were salted. It was therefore interesting to share their experience before beginning the Gotland project.

During the last visit, the results of MINSALT were presented and the residents of Åland presented differences in the price of used cars from Åland and from the Finnish mainland. Different car dealers and insurance companies valued a 5-year old car from Åland 10–20% higher than a car from the Finnish mainland. On Åland, cars are not driven as far as cars on the mainland, which could account for part of the difference. However, when asked, they said that the cars were similar.

**Ragnøy (1986)**
This project studied the corrosion effects of road salt, air pollution and proximity to the sea on cars in traffic in different geographical areas.

The owners were asked to participate in a postal questionnaire about vehicular corrosion. The method had previously been compared with the results from the Swedish Motor Vehicle Inspection Company’s results and was found to have certain weaknesses with regard to the quantification of the amount of rust. However, the method is quite sufficient for comparing the amount of rust in different geographical areas.

The study shows that there is noticeably less rust on vehicles in areas without corrosive factors compared with other areas. Less rust means a smaller number of cars with rust, fewer observations per car, a smaller amount and a lower degree of severity.

Road salt is the factor that causes the most corrosion, followed by proximity to the sea. If the vehicle is subjected to multiple corrosive factors, the combination will result in a greater amount and a higher degree of severity than the individual factors on their own.

**Ragnøy (1996)**
This report mainly lists the financial consequences of corrosion using the terms cost of damage, cost of remedial measures and the willingness to pay.

The cost of defect is directly related to the improvement/replacement of parts that have been destroyed as a direct result of corrosion and to the reduction in value as a result of neglecting to take precautionary measures.

The cost of remedial measures is related to the action taken to prevent corrosion. This could be follow-up treatment, e.g. undercoating, but also the cost of the choice of design and materials which will increase the resistance to corrosion. The results are summarised in Table 7.2.1.
Table 7.2.1  Total costs of corrosion, road salt-related corrosion costs and costs that are a result of changes in the vehicle’s exposure to road salt. Kronor/vehicle and year, Kronor/year for the entire fleet, SEK/km driven.

<table>
<thead>
<tr>
<th>Cost factor</th>
<th>Total cost Kronor/year</th>
<th>Salt-related Kronor/year</th>
<th>Cost margin Kronor/year</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prevention</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Choice of material/design</td>
<td>350</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>Follow-up treatment/underbody treatment</td>
<td>500</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Depreciation</strong></td>
<td>2000</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td><strong>Damage costs</strong></td>
<td>1000</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Sum in Kronor/year driven</td>
<td>3850</td>
<td>875</td>
<td>0.15</td>
</tr>
<tr>
<td>Sum in Kronor/km driven</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum in mill Kronor/year for the entire fleet</td>
<td>6160</td>
<td>1400</td>
<td></td>
</tr>
</tbody>
</table>

The total cost per vehicle and year is 3,850 kronor, of which 875 kronor is directly related to the use of road salt. The cost for the entire Norwegian fleet is estimated at 6.6 billion kronor, of which 1.4 billion is blamed on road salt. The table also shows that if the use of salt is increased, the cost for each new car that is driven on salted roads, that previously was not, will be approx. 0.15 kronor/km.

7.3 Investigations made outside the Nordic countries

7.3.1 Fuel consumption

Claffey (1972)

The following data in Table 7.2.2 is an example of increases in fuel consumption caused by ice and/or snow on the road compared to the consumption on dry, bare ground. It should be mentioned that the test car was a Chevrolet V8, 1964 model with automatic transmission.

Table 7.2.2  Increase in fuel consumption on different types of winter roads.

<table>
<thead>
<tr>
<th>Speed km/h</th>
<th>Packed snow</th>
<th>Loose snow on packed snow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 cm</td>
<td>5 cm</td>
</tr>
<tr>
<td>35</td>
<td>23 - 30%</td>
<td>43%</td>
</tr>
<tr>
<td>70</td>
<td>11 - 14%</td>
<td>23%</td>
</tr>
</tbody>
</table>

In a later report, (Claffey, 1980) it is assumed that the increase in fuel consumption on packed snow or ice is at least 25% compared with dry, bare ground plus an additional 10% for each cm of loose snow.
8 Traffic safety

8.1 Swedish investigations

Accident data
Traffic accidents reported to the police constitute the material that is most often used in traffic safety studies in Sweden. Information from hospitals concerning patients injured in traffic accidents mainly contains further particulars about single vehicle accidents involving unprotected road users. The police do not consider these accidents (at least not those involving pedestrians) as being traffic accidents. Insurance companies can provide more information pertaining to property damage than the police can.

Normally none of these sources has any information about, for example, vehicular equipment that is of particular importance to safety in the winter. When winter accidents are to be followed up, the information from the above sources must therefore be supplemented by changing the information on forms or filling in additional forms. The following additional information was collected on one or more occasions:

• During one winter, the police reports were supplemented with information concerning the type of tyres the cars had.
• Hospital reports were supplemented with information about the condition of the road/road surface at the site of the accident.
• The insurance company has requested additional information about the vehicle and the conditions at the site of the accident.

Exposure data
It is difficult to obtain information about vehicle mileage in relationship with different winter road maintenance measures. ADT (annual daily traffic) values are often revised with regard to month, weekday and hour of the day. Sometimes revisions are also made for areas with a great deal of precipitation, whereas there is no information that allows us to revise condition for the time prior to and following a road maintenance measure.

With regard to the exposure to different road conditions, observations were made of the road conditions in relationship with the counting of traffic in 1973 and 1977. If the condition of the road was the same when the apparatus was retrieved as when it was put out, all traffic during the measurement period was considered as having driven on this type of road surface. If the conditions of the road differed, the traffic was divided into two different types of road conditions.

In the early ‘90s, the Swedish National Road Administration began following up winter road maintenance by observing the condition of the roads. Consequently, it is possible to determine the type of road maintenance used for the different road conditions using these comprehensive observations and the ordinary traffic measurements. The first winter this was done was 1993/94 (see chapter 3.1.1). Since the studies of the condition of the roads will continue, either manually or automatically, it is now quite possible to carry out new winter traffic accident studies.

With regard to the exposure of vehicles with different types of tyres, different methods have been used. In connection with the inspection of the vehicles, the road users were asked about their driving during the two days prior to the inspection. If the car was inspected on a Monday, the drivers were also asked
about the stretches of road driven the previous Friday. The inspector filled in information about the tyres. In another study, questionnaires were sent to the car owners and he or she was asked to answer almost the same questions and to provide information about the condition of the roads the day before.

The flow of vehicle traffic varies depending on the month, day of the week and time of day. These variations are normally much greater than those measured when the condition of the road changes from bare ground to ice and/or snow. The effect on the flow of traffic when the weather/condition of the road is bad is greatest in connection with holiday traffic.

The total amount of pedestrian and bicycle traffic is approx. the same on a yearly basis, with the pedestrian traffic fairly evenly divided during the year. See figure 8.1.1. Naturally, the greatest amount of bicycle traffic occurs during the summer. It is also important to point out that the variation in the amount of bicycle traffic from month to month depends on the weather and there can be a major differences depending on whether a particular month is rainy and windy as opposed to sunny and calm. The summer cyclists are more affected by the weather than the winter cyclists. There was a general decline in the amount of pedestrian and bicycle traffic between the years 1992–1994.

![Figure 8.1.1](image.png)

**Figure 8.1.1** Exposure in Sweden for pedestrians and cyclists on a monthly basis in 1993. Source VV/VTI’s study of travel experience.

**VTI (1991)**

The flow of pedestrian and bicycle traffic, during winter and spring, and whether or not the unprotected road-users used the streets instead of sidewalks/cycle tracks, was studied in the two small towns of Finspång and Ätvidaberg. Recordings were made in one of the urban areas in the morning, (6:30 a.m.–9 a.m.), and in the other in the evening, (4:00 p.m.–6:30 p.m.).

When there was 5 cm of snow on the cycle tracks, every second cyclists chose to cycle on the ploughed road instead.
8.1.1 Public road network

Many studies are based on information that is 20 years old. However, it was only during 1973 and 1977 that the condition of the roads was observed to a great extent that the vehicle mileage could be divided into different road conditions during winter. During the past few years, the condition of the roads has been followed up in order to determine whether winter road maintenance has been carried out according to the rules. This data has not yet been utilised in new accident studies.

Nilsson (1976)

Data (accidents reported to the police, traffic measurements and observations of road conditions) from 1973 is processed.

The accident rate for all of 1973 was 0.75 and 0.26 for accidents involving personal injury.

Some of the figures below were calculated based on information in the report.

<table>
<thead>
<tr>
<th>Northern Sweden</th>
<th>Bare ground</th>
<th>Bare ground</th>
<th>Bare ground</th>
<th>Ice/snow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daylight</td>
<td>0.37</td>
<td>0.41</td>
<td>0.28</td>
<td>1.07</td>
</tr>
<tr>
<td>Darkness</td>
<td>0.83</td>
<td>1.38</td>
<td>0.60</td>
<td>1.43</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Central Sweden</th>
<th>Bare ground</th>
<th>Bare ground</th>
<th>Bare ground</th>
<th>Ice/snow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daylight</td>
<td>0.46</td>
<td>0.51</td>
<td>0.39</td>
<td>2.67</td>
</tr>
<tr>
<td>Darkness</td>
<td>1.01</td>
<td>1.69</td>
<td>0.76</td>
<td>3.30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Southern Sweden</th>
<th>Bare ground</th>
<th>Bare ground</th>
<th>Bare ground</th>
<th>Ice/snow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daylight</td>
<td>0.55</td>
<td>0.59</td>
<td>0.49</td>
<td>5.29</td>
</tr>
<tr>
<td>Darkness</td>
<td>1.06</td>
<td>1.48</td>
<td>0.91</td>
<td>7.93</td>
</tr>
</tbody>
</table>

Figure 8.1.2 shows that the accident rate when the ground is bare is higher in the summer than during the rest of the year. In daylight, the accident rate is 20–50% higher in summer than in winter, and in darkness it is almost twice as high in summer as it is in winter. During the winter, the majority of all travel to and from work occurs during hours of darkness, while in summer there are only a few short hours of darkness late at night, at which point fatigue and the influence of alcohol could play a part. It is likely that more inexperienced drivers are about during summer than in winter. Some people even deregister their cars during the winter.
In northern Sweden, the accident rate for icy/snowy roads is 2–3 times that of bare ground in winter, 4–7 times greater in central Sweden and 9–11 times greater in southern Sweden.

In northern Sweden, the bare ground accident rate is 70–75% of the bare ground accident rate for the whole year and in southern Sweden it is just under 90% of the accident rate for the entire year. There is little difference in this relationship between daylight and darkness.
Figure 8.1.2 Accident rate for different road conditions and daylight/darkness in 1973. The median accident rate for the entire country is marked with a line. Base on accidents reported to the police.
On the whole, the accident rate in darkness, regardless of region, is twice as high in daylight on bare ground and 1.5 times as high when the roads are icy/snowy.

Accidents involving personal injury account for approximately one-third of all traffic accidents reported to the police. The percentage of accidents involving personal injury is highest in the north and lowest in the south. The percentage of accidents involving personal injury is highest in daylight, and primarily when the ground is bare.

When conditions are icy/snowy, the accident rate is highest at the end of spring and beginning of autumn.

**Andersson (1978)**
Data from 1970–1974. The report gives an account of three attempts to determine the effect the application of salt has on the number of accidents on the public road network that are reported to the police.

- A follow-up of the increased salt program shows that salting does not have a significant effect on the total number of accidents during the winter. The method was too rough.
- A comparative study with regard to the condition of the road shows that:
  - the accident rate is 3–20 times higher on ice/snow than on bare ground,
  - the more uncommon it is to find ice/snow on the road, the higher the accident rate in these conditions,
  - the reduction in the number of accidents in icy/snowy conditions is not in proportion to the improvement in road conditions,
  - the increase in the number of accidents brought about by icy/snowy conditions is the same on salted roads as on unsalted roads and amounts to 52% of all accidents between November and February and 22% in March, April and October.
  - the number of accidents is not affected by salting,
- Before and after studies with regard to road conditions
  - salting does not affect the number of accidents,
  - the percentage of accidents that occur in icy/snowy conditions dropped on test stretches (those where salt was first applied after the winter) but increased on the control stretches (same winter road maintenance before and after).
  - most on those that were salted during both winters. This indicates that the difficult winter road maintenance problems are on the roads with the most traffic.

The study is non-experimental, with no control over important background factors, which in principle render all conclusions uncertain. The result could indicate that salting should be combined with measures to reduce speeds in order to produce an effect that will reduce the number of accidents.

**Brüde, Larsson (1980)**
An accident index (1973 & 1977) is presented for a number of different groupings of icy/snowy roads as well as the total. There are groupings for temperature, precipitation, snow depth, changes in snow depth, region, months, weekdays and weekends. This is good reference material, but again, too old.
Brüde, Larsson (1981)
The report deals with the correlation in winter between weather conditions, road conditions and traffic accidents and is a statistical processing and analysis of data from 1973 and 1977.

In 1973, the roads were split into two categories, salted and unsalted, while in 1977 they were split into A-salt, B-salt and unsalted roads. A-salted roads were salted all winter when conditions were slippery, while B-salted roads were mostly salted during the autumn and spring. Henceforth, the term salted roads refers to salted roads in 1973 and A-salted roads in 1977.

The accident rate on bare ground is 1.5–2 times greater for unsalted roads than for salted roads. On the other hand, the accident rate when icy/snowy roads are salted is almost twice as high as when they are not. This is probably explained by the fact that road users do not adapt their speeds well enough to icy/snowy conditions on salted roads.

The total accident rate is much lower for (March+April) than for (October+November) and (December+January+February). When comparing (October+November) with (December+January+February), the accident rate for each individual road condition is highest in (October+November). However as a whole, the accident rate is highest in (December+January+February).

