Utilisation of new road surface sensors

Nordic co-operation in dynamic speed management
Preface

Recent studies have clearly shown that the benefits of dynamic weather-related speed management applications (utilising variable speed limits) are obtained only for systems with high-quality real-time control. This high-quality control means that the speed limits displayed to the driver better correspond to the current road surface conditions than the static posted speed limits. Such control requires reliable real-time information of the current road surface condition and especially road surface grip. Until now, the road surface condition monitoring systems have not provided reliable information in all conditions with special problems in very slippery conditions. The recent new optical road surface state sensors as well as new friction assessment systems based on in-vehicle sensors have, however, improved the quality of road surface condition monitoring and especially road surface grip monitoring to a considerable extent. Validation projects have been carried out and are extended in both Finland and Sweden.

To take the efforts in detection, validation, weather modelling and speed management further, a common workshop was held in September 2010. In this report the further development after the workshop is summarised. In the end recommendations are given to the still open questions that remain.

Mikko Malmivuo has contributed to the Finnish status report (Chapter 2), Mats Galmén and Anders Lindkvist to the Swedish report (Chapter 3) as well as Cilius Gintaras to the Lithuanian up-date.

Johnny Alf            Gunnar Lind
project co-ordinator  project manager
Swedish Transport Administration  Movea Trafikkonsult AB
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Summary

Recent studies have clearly shown that the benefits of dynamic weather-related speed management applications (utilising variable speed limits) are obtained only for systems with high-quality real-time control. To take the efforts in detection, validation, weather modelling and speed management further, a common Nordic workshop was held in September 2010. In this report the further development after the workshop is summarised. In the end of this report, recommendations are given to the still open questions that remain.

Co-operative research and innovation

The potential for improvement has been studied, guided by research results in Finland and Sweden. Liaison has also been made with Lithuania, which participated in the workshop (Chapter 4). In Finland, the performance of the new Vaisala sensors has been studied as well as new in-vehicle friction monitoring systems. Minor studies of sensors have also been carried out in Sweden.

A feasibility study for a possible co-operative trial was made in 2009, where the experience in the two countries was compared. It was finished with an international workshop in 2010. Due to lower activity level in Finland and organisational changes in Sweden, the planned trials to fill knowledge gaps and needs in both countries, were decided not to be carried out. This part of the project has been replaced by updated exchange of results at the end of the project. Due to the fact that a new weather controlled VSL link was not selected in Sweden as expected, before/after measurements has been replaced by a reconsideration of the benefits and costs of weather-controlled VSL. The benefits have been estimated as a desktop study based on the changes in the technical performance of the system.

This study has been included in the VIKING work plans 2009-2012 in the EASYWAY action. The co-operation between Sweden and Lithuania is also included in the East-West Corridor project.

Cost-effective use of WCVSL

Weather-controlled VSL has as its objective to motivate users to reduce speed in bad road conditions, enhance response preparedness for abnormal conditions and to create conditions for more homogenised traffic. This can be done through the following overall governing principles:

- Make drivers pay attention to worse weather and road conditions by application of variable speed limits
• Motivate more spontaneous speed reductions by variable road signs (pictograms) in particularly difficult conditions
• Make drivers pay attention to deviations from the general weather situation through the information on VMS and in on-board systems
• Ensure that homogenization, and speed reduction is achieved through regular or automatic control of speed when the system is active

Summary of the recommended approach of WCVSL:
• Weather-controlled VSL is recommended on motorways where traffic-controlled VSL already are installed or planned (mostly roads with 50,000 veh / day or more)
• WCVSL is also recommended on other main roads where the traffic volume is significantly above average (more than 10000 veh/ day), and there is documented evidence showing that the slippery conditions are common and that the velocity is not well adapted to the road conditions.
• Information should additionally be provided by VMS of abnormal conditions
• The speed is reduced by poor road conditions (black ice, heavy rain, fog), but should be limited to no more than 10% of vehicle-mileage, to reduce the risk that road users are affected by over-exposure, which reduces compliance

Improved user interface
The drivers believe that observance and speed adaption can be increased by more speed enforcement. However to an even higher degree they think that information about the reasons for decreasing the speed limits leads to better attention and observance.