For salted and unsalted roads, using each region and time period as a unit of observation, the accident rate increases at a greater rate on icy/snowy roads in comparison to that on bare ground when the percentage of vehicle mileage on the icy/snowy roads drops.

When comparing heavy precipitation with little or no precipitation, the difference in the accident rate is greatest at temperatures around the freezing point or below. The accident rate is affected more by precipitation than by temperature. The accident rate on icy/snowy roads increases as the temperature increases.

The accident rate is twice as high in darkness than it is in daylight. This is due to the differences on bare ground. In icy/snowy conditions, there is no difference between daylight and darkness. Studies were carried out between the hours of 5 a.m.–11 p.m.

Each percentage point that the proportion of vehicle mileage drops when roads are icy/snowy should, primarily, reduce the accident rate for regions and time periods with a low proportion of icy/snowy roads. There would be less of a reduction, and possibly even an increase, in the accident rate for regions and time periods with a large proportion of vehicle mileage on icy/snowy roads. The accident rate curve maximises at approx. 15%. This information is uncertain.

Björketun (1983)
The aim of the accident analysis was to study the effects of the increased winter readiness that was applied in certain working areas from the winter of 1977/78 through the winter of 1979/80.

The increased standby meant either that a salt truck patrolled the roads with the most traffic on weekdays between the hours of 3 a.m. and 7 a.m. (patrol truck) or that an emergency worker was on duty during those hours (graduated standby).

Data from the Swedish National Road Administration’s road and traffic records was used. A total of 12,184 accidents from 78 working areas were included in the analysis.
Throughout the entire winter, (i.e. 24 hours, 7 days a week) in areas with graduated standby, there was a fairly strong tendency towards a reduction in the number of accidents in relation to the control areas.

If the comparison is limited to weekday mornings (i.e. 3 a.m.–7:30 a.m.), there is a relative reduction in the number of accidents by about 30% in connection with graduated standby.

The graduated standby has not resulted in any visible difference between the test and control areas with regard to the number of accidents on icy/snowy roads.

The total number of accidents for the entire winter in working areas with patrol trucks increased compared to the control areas. As a whole, the areas patrolled by trucks show no changes as a result of the increased standby. With few exceptions, it does not seem that the patrol trucks have reduced the number of accidents on icy/snowy roads.

**Schandersson (1986a)**

Data concerning precautionary action from the Swedish National Road Administration’s standard follow-up in 1982/83, together with accidents reported to the police and the amount of traffic (index hour by hour, i.e. weekends/public holidays and areas affected by major amounts of precipitation) have been used to calculate the accident rate before and after precautionary action was taken.

The risk of traffic accidents increases dramatically 1–3 hours before precautionary action is taken. It then drops quickly when the action takes affect.

No major differences where found when dividing the season into early winter, midwinter (December 15–March 15) and late winter. It seems that the accident rate was highest in early winter and lowest in late winter, while the effects of winter road maintenance seemed greatest in midwinter.

Many precautionary measures are carried out early in the morning but the increased risk of accidents at night does not seem to be of any major significance to the result. However, we cannot say for certain that this is true. The duration of early and late winter does not seem to have too great an effect on the result.

The accident rate on ploughed roads is higher than it is on roads where salt or gravel have been applied

**Schandersson (1986b)**

Data from the studded tyre investigations carried out in 1973 was used. The accident material was collected from all automobile insurance companies, which is why the results indicate a higher risk of accident and most likely greater differences in conditions of the roads than accidents reported to the police.

The primary result is that compared with bare ground the median accident rate is:

- 30–50 times higher when there is loose snow and/or slush,
- 8–12 times higher when there is ice and/or packed snow,
- 10–15 times higher when there patches of ice and/or snow.

Loose snow and slush also result in more serious accidents than the other two groups of ice and/or snow.

The accident rate for different road conditions is highest in southern Sweden and lowest in the north. In total, the accident rate is highest in central Sweden (depending on the distribution of the road conditions).
The percentage of accidents involving personal injury is 13–14% on bare ground, 10–11% on loose snow and slush and 7–9% on a hard layer or patches of ice and/or snow, except in southern Sweden where the percentage for patches of ice and/or snow is 12%. The percentage of accidents involving personal injury for all road conditions is; northern Sweden 9.4%, central Sweden 9.9% and southern Sweden 11.3%. The percentage for the entire country is 10%.

The percentage of single accidents is greatest (just under 60%) when there are loose layers and patches of ice and/or snow. When there are hard layers this percentage is 44% and on bare ground 33%.

The percentage of accidents at intersections is highest (25%) when the ground is bare. For all other road conditions, the percentage is less than half.

**Schandersson (1988)**
The study comprises data collected from 1977–80. The result indicates that the risk of accident increases rapidly when there are relatively small amounts of precipitation and then stabilises at 3–5 times, when 5–10 cm of snow has fallen and 2.5–3 times when a mixture of snow and rain has fallen for 24 hours.

The increased risk of accident is much greater on better roads with a higher speed limit and greater in the south than in the north of Sweden.

**Möller (1988)**
This study was based on information gathered from accidents reported to the police during the winters of 1985/86 and 1986/87 together with traffic work on different road conditions calculated according to a model based on observations of road conditions made during 1973 and 1977.

The calculations show that, if accidents involving wildlife are excluded, the increase in the risk of accidents is greatest when there is loose snow and/or slush, since it is 10 times greater on A-salted roads and 5 times greater other roads than dry, bare ground. When there is thin ice on the road, the corresponding increase in the risk of accidents is a little more than 8 and just over 3 times greater respectively. The corresponding figures for packed snow/thick ice are a little less than 7 and slightly less than 2 times respectively.

**The Swedish National Road Administration (1987)**
The study had two objectives:
− to attempt to analyse the effects of the gradual improvement in winter road maintenance during the ‘70s and ‘80s and
− to develop a model for the road maintenance authorities to analyse the traffic safety effects of their winter road maintenance and to create a means of assistance in selecting the level of service.

In order to determine the effects of the Swedish National Road Administration’s increase in winter road maintenance, a decision was made to study how the percentages of winter accidents, regardless of road conditions, changed during the period 1972–1985. Using this method, there was no positive development in traffic safety during the winter during the 1970s. However, the study does show that there has been a positive development since the beginning of the 1980s. When comparing the number of single accidents that took place 1983–1985 with 1972–1974, there was a maximum 8% drop, and there was a maximum
6% drop in the number of multi-vehicle accidents on the road network with heavy traffic.

Naturally, there are other factors that affect the results. For example, the use of studded tyres has increased from 50–70%.

The results obtained for the roads with heavy traffic indicate that intensive, efficient winter road maintenance can further increase traffic safety in the winter. Since there has been a positive development with regard to the number of accidents involving personal injury on salted roads, we can conclude that salt has a positive effect on traffic safety.

**The Swedish National Road Administration (1989)**
The aim of this report is to document operations, weather, traffic and accidents. The administrative districts that show a positive development regarding the number of accidents are those that invested in technology and an organisation, which permits precautionary measures, the utilisation of RWIS, weather forecasts and better monitoring after working hours. When better methods were introduced and when the entire organisation was committed to the winter questions, the risk dropped by 20–30%.

**Öberg, Gustafson, Axelson (1991)**
Among other things, the MINSALT project studied the effects of discontinued salting on a large number of roads and streets. These tests were carried out during the second half of the 1980s. Many measurements were carried out on the test-road network and on a similar control-road network both before and after the change on the test-road network.
The roads included in the test and the control roads were divided into different ADT classes. The changes in the number of accidents for these classes were studied. The results indicated that on roads with an ADT < 1800, the number of accidents dropped when they were no longer salted and increased on the larger roads (not statistically confirmed). See Figure 8.1.3. This is probably a result of different salting policies for different roads. On larger roads, salt melts the layer of ice and/or snow so much that it compensates for the increased risk of accident on icy/snowy roads when there is a small percentage of ice and/or snow during a particular winter. On smaller roads however, it is better that road users are aware that the road becomes slippery at certain temperatures and in certain weather conditions and that they are not surprised by the fact that they have not been salted due to lack of resources.

The days during the different winters for both the unsalted roads on Gotland and its control area have been classified according to the worst weather/road conditions that prevailed during the 24-hour period and the accidents have been distributed among these days. See Figure 8.1.4. The difference between the number of accidents on Gotland and in the control area is that the risk of accident when there is frost in autumn and when wet roads freeze is proportionately much higher on Gotland than in the control area. Salt combats these conditions quickly. Consequently, it is likely that that this difference in the risk of accidents is due to the difference in winter road maintenance. When there is a snowfall (more than 2 mm of melted snow and when there is wet snow), the risk of accidents is often slightly higher in the salted control area. The reason for this could be that the salted stretch of road probably looks wetter and that the road user therefore does not perceive it as being slippery. Otherwise there are no major differences. No differences have been statistically confirmed.

Figure 8.1.3 Accident results (regression change with 95% confidence interval) on the roads that were not salted during the test in relation to the annual daily traffic (ADT) and the control roads.
O = bare ground  
W = bare ground, snowfall < 2 mm in melted form  
Q = bare ground, wet snowfall  
R = bare ground, snowfall > 2 mm in melted form  
X = ice/snow, snowfall < 2 mm in melted form  
N = ice/snow, wet snowfall  

K = ice/snow, snowfall > 2 mm in melted form  
S = ice/snow, dry, cold  
F = wet road that freezes  
B = frost in autumn  
T = frost in winter

**Figure 8.1.4** Accidents reported to the police on Gotland and its control area Västervik during the winters of 86/87-88/89 distributed according to the categories ”worst weather/road conditions” during one day.

**Table 8.1.1** Summary of all results obtained in the accident studies included in the MINSALT-project.

<table>
<thead>
<tr>
<th>Administrative district</th>
<th>Change</th>
<th>95 % confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accidents on unsalted roads that were reported to the police</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Västerbotten</td>
<td>+33%</td>
<td>(-14%  +105%)</td>
</tr>
<tr>
<td>Kopparberg</td>
<td>+5%</td>
<td>(-8%  +19%)</td>
</tr>
<tr>
<td>Gotland</td>
<td>+6%</td>
<td>(-17%  +35%)</td>
</tr>
<tr>
<td>Accidents on all roads and streets that were reported to the police</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gotland (state)</td>
<td>-10%</td>
<td>(-27%  +12%)</td>
</tr>
<tr>
<td>Gotland (municipality)</td>
<td>-36%</td>
<td>(-53%  -13%)</td>
</tr>
<tr>
<td>Traffic injuries according to the police</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gotland</td>
<td>-23%</td>
<td></td>
</tr>
<tr>
<td>Traffic injuries according to hospital reports</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gotland</td>
<td>+11%</td>
<td>(-23%  +72%)</td>
</tr>
<tr>
<td>- pedestrians</td>
<td>+15%</td>
<td>(-51%  +83%)</td>
</tr>
<tr>
<td>- cyclists/moped riders</td>
<td>-27%</td>
<td></td>
</tr>
<tr>
<td>- road users</td>
<td>-5%</td>
<td></td>
</tr>
<tr>
<td>Damaged cars according to county insurance companies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gotland</td>
<td>+18%</td>
<td></td>
</tr>
</tbody>
</table>

It is worth noting the difference in results with regard to the number of traffic injuries reported to the police and those reported to the hospitals (Table 8.1.1).
The information given to the police concerns primarily motor vehicle accidents, while the information given to hospitals shows that the number of injured pedestrians has increased at the same time as injuries in other categories have decreased.

With regard to information from insurance companies, the study only includes information from one insurance company on Gotland. This company has barely 25% of the car fleet in their register. There is no control material analysed.

The winter after the tests with unsalted roads began, another test involving the new MINSALT strategy was carried out in the administrative districts of Kopparberg and Västerbotten. In the administrative district of Kopparberg, preventive salting was practised on the entire road network that was salted before and after winters when no salt was used. Part of the redistribution was carried out between the A- and B-salt road networks. In Västerbotten, the entire E4 highway was salted as a preventive measure, i.e. the road was to be salted before it became slippery. The salt was moistened.

Since the entire salted road network in the administrative district of Kopparberg was affected by this test, only the major road network was used, i.e. the roads corresponding to those in the administrative districts of S, T, U and X. In this analysis, the five winters before the unsalted test was carried out were also "BEFORE" winters.

The results of the analyses of accidents reported to the police are listed below:

<table>
<thead>
<tr>
<th>Combating slippery roads</th>
<th>Change</th>
<th>Confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>86/87</td>
<td>89/90</td>
<td></td>
</tr>
<tr>
<td>A-salt</td>
<td>A-salt</td>
<td>-8%</td>
</tr>
<tr>
<td>A-salt</td>
<td>B-salt</td>
<td>+3%</td>
</tr>
<tr>
<td>B-salt</td>
<td>B-salt</td>
<td>-21%</td>
</tr>
</tbody>
</table>

Consequently, there has been a reduction in the number of accidents (not statistically confirmed) on the road networks that combated slippery conditions in the same way but by taking precautionary action. However, there was an increase in accidents on the A-salt road network that subsequently changed to B-salting. The increase was only slight and was not confirmed by statistics.

The E4 in the administrative district of Norbotten was chosen as the control area for studying the effects of the new salt strategy in Västerbotten’s administrative district. The entire E4 in the administrative district of Västerbotten, with the exception of the previously salt-free section in the Robertfors traffic area, constituted the new test area. The results of studies of 7 "BEFORE" winters showed a 21% increase in the number of accidents reported to the police with a 95% confidence interval (-7 + 58). The result implies that this increase could have come about purely by chance.

On the whole, the preventative salting had slightly different effects on the different road networks. It is possible that even using this new method, a certain amount of time is required before full effect is realised. Unfortunately we do not know how the conditions of the roads in the administrative district of Västerbotten changed because no observations were carried out. However, observations were carried out in the administrative district of Kopparberg (Velin, 1991). These observations show that during the winter of 1989/90 there were a few percentage
points less ice and/or snow than during the "BEFORE" winter of 1986/87 and 10-15 percentage points more wet/moist, bare ground. These winters differed a great deal, which could account for part of the difference.

In order to obtain better results, the effects of the MINSALT strategy should be studied in further detail.

In 1997, the MINSALT results were revised (Öberg, 1997) due to the zero vision so that the effect on people who were seriously or fatally injured and accidents involving them could be calculated. The Swedish National Road Administration has adopted a zero vision, which means that they plan to prevent fatal and serious accidents and long-term loss of health.

The effects on the fatal or serious accidents is a total increase of 7%, i.e. basically the same results as when all accidents reported to the police were studied.

The number of persons killed or seriously injured, in all areas, is not affected by not salting the roads.

It seems as if the difference in effect is less between roads with different ADT for the more serious accidents and the accidents that are fatal or in which passengers are seriously injured than for all accidents reported to the police.

These results are extremely uncertain.

Sävenhed (1995)
For the winters of 1988/89 and 1989/90, winter road maintenance measures, accidents reported to the police (excluding those involving wildlife and those in intersections) and vehicle mileage were studied to estimate the risk of accident before and after winter road maintenance. The vehicle mileage was calculated based on ADT and revised to account for variations in monthly, weekly and daily variations. On the other hand, no revisions were made on account of weather or road conditions.

The accident rate increases during the hours before winter road maintenance, and reaches its peak 1–1.5 hours before maintenance is carried out. This maximum value of 2.6 is an increase by a factor of 12 compared with the median accident rate at least 12 hours before or after winter road maintenance. In comparison with 6–12 hours before winter road maintenance, the increase is six-fold and equally as large for accidents involving personal injury. See Figure 8.1.5.
During the winters covered by the accident analysis, the Swedish National Road Administration began carrying out preventive salting. For this action, the accident rate reaches a maximum value that is only half of that for conventional salting (see Figure 8.1.6). However, the increase in accidents occurs before salting and not after as it should do if it had been a preventive measure, but which sometimes fails. This indicates that conventional salting is also included in this data. This could be due to the fact that the method was perceived as preventive just because the salt was moistened in solution or that it began as a preventive measure but took so long that it became conventional. In other words, the conditions became slippery before the action was complete. However, this result suggests that preventive salting should be an effective method of reducing the increase in the number of accidents in slippery conditions.
The maximum value for single accidents is 3-4 times higher than the corresponding maximum value for other types of accidents. There are also major regional differences. The maximum accident rate for southern Sweden is approx. 3 times as high as the corresponding value for northern Sweden.

### 8.1.2 Urban areas

**Möller, Wallman, Gregersen (1991)**

During the winters of 1986/87–1989/90, studies were carried out regarding winter road maintenance in several urban areas and the effects that different types of maintenance have on the ability of drivers to reach their destinations as well as traffic safety. In addition, the road users’ views regarding winter road maintenance were studied.

The project was carried out during a number of mild winters. Therefore, only the results from urban areas where a relatively large amount of data was collected are presented here.

In a test area in Skellefteå, a number of changes were made to increase traffic safety primarily for pedestrians and cyclists. The following are a few examples:

- Snow ploughing began when there was less snow on footpaths/bicycle tracks.
- In these areas, fine gravel was used instead of sand.
- Certain footpaths, which previously had been used as places to pile snow, were ploughed and action was taken to combat slippery conditions.
During the first test winter, the cost of combating slippery conditions on footpaths and cycle tracks in the test area was almost twice as high as in the control area. During the second test winter the cost was slightly higher and during the third winter it was almost the same as in the test and control areas. With regard to snow ploughing, the follow-up of remedial action did not indicate that the costs had increased more in the test area. On the contrary, it suggested that they were somewhat lower.

There was no considerable change in the condition of the road other than a certain reduction in the amount of snow/slush. The thickness of the layer of loose snow/slush was reduced considerably. The number of observations of road conditions with improved friction thanks to the combating of slippery conditions increased.

In the entire urban area of Skellefteå, excluding the test area, the number of accidents involving pedestrians and cyclists during the first winter increased by 10% and by 30% the next two winters compared with the winter before the test. This information refers to all accidents reported to hospitals and to the police.

The number of accidents that occurred during test winters 1 and 3 was approx. 60–70% greater than expected without a change in remedial action. There was no improvement in traffic safety during the intermediate winter either. The increase refers only to single pedestrians, i.e. pedestrians who slipped, stumbled or fell. These accidents took place on footpaths and pedestrian/cycle tracks. These results do not correspond with the expectation that the change in remedial action would increase traffic safety. It should be pointed out that the increase has not been confirmed by statistics. The effects of chance are also sufficient to explain the increase in the calculation. Another possible explanation for the increase rather than the expected decrease could be increased exposure. The improvement in winter road maintenance could be the reason for this.

One of the questions this project was to illuminate was:

- How much greater is the risk of accident if there is ice and/or snow on the road compared with bare ground?

An attempt to quantify the results was made by comparing the percentage of accidents on icy/snowy roads and bare ground respectively with the number of icy/snowy roads and bare ground areas.

The material needed for these calculations was taken from the island of Hisingen in Göteborg and from Skellefteå. The changes in winter road maintenance in Skellefteå are accounted for above. On Hisingen in Göteborg, the roads were ploughed and measures were taken to combat slippery conditions on both streets in residential areas and the major arterial roads. During the test winters, ploughing began when there was 5 cm of snow rather than the standard 8 cm. The measures for combating slippery conditions were to be completed within 3–7 hours rather than the standard 24 hours. Footpaths and cycle tracks were ploughed more often and more work was done to combat slippery conditions, which meant that action was taken even outside of normal working hours.

In Göteborg, the calculated risk of accident varied insignificantly from one winter to another and was approx. 5 times higher on icy/snowy roads than on bare ground. In Skellefteå, the variation was greater from one winter to another. The risk of accident is between 7.5 and 11 times higher on icy/snowy roads than it is on bare ground. The calculations that refer to Skellefteå are based on 1-2 bare
ground accidents and are therefore very uncertain. It should be pointed out that there was no information regarding exposure on different road surfaces. The road conditions and accident percentages for Göteborg and Skellefteå are listed in Figures 8.1.7 and 8.1.8.

An attempt was also made to study whether the risk of accidents increases for pedestrians and cyclists when road conditions are unusually poor. In one extreme case, when a long period of frozen rain covered streets and footpaths with a very slippery layer of hard ice, there was a significant increase in the number of accidents per day involving pedestrians/cyclists. This increase was approx. 20 times higher than normal for the winter.

**Figure 8.1.7** Percentages of bare ground and ice/snow according to observations of road surfaces and accident reports involving pedestrians and cyclists during three winters on Hisingen in Göteborg.

**Figure 8.1.8** Percentages of bare ground and ice/snow according to observations of road surfaces and accident reports involving pedestrians and cyclists during three winters in Skellefteå.
Öberg et al. (1997)

Single accidents involving pedestrians and cyclists have become a major problem for hospital personnel. This particularly pertains to days when the road conditions are slippery and when many injuries, primarily among pedestrians, increase the work load of hospital personnel. Official statistics do not define single accidents involving pedestrians as a traffic safety problem because there are no vehicles involved. Furthermore, a police report is usually not filed when a cyclist falls off his/her bicycle.

Registration of traffic injuries and an estimate of the number of pedestrians and cyclists in Göteborg, Linköping and Umeå began in December 1993 and continued throughout 1994. The exposure measurement used when calculating the injury rate is based on the calculations but revised using the number of residents living in the urban area and for cyclists based on travel experience surveys. The classification of days that was carried out based on observations of road conditions means that on days when the ground was bare, there could be ice and/or snow on the road. It has also been proven that on days that were classified as having bare ground during the winter, more than half of the pedestrian accidents occurred on icy/snowy roads and approx. one-third of the accidents involving cyclists occurred on ice/snow.

![Figure 8.1.9](image_url)  
**Figure 8.1.9** Injury rate for pedestrians in single accidents. Confidence interval of 95% with regard to uncertainty in the number of persons injured is indicated by the arrows. Adults: 16-65 years old.
In all urban areas, the injury rate for pedestrians on bare ground in the winter is about twice as high as in summer. See Figure 8.1.9. Days when the road conditions were mixed were just over 6 times more dangerous, while snow and/or ice was just under 8 times more dangerous than in summer. Each of these differences is statistically confirmed with the exception of the difference between mixed road conditions and ice and/or snow. (The uncertainty in the exposure data was not taken into consideration).

In all three urban areas, the injury rate for cyclists on bare ground in the winter is approx. only half of what it is in summer. See Figure 8.1.10. Other winter road conditions are insignificantly more dangerous than summer roads. This is mainly due to the large number of cycling accidents involving children in the summer time in Göteborg. It could also be that there is another category of cyclists in the winter. Elderly cyclists run twice as much of a risk as other adults except on ice and/or snow where the risk is much greater. The only difference that has been confirmed by statistics is the difference between adults and elderly in icy/snowy conditions.

![Figure 8.1.10 Injurity rate for cyclists. Confidence interval of 95% regarding the uncertainty in the number of people injured is indicated by the arrows. Adults: 16–65 years old.](image-url)
The following recommendations to road maintenance authorities are based on risk of accidents for pedestrians and cyclists in single accidents. No other considerations were made. Recommendations regarding maintenance of bare ground are also made.

Injuries to pedestrians and cyclists must be taken seriously. In comparison with those injured in collisions, they are:

- At least as many
- At least as serious measured in percentage of those admitted to hospital (=seriously injured)
- Almost as serious when measuring the median cost of care

To a very large degree, these injuries can be considered the responsibility of the road maintenance authority (especially with regard to injured pedestrians).

The primary cause of injuries to pedestrians is slippery conditions in the winter. However, elderly people are also affected by falls on bare ground, while this type of injury is very unusual for other age groups. Furthermore, pedestrians show several clear signs of behavioural changes. This means that improving the standard of footpaths does not automatically reduce the number of accidents. The relationship between the number of accidents and the surface quality for cyclists is simpler: good standard results in fewer accidents.

Based on these comprehensive results, the following recommendations can be made to road maintenance authorities:

- Concentrate primarily on improving winter road maintenance for pedestrians.
- The standard of winter roads should be of good, even quality.
- An increase in the number of heated footpaths.
- Improved winter road maintenance for (listed in order of priority):
  - elderly pedestrians
  - adult pedestrians
  - elderly cyclists
  - adult cyclists.
- Sand and gravel should be swept up as soon as the winter is over – especially on hills in cycle tracks!
- Bare ground maintenance should aim to achieve an even standard for pedestrians, but also a high, median standard for the cyclists.
- Concentrate on bare ground maintenance, primarily in areas where there are many elderly pedestrians.
- Do not focus on maintaining tiled areas in the centre of town. Most accidents occur on asphalt, on the outskirts of town.

There may also be a greater number of behavioural changes than discussed above. On an international level, the quality of footpaths and cycle tracks is very high in Sweden. One reason for this is the winter conditions, which in themselves require large areas for the efficient removal of snow and ice. This could mean that the expectations of pedestrians and cyclists are far too high regarding the quality of the surfaces, and that minor faults could lead to problems that are just as troublesome as the conditions where they expect faults.
8.1.3 Total

Nilsson (1986)

During the period 15 September 1983 – 15 September 1984, records were kept of injuries that occurred when travelling on roads and where the person injured went to one of the emergency rooms in the administrative district of Östergötland. This accounted for just over 90% of all emergency room cases.

The number of residents in Östergötland was about 400,000 and approximately 4,000 injuries were registered in the administrative district in one year. This means that one percent of the population was injured in traffic in one year and had to seek medical treatment. The total number of injuries recorded was 3,649 of which 53% were single accidents involving pedestrians and cyclists. See Table 8.1.2.
Table 8.1.2  Injuries registered during one year in Östergötland according to method of transportation and type of accident.

<table>
<thead>
<tr>
<th>Method of transp.</th>
<th>No. of injuries</th>
<th>Method of transp.</th>
<th>No. of injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single</td>
<td>Collision</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It was possible to divide the number of injuries in the four largest emergency rooms according to the road conditions (slippery – not slippery). See Table 8.1.3.

Table 8.1.3  Injuries registered at the four largest emergency rooms in Östergötland according to road conditions – slippery and not slippery and time of the year as well as the proportion of injuries resulting from slippery conditions during the period November - March.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrians</td>
<td>1164</td>
<td>301</td>
<td>863</td>
<td>614</td>
<td>0.71</td>
</tr>
<tr>
<td>Cyclists</td>
<td>1028</td>
<td>815</td>
<td>213</td>
<td>128</td>
<td>0.60</td>
</tr>
<tr>
<td>Moped riders</td>
<td>141</td>
<td>103</td>
<td>38</td>
<td>16</td>
<td>0.42</td>
</tr>
<tr>
<td>Motorcyclists</td>
<td>183</td>
<td>172</td>
<td>11</td>
<td>3</td>
<td>0.27</td>
</tr>
<tr>
<td>Car drivers</td>
<td>466</td>
<td>263</td>
<td>203</td>
<td>89</td>
<td>0.44</td>
</tr>
<tr>
<td>Car passengers</td>
<td>326</td>
<td>199</td>
<td>127</td>
<td>66</td>
<td>0.52</td>
</tr>
<tr>
<td>Bus passengers</td>
<td>70</td>
<td>33</td>
<td>37</td>
<td>20</td>
<td>0.54</td>
</tr>
<tr>
<td>Total</td>
<td>3378</td>
<td>1886</td>
<td>1492</td>
<td>936</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Almost 25% of those injured had to be admitted for care. Half of these were pedestrians or cyclists. As illustrated in Figure 8.1.11, the number of injuries to pedestrians and cyclists varied depending on age. The majority of the injured cyclists were young while the majority of injured pedestrians were elderly.
Figure 8.1.11 Number of injuries among pedestrians, cyclists and others in Östergötland 1983/84 according to age.