The difficulty to exactly define the status of the road surface by sensors is foremost valid for severe and very severe road surface conditions. The optimal vehicle speed in every situation is therefore difficult to predict. A better solution can, based on this experience, be to start with a moderate reduction (20 km/h) which is supplemented in dangerous road surface and weather conditions by warning signs/pictograms that illustrate why the speed limit is reduced. The driver will with this solution be slightly more forced to be active himself and his own ability to pay attention to the road conditions and adapt vehicle speed can be utilized. Speed control will in this way be replaced by speed management.

Traffic safety studies in Finland and also on E6 in Halland show that improved safety not only is attained in slippery road conditions, but also during autumn and spring and even during summertime. Most important seems to be to alert the driver of abnormal weather and road surface conditions. The driver’s focus on the road surface will in this way be reinforced, which has been stated by many drivers in the road user survey. It would therefore be suitable within the framework of a possible continuation of the Easyway project to test an extended use of pictograms as illustrated in Figure 6.1.
Advantages of this approach is that it is easier to understand. A reduced variable speed limit with 20 km/h signals that the traffic situation demands extra attention. The pictogram indicates the type of problem, but the driver must himself adjust the vehicle speed to varying conditions on the link.

Flexible system design
It is recommended that fixed stations with optical sensors for detection of bad road conditions are located at least every 8 km on weather-controlled roads. Stations should be closer in varying alignment. The Vaisala DSC 111 optical sensor works best at low friction, when it is most important. Other sensors require more testing before they are operational.

The weather control should be based on automated, exact, fast and reliable monitoring and classification of the conditions. Thermal mapping should be used to find extreme values of friction along the road. Weather stations should be located at points with average conditions, not with extreme conditions.

Vehicle sensors can be used to measure the current friction over distance. Equipment should be mounted on the Transport Authority and contractor vehicles, especially for winter maintenance. The road weather models may be enhanced by the combination of mobile and fixed friction measurements.

Frequent speed checks should be conducted so often that speed limits are respected, especially when establishing the system. Average speed-over-distance systems (section control) would be suitable for weather controlled VSL.

Suitable organisation
In the current situation, it is uncertain if the Swedish Transport Administration will initiate any further ventures within WCVSL. It is, however, recommended that the development of the third generation of WCVSL is resumed with a clear objective in the work to develop detection and modelling techniques and significant development resources and calendar time to meet the technical challenges.

The cooperation between Sweden and Finland should continue in order to make accurate and informed decisions. The Swedish Transport Administration and the Finnish Transport Agency should form a working group aiming at a common strategy for management of WCVSL. The co-operation efforts should be included in the agenda of the Nordic Road Association.

The strategy should include:
- Objectives for WCVSL management
- Considerations concerning extended use of WCVSL (road types, traffic volume, climate zone)
• Considerations concerning WCVSL management (speed levels, VMS, instrumentation, models)
• Common research program for extended validation of sensors
• Common research program for extended speed measurements

The Swedish Transport Administration and the Finnish Transport Agency should also form a WCVSL group for information exchange and networking. Efforts should be made to include Norway and Denmark in the cooperation. A new workshop is recommended within 12 months. It might be organised within the Nordic Road Association, the East-West Project or Easyway.
1 Introduction

1.1 Background

Recent studies have clearly shown that the benefits of dynamic weather-related speed management applications (utilising variable speed limits) are obtained only for systems with high-quality real-time control. This high-quality control means that the speed limits displayed to the driver correspond to the speed that can be used safely during the current weather and surface conditions. Such control requires reliable monitoring of friction, road surface conditions, wind strength and sight distance. Until now, the road surface condition monitoring systems have not provided sufficient reliability. The recent new optical road surface condition and temperature sensors from Vaisala as well as new friction assessment systems based on in-vehicle sensors have, however, improved the quality of road surface condition monitoring and especially road surface friction monitoring to a considerable extent.