In order to illustrate the consequences of the injuries, the median length of the hospital stays for pedestrians, cyclists and others (primarily road users) injured in slippery and non-slippery conditions in Motala during the year of the investigation are listed in Table 8.1.4.

Table 8.1.4 Number of days in hospital in Motala for those injured in slippery and non-slippery conditions.

<table>
<thead>
<tr>
<th>Method of trans.</th>
<th>No. of days in hospital</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Not slippery</td>
</tr>
<tr>
<td>Pedestrians</td>
<td>13.2</td>
</tr>
<tr>
<td>Cyclists</td>
<td>5.4</td>
</tr>
<tr>
<td>Others</td>
<td>6.1</td>
</tr>
</tbody>
</table>

* only 11 cases

As illustrated by the table, the injuries incurred by pedestrians and cyclists in slippery conditions required a much longer stay in hospital than for those injured in non-slippery conditions. Pedestrians injured in slippery conditions spent an especially long period in hospital.

Of those injured in slippery conditions, the majority are women (twice as many as men) and many are over 50 years old.

Consequently, the transportation safety problems involving pedestrians and cyclists are mostly single accidents where slippery conditions play a major role as do the conditions of the surfaces of the footpaths and bicycle tracks. With regard to pedestrians, women and the elderly are injured most, while the cycling problems mostly afflict younger people of both sexes.

If the information above were translated to a national level, 5 out of every 1,000 inhabitants in Sweden would be injured in traffic either as a pedestrian or a cyclist. This means that there are approximately 50,000 injuries resulting in hospital visits among these two groups of road-users. 40,000 of these are single accidents where pedestrians have either stumbled or slipped or where the cyclist...
has fallen off the bicycle. Thus, these injuries constitute about half of all injuries that occur in traffic. Approximately 20,000 of the injuries that come to the attention of hospitals apply to road users. Pedestrians and cyclists travel 6 billion person-kilometres a year, while road users travel approximately 90 billion. This should imply that it is 35-40 times more likely that a pedestrian or cyclist will be injured and have to go to the hospital than it is for a road user.

**Brorson, Ifver, Rydgren (1988)**

The percentage of single accidents involving personal injury in winter varied from 21.5–43.1% during the years 1966-84. At other times of the year, the percentage maintained a more stable (high) level.

The hypothesis for this study was that snow cover and ploughed banks of snow act as a type of prevention, i.e. that there are fewer single accidents resulting in injury during winters when there was a lot of snow compared with winters when there was less.

The Swedish Meteorological and Hydrological Institute’s (SMHI) statistics provided information such as median snow depth, number of days with precipitation and number of days with temperatures below freezing point for the winters 1966–84 based on observations made in each administrative district.

Information concerning accidents reported to the police was obtained from the Central Bureau of Statistics (SCB) for the years 1966–84 and from the Road Data Bank (VDB) for the years 1978–84.

It was assumed that the exposure (flow of traffic) was directly proportional to the amount of petrol sold on a monthly basis during the years 1966–77. The flow values for each administrative district for the years 1978–84 could be obtained directly from VDB.

Two separate analyses were carried out. The first was for the period 1966–84, where the winter was defined as the months December–March, and where an aggregated study comprised the entire country.

The second analysis applied to the period 1978–84, where data from VDB made it possible to consider each region individually. The administrative districts were compiled into three regions, southern, central and northern Sweden. The winter months were defined here as the months in which there was a snow cover of at least 0.5 mm (in melted form). In this analysis, it was possible to group the accidents into degree of severity, snow depth and regional flow.

Among other things, the result indicates that the number of single accidents per month involving personal injury is 45% higher during months without snow than it is during the snow season. However, the number of multi-vehicle accidents per month is about the same, regardless of the time of year.

The result also indicates that 31% of single accidents involving personal injury during the snow season and 40% during months without snow are fatal or involve seriously injured persons. The corresponding percentages for multi-vehicle accidents are 37 and 36 respectively.

The relationship between the depth of the snow and the number of single accidents involving personal injury is illustrated in Figure 8.1.12.
Figure 8.1.12 Relationship between snow depth and the number of single accidents involving personal injury, per region, 1978–84.

Ragnarsson et al. (1991)

Some administrative districts are more active than others regarding winter road maintenance. This should be reflected by the level of traffic safety. There is a need for a simple model that would give the road maintenance authorities "feedback" concerning how well they have succeeded with their maintenance.

The Swedish National Road Administration proposed a simple model, which looks at the percentage of single accidents that occur during the winter:

\[
\text{Winter percentage} = \frac{\text{single accidents}_{\text{winter}}}{\text{single accidents}_{\text{summer}} + \text{single accidents}_{\text{winter}}} \]

If the winter percentage drops on a yearly basis, it indicates that winter road maintenance is improving. In order to use the simple model, a number of assumptions must apply. The following account shows the validity of these assumptions:

Assumption (1) \( \text{No. of single accidents}_{\text{summer}} = \text{Risk}_1 \times \text{vehicle mileage} \)

Assumption (2) \( \text{No. of single accidents}_{\text{winter}} = \text{Risk}_2 \times \text{vehicle mileage} + k_1 \times \{\text{weather/road conds.-term}\} + k_2 \times \text{Winter Road Maintenance} \)

Assumption (3) If single accidents are reduced so are multi-vehicle accidents

Assumption (4) If the number of accidents is reduced so is the number of injuries.

Assumption 1 seems to apply in each case for the investigated time period 1970–1988.
There are two additional terms in the second assumption. A weather term (slippery days, snow depth and days with precipitation) and a dummy term where the Swedish National Road Administration has helped classify the different road maintenance authorities that are more or less active with regard to using new technology in the field of winter road maintenance. Because of the different winters in the different parts of the country, the administrative districts have been divided into three different climatological regions. All analyses were done on a regional basis.

The assumption was studied with the help of a regression analysis. The result indicated that it was not possible to prove any difference between the active and less active administrative districts, with the exception of one region.

The following is a list of the four regression equations in common form:

\[
OK = \beta_0 + \beta_1 \cdot TA + \beta_2 \cdot \text{depth} + \beta_3 \cdot \text{slippery conditions}
\]

where

- \( OK \) = accident rate for single accidents
- \( TA \) = vehicle mileage
- \( \text{depth} \) = snow depth on the ground
- \( \text{slippery conditions} \) = slippery days (determined on the basis of temperature, humidity and precipitation)

The different coefficients are listed in Table 8.1.5, where the degree of explanation is also given.

<table>
<thead>
<tr>
<th></th>
<th>( \beta_0 )</th>
<th>( \beta_1 )</th>
<th>( \beta_2 )</th>
<th>( \beta_3 )</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active admin. distrs. region 1</td>
<td>0.29</td>
<td>-0.0009</td>
<td>-0.0045</td>
<td>0.012</td>
<td>0.21</td>
</tr>
<tr>
<td>less active admin. distrs. Region 1</td>
<td>0.27</td>
<td>-0.0003</td>
<td>-0.0039</td>
<td>0.020</td>
<td>0.19</td>
</tr>
<tr>
<td>region 2</td>
<td>0.16</td>
<td>0.0001</td>
<td>-0.0036</td>
<td>0.017</td>
<td>0.29</td>
</tr>
<tr>
<td>region 3</td>
<td>0.09</td>
<td>0.0007</td>
<td>-0.0020</td>
<td>0.008</td>
<td>0.39</td>
</tr>
</tbody>
</table>

The third and fourth assumptions were checked with the help of three simple regression analyses. All three showed clear connections, which means that they can be considered valid.

No direct studies were carried out to determine whether improved winter road maintenance leads to an improvement in traffic safety. Instead, this was done step by step and there is some uncertainty in each of the steps, which makes it difficult to come to any certain conclusions about the entire study.
Meteorologically slippery days and the depth of snow were the parameters that seemed to affect the accident rates most. As expected, an increase in the number of slippery days increases the accident rate, as does a reduction in the snow depth.

The model was considered insufficient for following up the effects of winter road maintenance on traffic safety.

**Björnstig (1993)**

In Umeå, an analysis of vehicular accidents resulting in personal injury was carried out. This means that the pedestrians studied were hit by a vehicle. For this reason, only the results for cyclists are presented. Most cyclists are injured during the summer months and this probably reflects the exposure. Of the 353 cyclists treated by the University hospital, 39% of the accidents occurred in January–April and October–December, i.e. the winter months. Of these 40% (56 people in all), stated that the accident was caused by slippery roads. Seven cyclists stated that they had fallen because of gravel on the cycle track. This could be an after-effect of winter road maintenance. 25 people (7% of those injured during the entire year) had either run into the kerb/stone or a hole in the road and 11 people (3%) had collided with either a cement obstacle, light post, etc.

Most of these people were only slightly injured and on median they visited the hospital 1.4 times per person. 78 people (22%) were admitted for inpatient care for a total of 151 days, i.e. just under 2 days/person. The median cost of care was 3,300 SEK/person. Almost every seventh cyclist had been reported to or by the police.

**Öberg, Junghard, Wiklund (1993)**

The aim of this study was to find a sufficient method of estimating the effects that different types of tyres had on traffic safety.

The study contained information about vehicles involved in traffic accidents that were reported to the police. Changes to the police report form (2 pages) were made according to the following: "total number of people in the vehicle" and "defects in the vehicle" were replaced by tyre equipment, i.e. studded tyres, summer tyres, other types of tyres.

Questionnaires were used to collect information about the control vehicles (vehicles in traffic). The questionnaires were to provide answers about the scope of the vehicle mileage for passenger cars with different tyres in different road conditions in the different administrative districts.

The results are extremely uncertain. The aim was not to produce any exact answers but rather to test different methods.

The distribution of tyre types on passenger cars is as follows; 66% studded tyres, 27% summer tyres and 7% other types of tyres. A few more women than men had studded tyres on their cars.

The relative risks on the public road network were calculated for passenger cars that had been damaged and/or whose occupants had been injured in a number of different ways, and gave rather similar results: cars with studded tyres ran a 36-50% lower risk of having an accident than cars without studded tyres on slippery roads.

For cars that were in accidents involving personal injury in areas that are not densely populated, the risk was 40% lower with studded tyres than without. In
densely populated areas, the risks varied a great deal depending on the method of analysis used.

The conclusion was that the method studied, i.e. questionnaires, seems useable.

**Carlsson, Centrell, Öberg (1995)**

The effect of a ban on the use of studded tyres on traffic safety is calculated using the new model with the effects that resulted from a method study 1989/90 (see previous reference). Since the results emerged in a method study, where different methods of investigation are studied and the primary aim was not to produce confirmed results, we have been cautioned not to use them. However, later Finnish studies show an effect on traffic safety that is in line with the Swedish method studies. Consequently, the Swedish results are used here despite this caution.

The calculations were performed both for the winter of 1993/94 and for the turn of the century. The conditions during the winter of 1993/94 constitute the basis for the calculations and it was a rather normal winter. It is assumed that the conditions at the turn of the century will be the same, except for the fact that everyone using studded tyres will have lightweight studs and that the hard-wearing surfaces on the public road network will be more commonplace.

The effects used in the new model are that studded tyres reduce accidents on icy/snowy roads by 40% in rural areas and 35% in densely populated areas compared with summer tyres. The corresponding numbers for other snow tyres are 25 and 20% respectively. The term "types of tyres" refers to everything from brand new to old worn out tyres, i.e. it is the effect of the good-bad tyres that is actually used in January–February 1990.

If studded tyres are banned, the redistribution of the vehicle mileage is calculated so that 80% of the drivers who had studded tyres previously now use snow tyres without studs and 20% summer tyres.

The results according to the new model mean an increase in the number of accidents by almost 10% of the total number of accidents reported to the police involving cars during one winter or just over 20% of the number of accidents on icy/snowy roads. The total increase would be 3,000–6,000 accidents/year. In addition, there are indirect accident effects such as, for example, that wet friction on surfaces is reduced since the studs no longer give the rough texture. The studies no longer create tracks and there is less defilement. All told, these indirect effects imply that a ban against studded tyres would mean an addition 600–700 accidents.

Table 8.1.6 shows a summary of the calculations carried out.

The calculations refer to a ban against studded tyres during the winter of 1993/94 when approximately 17% of the cars fitted with studded tyres had lightweight studs. Since only lightweight studs are available nowadays, and everyone using studded tyres will eventually have them, calculations have been carried out to this effect. This should be the case around the turn of the century.
Table 8.1.6  A ban against studded tyres implies the following changes in costs (millions of SEK/year).

<table>
<thead>
<tr>
<th></th>
<th>Increase</th>
<th>Following drop in percentage of lightweight studs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>17 %</td>
</tr>
<tr>
<td>Accidents</td>
<td></td>
<td></td>
</tr>
<tr>
<td>direct</td>
<td>1,190–1,450</td>
<td></td>
</tr>
<tr>
<td>indirect</td>
<td>240–290</td>
<td></td>
</tr>
<tr>
<td>Road wear</td>
<td></td>
<td></td>
</tr>
<tr>
<td>surface</td>
<td>150–200</td>
<td>65–90</td>
</tr>
<tr>
<td>road sign(s)</td>
<td>35–70</td>
<td>20–35</td>
</tr>
<tr>
<td>Car costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>tyres/rims</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>petrol consumption</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>cleaning</td>
<td>300–700</td>
<td>130–300</td>
</tr>
<tr>
<td>Environment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cleaning cars</td>
<td>25–50</td>
<td>10–20</td>
</tr>
<tr>
<td>miscellaneous</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,430–1,740</td>
<td>625–1,135</td>
</tr>
</tbody>
</table>

Studded tyres have a major effect on the number of accidents and the cost of the increase in accidents that would be brought about by a ban on studded tyres would not be compensated for by other known reductions in costs. It is difficult to measure and evaluate the effects on the environment, however, and for this reason only a few were included above. With the above results for the other effects, the negative effect on the environment must be major before a balance is reached. Around the turn of the century, the difference between the advantages and disadvantages of a ban on studded tyres will be even greater. By then, 100% of all cars with snow tyres will have lightweight studs. This will reduce car and wear costs and will be more environmentally friendly with the same traffic safety effects as studded tyres.