1.2 Aim of the project

The objective was to study:

- how the information provided by new road surface condition and friction sensors can be utilised in dynamic speed management
- how much new sensors improve the technical performance of the weather-related speed management systems
- what safety and other benefits that can be expected from systems enhanced by the new sensors

1.3 Activities

The potential for improvement has been studied, guided by research results in Finland and Sweden. Liaison has also been made with Lithuania, which participated in the workshop (Chapter 4). In Finland, the performance of the new Vaisala sensors has been studied as well as new in-vehicle friction monitoring systems. Minor studies of sensors have also been carried out in Sweden.

The main study was planned to take place in 2010-2012. It was started with a feasibility study in 2009, where the experience in the two countries was compared. It was finished with an international workshop in 2010. Due to lower activity level in Finland because of small resources and lack of calendar time of parties involved and organisational changes in Sweden, the planned trials to fill knowledge gaps and needs in both countries, were decided not to be carried out. This part of the project has been replaced.
by updated exchange of results at the end of the project. Due to the fact that a new weather controlled VSL link was not selected in Sweden as expected, before/after measurements has been replaced by a reconsideration of the benefits and costs of weather-controlled VSL. The benefits have been estimated by a desktop study based on the changes in the technical performance of the system.

In Finland, during 2010-2012 the attention has been focused on testing slipperiness detection by different methods by Finnish Transport Agency and forecasting of friction by Finnish Met Institute. Finland organized 2012 two international conferences on the area of road weather. COST TU0702 “Real-time Monitoring, Surveillance and Control of Road Networks under Adverse Weather Conditions” final seminar and SIRWEC, 16th International Road Weather Conference. Both were held in Helsinki during May 21-25. The presentations are in web pages www.sirwec2012.fi.

In Finland, the service level definition of different road classes is ongoing. The common operating policy for variable speed limits and the wide situation picture system project is going on during next years. All these together create possibilities to operate better also the weather controlled variable speed limits in coming years.

The study has been included in the VIKING work plans 2009-2012 in the EASYWAY action. The co-operation between Sweden and Lithuania is also included in the East-West Corridor project.

2 Use of WCVSL in Finland

2.1 Deployment of weather controlled variable speed limits

In Finland, weather controlled variable speeds limits (WCVSL) are used because it has been clearly shown, that drivers can’t always adopt their speeds according to prevailing road weather conditions. According to the studies made, in poor road weather conditions the drivers decrease their speed more in road sections with VSL compared to sections without VSL. Thus the use of VSL has clear positive traffic safety effects compared to roads with fixed signs. VSL can also be used in other traffic control situations than for road weather purposes. For example during changing traffic situations, accidents and road works, VSL can easily be adjusted manually according to the needs.

In Finland, there are about 370 km’s of roads with road weather controlled VSL around the country (Table 2.1 and Figure 2.1).
Table 2.1  Road sections with weather controlled VSL in Finland (update 1.9.2012).

<table>
<thead>
<tr>
<th>Number</th>
<th>Road section</th>
<th>Length (km)</th>
<th>Motorway</th>
<th>Speed levels (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vt 1 Turku-Kehä III</td>
<td>137</td>
<td>Yes</td>
<td>60, 80, 100, 120</td>
</tr>
<tr>
<td>2</td>
<td>Vt 4 Kirri-Äänekoski</td>
<td>30</td>
<td>No</td>
<td>60, 80, 100</td>
</tr>
<tr>
<td>3</td>
<td>Vt 4 Kemi-Tornio</td>
<td>34</td>
<td>Yes</td>
<td>60, 80, 100, 120</td>
</tr>
<tr>
<td>4</td>
<td>Vt 4 Laanila-Kontinkangas (Oulu)</td>
<td>4</td>
<td>Yes</td>
<td>60, 80, 100</td>
</tr>
<tr>
<td>5</td>
<td>Vt 20 Oulu-Korvenkylä</td>
<td>1</td>
<td>No</td>
<td>50, 60, 70, 80</td>
</tr>
<tr>
<td>6</td>
<td>Vt 4 Rovaniemi</td>
<td>1</td>
<td>No</td>
<td>30, 50, 60, 70</td>
</tr>
<tr>
<td>7</td>
<td>Vt 7 Hamina-Vaalimaa</td>
<td>33</td>
<td>No</td>
<td>50, 60, 80, 100</td>
</tr>
<tr>
<td>8</td>
<td>Vt 9 Tampere-Orivesi</td>
<td>35</td>
<td>No</td>
<td>70, 80, 100</td>
</tr>
<tr>
<td>9</td>
<td>Vt 9 Kanavuori-Hankasalmi</td>
<td>41</td>
<td>No</td>
<td>60, 80, 100</td>
</tr>
<tr>
<td>10</td>
<td>Vt 10 Lieto-Kausela</td>
<td>6</td>
<td>No</td>
<td>60, 80, 100</td>
</tr>
<tr>
<td>11</td>
<td>Vt 12 Tampere-Kangasala</td>
<td>13</td>
<td>No</td>
<td>60, 80, 100</td>
</tr>
<tr>
<td>12</td>
<td>Vt 3 Lempäälä-Tampere</td>
<td>14</td>
<td>Yes</td>
<td>60, 80, 100, 120</td>
</tr>
<tr>
<td>13</td>
<td>Vt 6 Kärki-Muukko (Lappeenranta)</td>
<td>20</td>
<td>Yes</td>
<td>60, 80, 100</td>
</tr>
</tbody>
</table>