Carlsson, Öberg (1995)

The effects of the following scenarios were determined:

Requirements for snow tyres on cars (or snow chains if summer tyres are used) when driving on slippery roads.
Requirements for snow tyres on cars from 1 November until the first Sunday after the Easter weekend.
Requirements for snow tyres on cars during December, January and February.

The conditions and methods of implementation were made clear in the previous reference.

Table 8.1.7 illustrates a summary of the reduction/increase in costs arising from the different requirements for snow tyres.
Table 8.1.7 Requirements for snow tyres on slippery roads result in changes, which are listed in MSEK below.

<table>
<thead>
<tr>
<th></th>
<th>Decrease</th>
<th>Increase in percentage of lightweight studs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17 %</td>
<td>100 %</td>
</tr>
<tr>
<td>Accidents</td>
<td></td>
<td></td>
</tr>
<tr>
<td>direct</td>
<td>385–485</td>
<td></td>
</tr>
<tr>
<td>indirect</td>
<td>75–95</td>
<td></td>
</tr>
<tr>
<td>Road wear</td>
<td></td>
<td></td>
</tr>
<tr>
<td>surface</td>
<td>25–35</td>
<td>10–15</td>
</tr>
<tr>
<td>road sign(s)</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Car costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>tyres/rims</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>petrol consumption</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>cleaning</td>
<td>50–120</td>
<td>20–50</td>
</tr>
<tr>
<td>Environment</td>
<td>5–10</td>
<td>0–5</td>
</tr>
<tr>
<td>cleaning cars</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>miscellaneous</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>TOTAL</td>
<td>460–580</td>
<td>155–240</td>
</tr>
<tr>
<td></td>
<td>+?</td>
<td>+?</td>
</tr>
</tbody>
</table>

The traffic safety benefits of this requirement are much greater than its known negative effects. This will require some vehicle mileage with summer tyres when conditions suddenly become slippery, which reduces the top traffic safety benefit above.

It is estimated that the number of accidents reported to the police involving cars would drop by 1,100–1,400. There would be approx. 6–7 fewer fatalities in traffic, 50–60 fewer with serious injuries and 200–250 fewer with minor injuries. There is a great deal of uncertainty in these figures.

Snow tyres required from 1 November-15 April
The difference between know advantages and disadvantages is slightly less than for the previous requirement, but it is probably less likely that anyone would drive with summer tyres on icy/snowy roads.

It is estimated that the number of accidents reported to the police involving cars would drop by 1,000–2,000. There would be approx. 6 fewer fatalities in traffic, 50 fewer with serious injuries and 200 fewer with minor injuries. There is a great deal of uncertainty in these figures.

Snow tyres required December-February
The traffic safety benefits of this proposal slightly outweigh the disadvantages that are known at this time.

It is estimated that there would be 700–900 fewer accidents involving cars reported to the police.
Johansson (1997)
In order to determine any relationships between the condition of the roads and the number of traffic accidents reported to the police, the number of accidents of different character were studied for three different types of winters: the very cold winter of 1986/87, the extremely mild winter of 1991/92 and the normal winter of 1993/94.

The hypothesis was, that if the condition of the road were of great significance to the traffic safety, the mild winter of 1991/92 should have produced the fewest accidents. The accidents during these three winters were regulated with the help of the number of accidents during the summers of the same years. This was done to eliminate the influence of differences in the size of the road network and in the flow of traffic, the accident trend and changes in the degree of reporting accidents.

The country was split into four climate zones; southern, central, lower northern and upper northern Sweden. The road network was split into five different traffic flow classes. The accidents were then grouped according to climate zone, flow class and the road condition that was reported at the time of the accident.

The comparisons indicate that the greatest number of accidents occurred during the normal winter and that there were approximately the same number of accidents during both the extremely mild and the cold winter. This shows that the condition of the road as such can not explain the number of accidents.

The explanations could be that there might have been less vehicle mileage during the cold winter and that the embankments caused by ploughing and snow on the side of the road could be significant with regard to both the number of accidents and their consequences. In addition, long periods with stable road conditions could be less risky than shorter periods interrupted by mild weather.

8.2 Nordic investigations
Puttonen, Vakkuri (1980)
The aim of this investigation was to study the relationship between the traffic accident rate and the weather situation. The analysis comprises all accidents on public highways in Finland between the years 1974–1977.

The median accident rate was 118 accidents per 100 million vehicle kilometers. The accident rate for different weather situations was: clear weather 108, cloudy 132, rain 88, snowfall or slush 130 and fog 137.

Different light conditions resulted in the following accident rates: daylight 97, twilight 222, darkness with street lighting 189 and darkness without street lighting 146.

The accident rate is highest when two or three of the weather, light or road conditions simultaneously complicate driving.

Ragnøy (1985a)
The aim of this study was to gain more knowledge about road traffic accidents in the winter. The accident analysis is divided into two parts: a description of the accident pattern and a calculation of the maximum reduction in the number of accidents as a result of winter road maintenance.

54% of all traffic accidents take place during the winter, 10 October–30 April, in Norway, (1978–1983). Of these, 60% occur on icy/snowy roads while the rest occur on bare ground (dry or wet). 49% of the winter accidents occur in densely
populated areas and 51% outside. 58% of accidents that take place on icy/snowy roads take place outside the densely populated areas.

The report defines the degree of severity as: \( \frac{killed}{killed + injured} \times 100 \)

The degree of severity on icy/snowy roads is 3.68, on bare ground during the winter 3.88 and the total for the winter is 3.75. In summer it is 3.76. The accident material does not contain any data regarding two-wheeled vehicles.

The number of head-on collisions is considerably higher in the winter than in the summer, i.e. 19 and 10% respectively. 25% of all accidents on icy/snowy roads are head-on collisions. The majority occur outside of densely populated areas. On bare ground in the winter and summer every tenth accident is a head-on collision.

An estimated relative risk of accident, based on the distribution of vehicle mileage expressed as a percentage in summer and winter and the distribution of traffic in different standard classes, indicates that there is an increased risk when the ADT drops. The relative risk for the highest standard class during the winter is 0.97 and 1.06 for the lowest. The corresponding figures for summer are 0.97 and 1.05. The standard classes are based on the vehicle mileage (ADT).

Based on an assumption that 65% of winter vehicle mileage is carried out on bare ground and the remainder on icy/snowy roads, it is expected that the estimated relative risk of accident increases, from 0.61–0.66, in winter as the ADT on bare ground decreases and it decreases, from 2.46–1.43, with the drop in ADT on icy/snowy roads.

The report is concluded by calculating the maximum reduction in the number of accidents that can be achieved through winter road maintenance. The calculation is based on the fact that all traffic on icy/snowy roads runs the same risk as when driving on bare ground. In the most likely interval for the percentage of bare ground driving of winter vehicle mileage, 60–80%, the reduction in the number of accidents is 50–80%. There is a great deal of uncertainty in these calculations, however.

**Ragnøy (1985b)**

The aim of the project was to study the safety and accessibility of today's winter road maintenance standards and to calculate the economic consequences. The main focus was on the problems encountered by pedestrians. The analysis also included accidents that occurred in Oslo during the winter of 1983/84.

The report presents the results of three partial surveys:
- pedestrian accidents,
- accidents reported to the police involving personal injury,
- problems for the elderly on winter roads.

The data consists of injured pedestrians (only those who slipped and accidents that resulted in, for example a broken arm or leg) treated in emergency rooms in Oslo or by the Red Cross. Injuries were registered using a form, filled out by the injured person, which included information about themselves and the conditions at the time of the accident.

76% of accidents involving pedestrians occurred in icy/snowy conditions, 7% when the surface was sanded and 17% on bare ground or some other surface. Of
those who slipped on ice and/or snow (83%), 90% specified the condition of the surface was directly responsible for the accident.

Of every 10,000 inhabitants, women are twice as likely to be injured than men. The elderly are more likely to be injured than young people.

The injury picture is dominated by arm injuries, which account for 63% of the total number. 29% are leg injuries and the remaining 8% are injuries to other parts of the body. The amount of time it takes for the injured people to get well, the number of sick days, is on median 30 days.

When calculating the costs, four items of expenditure were calculated and then totalled. They are: the cost of emergency care, hospital costs (approx. 5% of those who come to emergency rooms are admitted to the hospital), loss of production and transportation. During the winter of 1983/84, the total socioeconomic cost of accidents on slippery surfaces were 12.3 million Norwegian kronor.

During the period November 83–April 84, there were 386 traffic accidents in Oslo. 35% were pedestrian accidents and 61% were accidents involving cars. Cycling accidents (which accounted for 4%) were not included in the analysis.

In order to consider both weather and road conditions, a snowy day was defined, when the precipitation exceeded 0.1 mm and the temperature was below 0 °C. The accidents that occurred on the snowy day and the first and second days after the snowfall were added and compared with the other days. There were no significant differences in either the number of pedestrian or vehicular accidents.

The socioeconomic costs of traffic accidents involving personal injury in connection with snowfall are estimated at 13 million Norwegian kronor. Pedestrian accidents cost 5.7 million and vehicular accidents 7.3 million.

In order to gain an understanding of the problems faced by elderly during winter travel, personal interviews were conducted with approximately 500 pensioners over the age of 67. 72% stated that they go out less often in the winter compared with the summer and 50% of these people said that this was due to slippery sidewalks. There are three main reasons why the elderly go out less in the winter. They are listed here in order of priority:

− slippery sidewalks,
− respiratory problems,
− other seasonal reasons (weather, darkness, cold).

Hvoslef (1986)
The text below is taken from a lecture given during the "International Winter Road Congress" in Finland in 1986.

Some of the reasons why the risk of accident is approximately 50% higher in Norway during the winter compared with the summer are reduced friction, lighting conditions, etc. On snowy/icy roads the risk of accident could be 3–6 times higher than on dry, bare ground. The more surprising and unexpected deterioration in the road conditions, the greater the risk.

The risk of property damage is twice as high during the winter (October–March) but often less serious. The risk of accident for pedestrians is 1.5–2 times higher in winter than in summer.

Approximately 50% of all head-on collisions occur on ice and/or snow and 60% of them take place in curves. On the other hand, the percentage of single accidents on ice and/or snow is lower than the median. One explanation for the fact that more single accidents involving only property damage are reported than
those involving personal injury, is that the snow embankments on the side of the road act as protection from trees, etc.

On a dry road, the stopping distance at 80km/h and with a friction level of 0.75 is approximately 55 metres. The corresponding distance for icy/snowy roads at a speed of 73 km/h and a friction level of 0.25 is 102.5 metres.

Different models have been developed which attempt to describe the consequences of a change in winter road maintenance. The consequences illustrated were: traffic safety, accessibility, cost of travel time and the effects on the environment.

Winter road maintenance measures such as, for example, information about poor road conditions, spot salting, improved and higher standards on footpaths and cycle tracks are all positive from a socioeconomic point of view.

Rytilä (1986)
The text below is taken from a lecture given during the "International Winter Road Congress" in Finland in 1986.

In Finland, approximately 6,000 km of the public road network is illuminated. This amounts to less than 10%.

In relation to the vehicle mileage, the number of traffic accidents in Finland increases from the beginning of October until the end of January. This increase can be blamed on darkness. If we exclude the accidents occurring in darkness, the monthly variation in the number of accidents is equivalent to the monthly variation in vehicle mileage. From February to April, it seems as if road users have become used to the winter conditions and the number of accidents decreases.

The most serious time is on a Friday afternoon in December between the hours of 4 p.m.-5 p.m.

Consequently, the measures should focus primarily on preparing road users for the autumn, (e.g. procure good winter/studded tyres), increasing the number of illuminated roads and implementing measures to increase friction.

Polvinen (1987)
The aim of this investigation was to study the risk of accident on winter roads during the winter of 1984–85 in Finland. The same investigation was also carried out during the winter of 1982–83.

The winter of 1984–85 was much colder than 1982–83. A comparison was made of the risk of accidents during these two winters.

Approximately 5,000 accidents were reported to the police during both winters, 25% of which involved personal injury. 40–80% of the accidents occurred on icy roads.

The only differences found between the two winters were on icy roads: the risk of accident was 46% higher during the winter of 1984–85. On main roads, the risk of accident in icy conditions was 20–35 times higher than on dry roads. The corresponding figures for other public roads were 11–13 times higher.

For both winters, the risk of accident on icy roads is strongly associated with how common this condition is: the more common icy/snowy roads are, the lower the risk of accident. Temperature also affected the risk of accident on icy/snowy roads. At lower temperatures, the risk of accident was higher compared with road conditions at 0 °C or above and when considering the frequency of icy roads during the winter.
\[ y = 19.13 \cdot x^{-0.845} \quad \text{temp. } > = -1^\circ C \]
\[ x = 41.31 \cdot x^{-0.902} \quad \text{temp. } < = -1^\circ C \]

\[ y = \text{accidents/million vehicle km driven} \]
\[ x = \text{percentage of icy roads} \]

**Giaæver (1988)**
This documentary study presents an overview of experience and research results regarding the traffic safety effects of winter road maintenance. The report deals with the risk of accidents on winter roads and the traffic safety effects of winter road maintenance and studded tyres.

**Risk of accident on winter roads**
Different Nordic investigations indicate that the risk of accidents in winter is 50–100% higher than in summer.

According to a Swedish study, the risk of accidents is 2–8 times higher on icy/snowy roads than on dry roads. The results of a Norwegian study are similar: 3–6 times higher risk on icy/snowy roads than on dry roads.

The results of a Finnish study carried out in 1980 indicate that on dry roads, the risk of accident is 0.77 accidents per million vehicle kilometres, on wet bare ground 1.23, on snowy roads 1.31, on icy roads 6.15 and in slush 2.52.

**Traffic safety effects of winter road maintenance**
According to the reports referred to, road salt has little significance with regard to traffic safety. Road users seem to utilise the increase in friction by increasing their speeds.

The direct effect of sanding is unknown.

**Traffic safety effects of studded tyres**
In Minnesota, the risk of accident increased by 4% on icy/snowy roads after studded tyres were banned. On the other hand, a Canadian study could not prove any increase in the number of accidents in the winter after a ban on studded tyres was introduced.

West Germany banned the use of studded tyres in 1975. During the winter immediately following this ban, the number of accidents increased on highways and slippery roads in proportion to the number of days that the roads were slippery. However, the total number of accidents decreased.

Finnish studies show that the use of studded tyres reduces the risk of accident. Studded tyres reduce the number of accidents during the winter by almost 20% and fatal accidents by about 10%.
Hagen (1990)
The aim of this project was to map out the number of pedestrians who slip on icy/snowy footpaths; estimate the percentage who slip because of ice and/or snow; estimate the costs of different winter road maintenance measures and evaluate any profits resulting from improved winter road maintenance.

In 1988, the Central Hospital in Buskerud treated almost 1,000 people who had slipped. The injured were asked to fill out a questionnaire providing information about the site of the accident, their age, address, cause of injury, type of injury and the degree of care received. Once both accidents that occurred in the summer and those that occurred on a surface other than ice and/or snow were excluded, approximately 350 remained.

More than 50% of those injured were over 60 years of age. The most common type of injury (58%) was a broken arm or leg. Sprains and dislocated joints accounted for 22% of the injuries and 10% of the injuries were so serious that the person had to be admitted to the hospital.

The total socioeconomic cost of injuries incurred when slipping on ice and/or snow in Drammen in 1988 was estimated at between 14 and 16 million Norwegian kronor. This includes the costs of medical care, loss of production and transportation.

If we link the fact that there were 140 km of footpaths in Drammen in 1988 with the maximum socioeconomic gain resulting from improved winter road maintenance (14-16 million), the estimated annual profit per 100 metres of footpath in Drammen in 1988 was 11,000 Norwegian kronor.

Fridstrøm et al. (1993)
Traffic accidents resulting in personal injury and fatalities were analysed in Denmark (for the period 1977–87), Finland (1975–87), Norway (1973–86) and Sweden (1976–87). It was assumed that the accidents were Poisson distributed and had a large number of explanation variables: exposure, reporting and legislation, weather and daylight, trends, administrative district (fylke, amt) and month.

Different combinations of explanation variables were included in fourteen models for the accident relations.

It was assumed that the monthly exposure (flow of traffic) was directly proportional to the petrol sales in each administrative district. However, this did not apply in Denmark, where traffic flow measurements were used.

The results for the different countries were fairly distinct: the explanation given for 60–80% of the variation in the number of fatal accidents was chance, exposure explained more than half of the remaining systematic variation, while changes in speed limits, daylight and weather conditions explain a further 6–14% (of the systematic variation). In total, these factors explain between 88 and 94% of the variation in the different countries.

Chance plays a much smaller role (3–9%) in accidents involving personal injury, while exposure explains 72–87% of the systematic variation. Changes in reporting routines, speed limits, daylight and weather conditions account for 4–12% of the systematic variation. In total, these factors explain between 86 and 94% of the variation in the different countries.

A few special viewpoints are worth mentioning: daylight promotes traffic safety, while rainy weather reduces safety. On the other hand, winter conditions
result in fewer accidents involving in personal injury or fatalities. The report deals with some possible explanations for this including: risk compensation, winter road maintenance measures, the use of studded tyres, enbankments of snow created when ploughing and snow that mitigates the effects of running off the road, and the composition of road users in the summer and winter respectively.

**Lundell (1993 och 1994)**
The aim of this report (thesis) was to clarify the influence from driver and snow tyres on traffic accidents in Finland. The working hypothesis was that the parties who had nothing to do with the accident constitute an interplay of the traffic system in general and that the guilty parties are somehow separated from this normal population.

The accident material included data regarding traffic accidents in which there were fatalities caused by a car during the winters (1 November–30 April) of 87/88, 88/89 and 89/90. Each accident specified; time, driver, vehicle, accident, road condition, weather and the cause and results. The material was derived from the Swedish Association of Traffic Insurance Companies’ Accident Commissions.

The report can be summarised by stating that the traffic safety effects of snow tyres are largely related to the depth of the tread pattern and primarily to the projection of the studs. On the other hand, the brand of tyre or parameters that were specified when they were manufactured are of little significance with regard to traffic safety. The driver’s attitude towards traffic safety is also significant. Snow tyres that are in bad repair are often mounted on vehicles whose driver has an indifferent attitude towards traffic safety.

This report concludes that in order to maintain a high level of traffic safety, the minimum tread pattern on snow tyres must remain at 3 mm and that the use of studded tyres in winter must be permitted in the future.

**Hagen, Ingebrigtsten (1993)**
In Norway, approximately 36,000 people who had been involved in traffic accidents sought hospital treatment during 1991. It is estimated that the number of pedestrians injured, (no vehicle was involved), is about the same. The aim of the report:
- to calculate the socioeconomic costs of traffic and pedestrian accidents in Akershus,
- to estimate the possible benefits of reducing the number of injuries on slippery surfaces with winter road maintenance measures,
- to estimate the possibility of reducing the number of traffic accidents and the costs of injuries by urging people to use public transportation rather than their own cars, trucks, motorcycles, etc.

The calculation of the costs of injuries incurred in traffic and pedestrian accidents is based on the following costs: health care, material costs, administrative costs and loss of production.

The real-economic cost of traffic and pedestrian accidents in Akershus in 1991 was 1,025 million Norwegian kronor. Traffic accidents cost 876 million and pedestrian accidents accounted for the remaining 149 million. Pedestrian accidents are divided into slipping on icy/snowy surfaces, which can be counteracted with
maintenance, and accidents with other causes. The cost for the first group is 76.5 million.

The change in the risk level when transferring travellers from one form of transportation to another consists primarily of:

- change in the individual risk level for the person changing methods,
- change in the risk level for other road users as a result of different distribution of traffic between methods of transportation.

One calculation example where it was assumed that 10% of the car traffic was transferred to trains, indicated that the annual cost of injuries was reduced by 44 million Norwegian kronor.

**Roine (1994)**
The aim of this investigation was to study the risk of accident in winter in Finland and primarily the difference between those who drive with studded tyres and those who drive without. The project consisted of three parts:

- a questionnaire was sent to 10,000 car owners, 58.7% answered,
- a questionnaire was sent to 3,000 drivers who were involved in accidents during 1992–93. 763 of those who answered had been in an accident in the winter,
- comparative material was taken from accident investigations during 1987–1991. (A total of 1,347 drivers, of whom 658 had been involved in accidents during the winter).

Based on the first questionnaire, it was impossible to satisfactorily explain all relevant data for the accident analysis since the drivers themselves answered. Previous studies have shown that the driver either did not remember or attempted to describe his/her part in the accident as positively as possible. The different sections of the study complemented each other well.

Drivers who drove a lot were involved in more accidents than those who drove less. Those who drove a lot in densely populated areas were at greater risk than those who drove mostly in the country. Young drivers ran a greater risk of having an accident in the winter. This seems to be a result of their driving habits, i.e. both lack of experience and the fact that they drive a lot. Drivers in the highest age group were often involved in winter accidents. Drivers who were driving in excess of the speed limit before the accident were more often than not the responsible party.

It was not possible to ascertain the effect of the use of so-called "friction tyres", since so few people used them. The drivers who drove without studded tyres ran a greater risk of accident than those who used studded tyres. Good studded tyres reduced the relative risk of having a fatal accident by an median of 20% and on icy/snowy roads by 48%. During the winter, 30% of the drivers used poor quality studded tyres, other snow tyres or summer tyres.

**Sakshaug, Vaa (1995)**
Two different studies were carried out based on accidents reported to the police involving personal injury:

Part 1 A before-and-after study of the accident effect of salting a previously unsalted road network. The test road network included roads that were first
salted during the years 1983-90. The network consisted of 1,947 km of public highway south of Sør-Trøndelag; during the period before and after, a total of 2,360 accidents were reported to the police. The unsalted public road network outside the densely populated areas was used as the control road network, a total of 12,900 km of road with an median of 1,300-1,400 accidents per year. The distribution of traffic on the salted road network is shown in Figure 8.2.1.

Part 2 Comparative study of salted – unsalted road network. The test comprised stretches of the main road network throughout the country. 839 km were salted, while 540 km of the control stretches were not. The number of accidents reported to the police was 427 and 137 respectively. The distribution of traffic on both road networks is illustrated in Figure 8.2.2.

![Before-and-after study](image)

**Figure 8.2.1** Before-and-after study: distribution of the salt stretches based on the amount of annual daily traffic.
Figure 8.2.2 The comparative study: the distribution of the stretches of road based on the amount of annual daily traffic.

According to the before-and-after study, salting reduced the number of personal injuries by 11% over the entire period 1983–1990. See Figure 8.2.3. It is claimed that the improvement in routines over the past few years produces a greater effect as seen in Figure 8.2.4. Therefore if salting is introduced, the number of personal injuries should drop by about 20%.

Figure 8.2.3 The effect of salting on the number of personal injuries.
**Figure 8.2.4** The effect of salting on the number of accidents involving personal injuries, according to start years.

For the comparative study, it was assumed that the relationship between accidents in the winter and summer on unsalted test stretches is the same as for the control stretches. Based on this, conventional methods can be used to calculate the expected number of accidents if salt is not used. The result of the comparative study is illustrated in Figure 8.2.5, where a 26% reduction in the number of accidents is established.

**Figure 8.2.5** The effect of salting on the frequency of accidents.
As illustrated in Figures 8.2.6 and 8.2.7, the effect of salting is greatest during the autumn and spring.

**Comparative study**

*Effect on accidents involving personal injury*

- Observed frequency unsalted
- Expected frequency salted (no effect of salting is assumed)
- Observed frequency salted

![Graph showing accident frequency during different seasons](image)

- Autumn (15 Oct - 14 Nov): 0.185, 0.100, 0.141
- Winter (16 Nov - 15 March): 0.221, 0.238, 0.188, 0.21%
- Spring (16 March - 15 April): 0.161, 0.173, 0.094

( ) More than a 10% likelihood that there will not be any difference
( ) Less than 5% likelihood that there will not be any difference

**Figure 8.2.6**  Reduction in the number of accidents during different seasons.

**Before-and-after study**

*Effects on accidents involving personal injury in different sections of the salting season*

*Sections that are salted all winter*

- Expected number
- Number observed

![Graph showing accident frequency during different months](image)

- October: 84, 78
- November: 92
- December: 82, 84
- January: 87
- February: 89, 87, 67, 71
- March: 65, 70, (+5%), (-17%)

( ) Difference in expected no. - no. observed
( ) More than a 10% likelihood that there will not be any difference

**Figure 8.2.7**  Reduction in the number of accidents on a monthly basis.

VTI rapport 423A 119
Alppivuori (1995)
Several of the Finnish reports from the first half of the ‘90s that are referred to in this VTI report were included in a major winter project. The summaries and conclusions of all these reports are included in the reference above. Table 8.2.1, which lists the changes in costs brought about by a reduction in the use of salt and studded tyres in millions of USD compared with the conditions in 1990 shows that a widespread use of studded tyres and salting gives the lowest socioeconomic costs and has a positive effect on traffic safety. It also seems that a 50% reduction in the use of studded tyres increases the cost of accidents by more than a 50% reduction in the use of salt.

Table 8.2.1  Changes in socioeconomic costs as a result of changes in the methods of combating slippery conditions and the use of studded tyres.

<table>
<thead>
<tr>
<th>Change in costs</th>
<th>Salting 120 000 t/a</th>
<th>Light salting c. 60 000 t/a</th>
<th>Nearly unsalted &gt; 30 000 t/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Million US$/a</td>
<td>Basic situation</td>
<td>+36</td>
<td>+36</td>
</tr>
<tr>
<td>&lt; 95% of pass. cars with studs</td>
<td>+47</td>
<td>+91</td>
<td>+98</td>
</tr>
<tr>
<td>c. 50% of pass. cars with studs</td>
<td>+100</td>
<td>+160</td>
<td>+202</td>
</tr>
</tbody>
</table>

1 US$=4.5 FIM

Vaa (1996)
In connection with a comparative study in Trondheim, an extra effort was made to combat slippery conditions on a test road during three winter seasons, 1993/94–1995/96. The ADT on the test road was 11,500–17,000 vehicles and its posted speed limit was 50 and 60 km/h. The ADT on the control road was 2,000 vehicles and its posted speed limit was 50 km/h. The extra effort mainly consisted of salting and, to a lesser degree sanding with a mixture of salt.

There was no control winter regarding precautionary measures and road conditions. However, accident reports from the four winter seasons that preceded the experiment were used.

The results showed that the number of accidents reported to the police involving personal injury and those reported to insurance companies were cut in half thanks to the increased effort in combating slippery conditions. The cost-benefit rate was estimated as 46.
8.3 Investigations made outside the Nordic countries

Scharsching (1988)
The accident rate in different road and light conditions was studied by Heinz (1981). The result is illustrated in Table 8.3.1.

Table 8.3.1  Accident rates in different road and light conditions.

<table>
<thead>
<tr>
<th>Travel conditions</th>
<th>All accidents</th>
<th>Single accidents</th>
<th>Collision accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>all</td>
<td>0.173</td>
<td>0.080</td>
<td>0.069</td>
</tr>
<tr>
<td>daylight/dry</td>
<td>0.128</td>
<td>0.054</td>
<td>0.054</td>
</tr>
<tr>
<td>daylight/wet</td>
<td>0.203</td>
<td>0.106</td>
<td>0.076</td>
</tr>
<tr>
<td>darkness/dry</td>
<td>0.222</td>
<td>0.089</td>
<td>0.105</td>
</tr>
<tr>
<td>darkness/wet</td>
<td>0.471</td>
<td>0.293</td>
<td>0.117</td>
</tr>
</tbody>
</table>

Durth, Hanke, Levin (1989a)
The aim was to study the extent to which ploughing and salting public highways affects road users’ passability and safety.

The relative risk of accident was estimated by placing the braking and stopping distances on different road conditions in relation to equivalent stretches of dry road. For these calculations, it was assumed that the driver’s reaction time was 1.0 seconds and that the friction rates were 0.75, 0.5 and 0.15 on dry, wet and slippery roads respectively. It was assumed that ploughed and salted roads had the same values as the wet roads. In principle, the results for the five stretches were the same. Figure 8.3.1 shows one example, which illustrates the relative braking and stopping distances for the median speeds and the 85 percentile speeds.

Figure 8.3.1  Relative braking and stopping distances at $V_{50}$ and $V_{85}$ respectively.

The figure shows that the reduction in speed on wet and slippery roads did not even come close to compensating for the reduced friction. However, there was a slight over-compensation on the ploughed and salted roads.
The accident analysis comprised 635 kms of road. The account of the precautionary measures taken included each measure and vehicle, (a total of approx. 7,000 measures). The measures, the plans for ploughing and salting and weather and traffic data formed the basis for the conclusions regarding the condition of the roads at the time of the accidents.

The most important results are accounted for in Figures 8.3.2 and 8.3.3 and Table 8.3.2 below.

**Figure 8.3.2** Accident rate before and after action is taken.

The accident rate is $8-10 \text{ ol/10}^6\text{ vehicle km}$ immediately before action is taken. Within two hours, the accident rate drops to 2.6.
Figure 8.3.3  The variation in the accident rate during the day.

Table 8.3.2  Representative accident numbers.

<table>
<thead>
<tr>
<th></th>
<th>All measures</th>
<th>No. of days without constant slippery conditions</th>
<th>No. of non-slippery days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>before</td>
<td>after</td>
<td>before</td>
</tr>
<tr>
<td>No. of accidents</td>
<td>352</td>
<td>198</td>
<td>213</td>
</tr>
<tr>
<td>Total accident costs (TDM)</td>
<td>13,414</td>
<td>4,557</td>
<td>10,222</td>
</tr>
<tr>
<td>Vehicle mileage (10^6 fkm)</td>
<td>37.5</td>
<td>74.0</td>
<td>26.9</td>
</tr>
<tr>
<td>Accident rate (ol/10^6 fkm)</td>
<td>9.5</td>
<td>2.6 (3.5:1)</td>
<td>7.9</td>
</tr>
<tr>
<td>Accident cost rate (TDM per 10^6 fkm)</td>
<td>358</td>
<td>62 (6:1)</td>
<td>380</td>
</tr>
<tr>
<td>Median degree of severity (DM/accident)</td>
<td>38,000</td>
<td>23,000</td>
<td>48,000</td>
</tr>
</tbody>
</table>
The percentage of accidents in slippery conditions varies slightly with the road’s alignment on the horizontal and vertical planes. This is illustrated in Figure 8.3.4

![Percentage of accidents in slippery conditions in relation to the geometry of the road.](image)

**Figure 8.3.4** Percentage of accidents in slippery conditions in relation to the geometry of the road.

**Durth, Hanke, Levin (1989b)**

Until now, the use of salt as a means of combating slippery conditions on German highways was considered irreplaceable. To attempt to reach a sensible compromise between traffic safety and environmental requirements, certain road maintenance authorities have tested using limited amounts of salt. Certain sections of these ”white networks” – with a small amount of traffic and few accidents – were selected, where gravel is normally used instead of salt, or where ploughing is the only winter road maintenance measure. The aim of this project was to study the effects of this limited use of salt on passability and traffic safety.

It was assumed that the risk of accident in different road conditions was the current stopping distance in relation to dry, bare ground at the 85 percentile speed. Since no friction measurements were carried out, they were assumed to be:

- Dry, bare ground: 0.75
- Wet, bare ground: 0.5
- Slippery conditions: 0.15
- Gravel: 0.2

The calculations only give the relative risk for each road. The speeds on dry roads were different for the different test roads.

The risk calculations for road M 11 in Bavaria are illustrated in Figures 8.3.5 and 8.3.6. As seen, the drivers did not compensate for the inferior friction by reducing their speeds. Two risk values were calculated for the dry road with patches of snow or ice. The one on the left applies to dry roads and the one on the right applies to snowy roads. Note the risks for ”transitional road conditions”: track wear and patches of snow and/or ice.
Figure 8.3.5 Risk factors for road M 11, Bavaria.

Figure 8.3.6 Effects of different agents for combating slippery conditions

Figure 8.3.7 illustrates the results for a stretch of road in Hessen. Note the extremely high risk when there is frost on the road.

Figure 8.3.7 Risk factors for road K 478, Hessen.

It was difficult to prove any effects of the restricted winter road maintenance on the actual accident rate. This was partly because the scope of the white network changed during the course of the study and that salt was actually used on several occasions.

The change in the accident rate was analysed before and after action was taken. This process is illustrated in Figure 8.3.8. After action was taken, the accident rate dropped dramatically for all types of measures. However, the rate for gravel stabilises at a value that is approximately 3 times higher than for salt.
Figure 8.3.8 Changes in the accident rate when combating slippery conditions. Bavaria.

Table 8.3.3 illustrates the variations in accident rate over a longer period of time.

**Table 8.3.3** Accident rates for the days action was taken and the subsequent days.

<table>
<thead>
<tr>
<th></th>
<th>Combating slippery conditions with gravel</th>
<th>Combating slippery conditions with salt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days when action was taken</td>
<td>3.5</td>
<td>2.5</td>
</tr>
<tr>
<td>First day after action</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Second and third days after action was taken</td>
<td>1.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Days that were not slippery</td>
<td></td>
<td>1.1</td>
</tr>
</tbody>
</table>

**Kuemmel, Hanbali (1993)**

This study shows the accident rate before and after action is taken (salting) and is based on material consisting of an unknown number of accidents during the winters of 1989/90 and 1990/91. The analysis was carried out in the same way as a German study at the beginning of the ‘80s.

The report also lists the results of a cost-benefit-analysis. The advantage of winter road maintenance is calculated using the change in the number of accidents before and after action is taken. The cost of an accident is determined by a number of factors.
The accident rate for so-called "Two Lane Highways" is about 8 times higher before action is taken (salting) than it is after. The accident rate for accidents involving personal injury is about nine times higher before action than it is after and the corresponding figure for accidents involving property damage is about seven times. The ratio between accidents involving personal injury and accidents involving property damage is approximately 30% higher before action is taken than it is after. Winter road maintenance reduced the cost of traffic accidents by 88%.

The accident rate for so-called "Multi-Lane Divided Freeways" is just over four (4.5) times higher before action is taken (salting) than it is after. The accident rate for accidents involving personal injury is approximately seven times higher before action than it is after. The corresponding figure for accidents involving property damage is the same as for those involving personal injury. The difference in the rate for accidents involving personal injury and accidents involving property damage is that it is approximately 200% higher before action is taken than it is after. Winter road maintenance reduces the cost of traffic accidents by 85%.

**Thoma (1994)**

Failing to adjust speeds in different road, traffic and visual conditions is one of the major causes of accidents. The aim of this study was:

- To analyse speed as a cause of accident through statistical analysis of different situations regarding the condition of the road, time of day and day of the week.
- To determine the speeds in the aforementioned situations.
- To illustrate the different risk levels depending on the situation and the speed.

Tables 8.3.4 and 8.3.5 illustrate the risk of accidents on different days of the week, times of day and in different precipitation conditions for public highways and motorways.

**Table 8.3.4**  
*Accident and fatality rates for public highways depending on the day of the week, time of day and precipitation. Accidents per million vkm(vehicle kilometres), fatalities per 100 million vkm.*

<table>
<thead>
<tr>
<th>Time of day</th>
<th>Dry road</th>
<th>Rain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accidents</td>
<td>Fatalities</td>
</tr>
<tr>
<td>Weekdays</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day</td>
<td>0.59</td>
<td>32</td>
</tr>
<tr>
<td>Night</td>
<td>1.00</td>
<td>50</td>
</tr>
<tr>
<td>Weekends</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day</td>
<td>0.53</td>
<td>33</td>
</tr>
<tr>
<td>Night</td>
<td>1.25</td>
<td>74</td>
</tr>
</tbody>
</table>
Table 8.3.5  Accident and fatality rates for motorways depending on the day of the week, time of day and precipitation. Accidents per million vkm (vehicle kilometres), fatalities per 100 million vkm.

<table>
<thead>
<tr>
<th>Time of day</th>
<th>Dry road</th>
<th>Rain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accidents</td>
<td>Fatalities</td>
</tr>
<tr>
<td>Weekdays</td>
<td>Day</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>Night</td>
<td>0.52</td>
</tr>
<tr>
<td>Weekends</td>
<td>Day</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>Night</td>
<td>0.65</td>
</tr>
</tbody>
</table>

The drivers were not very good at adjusting their speeds to the deterioration in driving conditions.

The action proposed to change the behaviour of the drivers was training, information, legislation and information technology.
9 Summary, comments and continued R&D

The following general conclusions may be drawn from the results of each chapter. There are also comments about the results and the need for continued R&D.

9.1 Distribution of road conditions

Observations of road conditions have been carried out on the public road network, primarily to control and follow-up the winter road maintenance measures. These observations were made in detail and can, together with other data, also be used to calculate the vehicle mileage and risk of accidents in different road conditions. Another interesting and important use would be to utilise the material as a basis for a road condition model. Road conditions are principally affected by weather, maintenance measures and the flow of traffic. A model that describes the road conditions would help us understand the prevailing correlations and, among other things, make it possible to forecast the effects of changes in winter road maintenance measures.

Naturally, the studies that have been carried out indicate that there are major differences in the distribution of road conditions in different regions and for different types of roads.

For the public road network, the continuous observations of the road conditions must be utilised as an important empirical basis for the road condition model, which will be of primary importance to a comprehensive model for calculating the effects of the winter road maintenance measures.

For the densely populated areas, it is especially important to develop methods that describe the road conditions for pedestrians and cyclists.

9.2 Friction

Friction is the road primary variable with regard to safety. The friction value is seldom constant on the road, especially on winter roads where it can vary greatly along the road. This depends largely on local differences in the thickness of the layer and the consistency of the ice and snow cover.

The measurement method is of major significance: for example, if the measurement is made using with a friction car with a braked measurement wheel or an oblique wheel, or with Digislope, etc. on a standard car.

The following friction rate (Saab Friction Tester, skidometer principle, tyres without studs) can be seen as a rough representation for different road conditions:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Friction Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry bare ground</td>
<td>0.8–1.0</td>
</tr>
<tr>
<td>Wet, bare ground</td>
<td>0.7–0.8</td>
</tr>
<tr>
<td>Packed snow</td>
<td>0.20–0.30</td>
</tr>
<tr>
<td>Loose snow/slush</td>
<td>0.20–0.50</td>
</tr>
<tr>
<td>Thin ice</td>
<td>0.15–0.30</td>
</tr>
<tr>
<td>Loose snow on thin ice</td>
<td>0.15–0.25</td>
</tr>
<tr>
<td>Wet, thin ice</td>
<td>0.05–0.10</td>
</tr>
</tbody>
</table>

It is considered likely that a road which has recently been sanded or new, studded tyres can increase the friction rate by 0.1 units.
After approximately 300 cars have driven on the sanded surface, it no longer has any effect on the friction rate.

Continuous friction measurements are proposed to map out the distribution of the friction levels during the winter and the variation in friction resulting from different weather and traffic conditions and winter road maintenance measures.

9.3 Speed – stopping distances
Speeds in winter road conditions vary within a fairly wide range, but for cars it can be assumed that they are roughly 75–90% of the speed on bare ground. In order to maintain a constant stopping distance, speeds should be halved. It is more likely the condition of the road (its appearance) than the friction or road maintenance standard that determines the reduction in speed. It is difficult for drivers to assess friction levels, and even more difficult the more slippery the conditions become, when the braking distance, and with that the risk of accident increases quickly.

Precipitation brings about much greater reductions in speed than slippery roads alone.

Thus far, few studies have been carried out where the conditions of the road have been observed frequently at the same time as speed measurements have been recorded. The correlation between speed, class of road and road condition should be studied in much more detail in order to be included, along with a road condition model, in a post calculation model.

9.4 Headways, capacity, flow, density
The headways in queues (i.e. when the maximum headway is 5 or 10 seconds in different studies) increase as the condition of the road deteriorates. The shortest headways (1 to just over 2 seconds) are those that are seen less often. The number of headways between 2 and approximately 4 seconds increase in number. The median headways in queues increase by 0.2–0.5 seconds in snowy weather.

In other words, in winter road conditions speeds decrease while headways increase. This means a reduction in both density and capacity. The capacity on snow-covered roads has been measured as being approximately 80% of that on bare ground. The total effect on traffic is that it becomes much more sensitive to disturbances and the risk for queues increases.

The most pressing need for further research in this area applies to the dependency of capacity on the condition of the road. This should be of great interest to densely populated areas.

9.5 Vehicle costs
9.5.1 Fuel consumption
The fuel consumption of cars and trucks increases considerably in untouched snow. The increase is reduced rapidly for each subsequent vehicle driving in the same tracks.

The increase in the fuel consumption of heavy vehicles has been measured as being between 50 and 80% in 5–6 cm of untouched snow compared with the amount consumed on a ploughed road or bare ground. After having driven over this surface a few times, the corresponding increases were measured as being 12 and 30% respectively.
A measurement of the amount of the fuel consumption of a car showed an increase of 25% on well-used roads after 13 cm of snow had fallen.

On another occasion with 13 cm of snow on the road, the increase varied by between 48 and 111% after the first car had driven through the untouched snow.

An increase of 10–30% was measured on well-used slushy roads.

In real traffic conditions, the snow is quickly compressed. The largest increases in fuel consumption, measured in untouched snow, hardly apply at this time. If conditions are not too bad, the increase in fuel consumption caused by bad weather/road conditions can be compensated for by the decrease brought about by a reduction in speed.

There is no urgent need to continue researching the amount of fuel consumed in different winter road conditions.

9.5.2 Corrosion

Corrosion on body sheet metal is an electro-chemical process which occurs through electrode reactions in a humid environment. A sufficient amount of oxygen and water are required for corrosion. The use of road salt contributes to corrosion in two ways. One of these ways is that the surface of the road stays wet longer and the other is that the presence of chlorides increases the conductivity and with that the speed of the corrosion process.

A moist steel surface rusts fastest at +12 °C and a relative humidity of 75%. Corrosion basically ceases when the temperature is less than –2 °C or the humidity level is less than 60%.

The greatest reduction in corrosion is brought about if the roads are no longer salted. If the cars are exposed to salt daily, a reduction in the amount of salt does not make a significant difference, nor does it matter much whether the car is washed. If salt is only used in the autumn and spring, and the car is washed carefully after being driven on salted roads, there could be a significant reduction in the amount of corrosion. The Swedish Motor Vehicle Inspection Company’s statistics, from unsalted Gotland and Västervik where salt is used, have been analysed regarding demerits given because of such extensive rust defects that the car did not pass inspection. The results indicate that the vehicles in Västervik fail inspection 2–4 times more often than the vehicles on Gotland.

Experts feel that if roads are no longer salted, the service life of cars will increase by 25%. In 1984, the cost of corrosion resulting from roads salted in the winter was estimated at 1.7 billion kronor or 12 öre per vehicle kilometre. The improvements made on cars to reduce corrosion resulted in a 20% drop in costs from 1982–1987.

New corrosion problems arise in that electronic devices are affected. Studies have shown that even very thin layers of corrosion products on the contacts can disrupt their conductivity. This has led experts to believe that even if sheet metal corrosion decreases, other types of corrosion will prevent a reduction in the cost of corrosion.

Continued research regarding corrosion should primarily focus on the problem of electronics.
9.6 Traffic safety

The relation that is generally considered most important to clarify is that between the condition of the road/friction and accidents, especially those involving serious personal injury.

9.6.1 Accident rates

An attempt to generalise the results of the projects accounted for in this report is shown below. It is always a question of relative accident rates, i.e. in relation to the accident rate on dry, bare ground or – when referring to rates prior to maintenance measures – in relation to the median accident rate a certain number of hours before and after measures have been taken.

Accident rates in different road conditions

A. Winter road only defined as ice/snow.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Daylight</th>
<th>Darkness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare ground</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Ice/snow</td>
<td>2–20</td>
<td>4–14</td>
</tr>
</tbody>
</table>

The relative accident rate on bare ground in winter is 0.8–0.9, while the summer value is 1.1. This difference is mainly due to the seasonal differences in speed and the number of road users on the road.

B. Winter road conditions with a more detailed classification.

This is also a classification according to the source of the report.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Accidents reported to the police</th>
<th>Accidents reported to insurance companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare ground</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Thin ice</td>
<td>3–8</td>
<td></td>
</tr>
<tr>
<td>Packed snow/thick ice</td>
<td>2–7</td>
<td></td>
</tr>
<tr>
<td>Ice/packed snow</td>
<td></td>
<td>8–12</td>
</tr>
<tr>
<td>Loose snow/slush</td>
<td>3–10</td>
<td>30–50</td>
</tr>
<tr>
<td>Patches of snow and ice</td>
<td></td>
<td>10–15</td>
</tr>
<tr>
<td>Snow and rain</td>
<td>2.5–3</td>
<td></td>
</tr>
</tbody>
</table>

Loose snow and slush cause more serious accidents than the other two groups of ice/snow. The accident rate for different road conditions is highest in southern Sweden and lowest in the north.

Accidents involving personal injury account for approximately one-third of all traffic accidents reported to the police and approximately 10% of those reported to insurance companies. The largest percentage of accidents involving personal injury occurs in daylight and primarily on bare ground and consequently at a higher speed. The percentage of these accidents is slightly higher in the south of Sweden than in the north. The highest percentage, i.e. 60%, of single accidents reported to insurance companies occurs on loose layers and patches of ice/snow, 44% on hard layers and 33% on bare ground. The percentage of accidents in
intersections is highest, i.e. 25%, on bare ground. In other road conditions the percentage is less than half of this.

**Accident rates before and after maintenance measures**

Swedish studies indicate that there is a significant increase in the accident rate just before maintenance measures are carried out; a detailed study shows a peak at 1–1.5 hours before measures are taken. This maximum value can be as much as 12 times higher than the median accident rate 12 hours before or after the measures are carried out. Compared to the time 6–12 hours before measures are carried out, the increase in the number of accidents is 6 times higher for accidents involving personal injury both with and without property damage included.

The Swedish results are confirmed by German studies, in which the accident rate was found to be 5–14 times higher than median during a 12-hour period before and after measures were carried out.

The results of studies carried out in the USA also confirm the Swedish findings. The accident rate on two-laned roads was 8 times higher before measures were carried out than it was after. The corresponding value for highways was 4.5 times.

**Risk of accidents depending on the use of different studded tyres**

Studded tyres reduce the risk of having an accident on slippery rural roads by about 40% compared with summer tyres. The reduction with unstudded snow tyres is approximately 25%. It is estimated that this effect is less in densely populated areas.

**9.6.2 Effects of standard changes or changes in remedial action**

The transition from salted to unsalted roads seems to reduce the number of accidents on minor roads (i.e. those with an ADT < approx. 2,000 vehicles) but increase the number on major roads. The transition from roads that are salted all winter to roads that are only salted during the autumn and spring seems to result in a slight increase in the number of accidents. However, this has not been confirmed by statistics (5% risk level). The transition to preventive salting with moist salt seems to reduce the number of accidents.

In Norway, the transition from an unsalted to a salted road network resulted in a 20% reduction of the number of accidents involving personal injury. Salting produced the greatest effects at the beginning and end of the winter respectively.

**9.6.3 Aggregated studies**

Three comprehensive investigations have been studied in this report. They are Brorson et al. (1988), Fridstrøm et al. (1993) and Johansson (1997).

The difference between these and other investigations referred to here, which are based on observed road conditions and traffic measurements during the test periods, is that the accidents have been analysed on the basis of general assumptions about the condition of the roads and the flow of traffic in regions comprising one or more administrative districts.

The first two of these reports assume that the winter road conditions can, to a certain degree, be described using meteorological statistics from only a few observation sites within each region (administrative district): precipitation, critical temperature, etc. The flow (exposure) within a certain region has often been
considered to be directly proportional to the amount of petrol sold there. However, the aggregated results of flow measurements have sometimes been used. Both studies apply only to accidents involving personal injuries or fatalities that have been reported to the police. The results of both studies indicate that the number of accidents decreases with a higher percentage of winter weather.

Johansson’s study of three very different winters shows that there is no obvious difference between them with regard to the total number of accidents reported to the police. However, the degree of severity decreases the colder the winter is. This concurs with the findings of both the other studies.

### 9.6.4 Pedestrians and cyclists

A fairly rough estimate of the risk of accidents facing pedestrians on icy/snowy roads is that it is 5–10 times greater than on bare ground.

Typical accident categories are, for cyclists, teenagers and for pedestrians people over 50, primarily women. 25% of those injured are admitted to the hospital for care. The median length of stay in hospital for pedestrians is 22 days for those injured in slippery conditions and 13 days for those injured in normal conditions. The median length of stay for injured cyclists is approximately half of this. The increase in the number of accidents resulting from slippery conditions is greater for pedestrians than for other road users. Pedestrians also suffer more serious injuries.

### 9.6.5 Comments

It is obvious that there are major variations in the size of the accident rates recorded in winter road conditions. There are substantial regional differences, but above all the term icy/snowy roads is a particularly heterogeneous concept. Not even attempts to make more detailed groupings produced a notable decrease in the variations. However, the studies which were based on observations of road conditions and traffic measurements show a distinct increase in the risk of accidents on icy/snowy roads. The risk level varies during the season so that it is higher in the beginning of winter and then stabilises at a lower level in continuous winter road conditions. The risk also increases when there are fewer occurrences of winter road conditions during the season. Certain results indicate that the risk level is at its maximum when winter road conditions are present approximately 15% of the winter. The risk is reduced when winter road conditions become less frequent and probably also when more frequent.

The aggregated studies do not support the assumption that there is an increased risk of accident in winter road conditions, at least not with regard to accidents involving personal injury. The studies deal with winters over long periods. It is therefore likely that a number of other factors play a part, e.g. the introduction of general speed limits, the increased use of seat belts, safer vehicles, increased use of studded tyres, a change in reporting routines, etc. These effects should be absorbed by the trend factor.

The collection of basic data is associated with a number of problems. The *weather conditions* during the season have often been taken from SMHI statistics or their equivalent.
The condition of the road at the time of the accident is often taken from the police report. In many cases, it seems likely that expert observations of road conditions would provide a different description than the one given by the police.

The sources of the accident reports – police, insurance companies and hospitals – do not comprise the same types of accidents and are of varying quality.

The degree of reporting varies, but increases with the degree of the accident’s severity. Probably almost 100% of all fatal accidents are reported by the police. The degree to which accidents involving serious personal injury are reported is only 59% and 32% for accidents involving minor injuries (SCB and SIKA, 1996). Property damage is mostly reported to insurance companies. In difficult traffic conditions it is likely that even fewer police reports are represented in this case. Hospital reports are the best source of information regarding single accidents involving pedestrians and cyclists.

The exposure (flow of traffic) is a critical factor. In the best case, flow measurements are carried out during the investigation. However, the use of ADT with standard corrections for seasonal and hourly distribution is common and, as mentioned above, estimates are also used. Weather and road conditions change quickly and the standard of winter road maintenance (at least on the main roads) is very good. An increased risk of accident under relatively short periods with poor road conditions and as a result of lower exposure can never be disclosed in comprehensive studies.

In cases where the study comprises large regions, the same problems as those regarding exposure are seen. There is a description on macro level, where local variations in weather, road conditions, flow, etc. cannot be studied.

Few studies are carried out on such a detailed level that they are related to the winter road maintenance measures used. It is likely that these measures have a noticeable effect on the flow of traffic and risk of accident, at least in the short-term.

It seems likely that there is also a certain amount of risk compensation. Road users generally drive somewhat slower in the winter and reduce their speeds even more in bad weather and road conditions. This produces effects, in particular regarding the degree of severity of the accident because the kinetic energy (braking distance), the accidents involving personal injury and the fatalities are directly proportional to the second, third powers and fourth powers respectively of the speed. Consequently, if the speed is reduced from 100 to 90 km/h (10%), the braking distance is reduced by 19%, accidents involving personal injury by 27% and fatalities by 34% in otherwise similar circumstances. Another method of compensating an increase in the risk of accidents is to increase awareness, while yet another is to improve the car’s equipment by, for example, fitting it with studded tyres.

As stated above, it is likely that embankments of snow created by ploughing and snow in ditches alleviate the effects of accidents.

Figure 9.6.1 attempts to illustrate the relation between weather, maintenance measures and road conditions on the one hand and accidents on the other.

As a rule, we try to study these relations directly, without going through the black box. It contains the variables flow, speed and risk of accident, which are affected by exterior factors. It is likely that when conditions increase the risk of accident, speed and flow are reduced and vice versa. This compensation means that there may be almost no change in the total number of accidents.
9.6.6 Continued studies
An interesting project would be to exploit the accident studies referred to here in a meta-analysis (Elvik 1994), i.e. where statistical methods are used to weigh the pros and cons of the results. Unfortunately, this requires access to all data for each study, which means that the project would demand extensive resources.

Bearing in mind the varying results obtained from the different studies, a thoroughly reviewed, very detailed and well controlled study would be desirable. Knowledge of the relations between weather, maintenance measures, road conditions, flow of traffic, speeds and accidents could then be gained from studies on micro-level.

With these studies, we aimed to explain the variation in the risk of accident during the winter, its dependence on the percentage of icy/snowy roads and, not least, on the type of winter road maintenance.

This means that data regarding weather, road conditions, flow of traffic, speeds, maintenance measures and accidents is collected on a very detailed level. Naturally, this requires extensive resources. As a start, a pilot study should be carried out at a few locations throughout the country.

The literary review shows what little interest there is in the risk of accidents facing pedestrians and cyclists. This is primarily based on the fact that
1. single accidents involving pedestrians are not considered traffic accidents,
2. a low percentage of single accidents involving pedestrians and cyclists are reported,
3. this is mainly a problem for densely populated areas.
It is quite urgent that a method be developed to study the safety of unprotected road users. This requires different methods than those used for vehicular traffic: for example, one square decimetre of slippery road surface could cause a pedestrian or cyclist to become an invalid, while a road user is not affected at all.

Figure 9.6.2 shows a greater number of significant relations for motor vehicle traffic. Other categories of road users have been excluded to make the diagram easier to interpret.

![Diagram showing links in winter traffic.](image)

The project proposals given in this chapter could also form the basis for a system, which describes all relevant effects of winter road maintenance – a winter effect model in the form of a causal model!
10 References


Heinijoki, H: **Influence of the type and condition of tyres and drivers’ perceptions of road conditions on driving speed.** FinnRa Reports 19. Helsingfors. 1994.


Öberg, G: **Vägbeläggning.** Vägverkets Trafiksäkerhetsskola.


11 Literature

This literature was added after the report was completed and is, consequently, not referred to there.