In road sections with weather controlled VSL, there are usually 3-4 different speed levels. The roads with one carriageway have typically three levels (60, 80, 100) km/h. The corresponding road weather levels are “very poor”, “poor” and “normal”. In motorways with four speed levels (60, 80, 100, 120) the weather levels are “very poor”, “poor”, “normal” and “good”. According to Finnish speed limit guidelines, the highest possible speed limit during wintertime, also in weather controlled roads, is 100 km/h. Because the speed limit alteration process in roads with old fixed speed limit signs is so time consuming, the time period with the wintertime lower speed maximum is shortest in roads with VSL (November 1st – February 28th).

Variable speed limits are used in Finland the year around. Even in summer, when difficult road weather conditions are rarer, variable speed limits are used where possible.
The starting and ending point of the sections has been indicated with small white circles. The numbers refer to Table 2.1. Motorways have been indicated with dark green colour.

### 2.2 Methods used to detect current road-surface conditions

When using VSL, the main road weather information comes from road weather stations. Operators in the traffic management centres can also use other kind of information (road weather cameras, satellite and radar images) and control VSL manually. When VSL are controlled automatically, the control is only dependent of road weather stations. As default, computers change the speed limits automatically according to the gathered road weather information. As an exception, Turku road district in Finland always changes speed limits manually, but also in that case operators follow actively
the computer recommendations. The system architecture in Finland is described in Figure 2.2. The data communication works as follows:

The information from the road weather stations is stored in a centralized database. The data from stations is transferred using applicable data communication network: with wires or wireless. The data from stations is gathered every 5 minutes.

The speed limit recommendation calculations are made in the computers in the local road authority offices. The calculations are made and the data from the centralized database is gathered every 5 minutes. The data from the centralized database is transferred via broadband.

The local computers control the VSL immediately after the new calculation is made. The data from computers to VSL is again transferred using applicable data communication network: with wires or wireless.

The time when the data is gathered from the stations (every 5 min) and the time when speed calculations are made in local offices (every 5 min) are not synchronized. Therefore the time lap between sudden weather change and speed limit adjustment can be anything between 0-10 minutes.

![Figure 2.2 System architecture for controlling variable signs and displays in Finland](image)

At the moment, the traditional road weather sensors as road weather, wind, visibility and rain (intensity and nature) play a major role in speed limit recommendation calculations. There are 105 new optical road grip sensors (Figure 2.3) used in road
weather stations, but only 5-6 of them are used in VSL road sections. The future recommendation is that there should be at least 1 optical sensor for each lane in every speed limit control section (about every 5 km).

There is not a single correct way to use optical sensors in the speed limit calculation process. Local circumstances determine the use. It takes typically 1-2 years to find the correct limit values for those sensors. The following examples describe the use:

In the VSL section in Orivesi (number eight in Table 2.1 and Figure 2.1) the speed limit calculations suggested too often the highest possible speed limit 100 km/h. When the new optical sensor was implemented, the situation became much better, but the sensor value (“friction”) needed to be as high as 0.50 before the highest speed limit could be used. The road was a one carriageway road and had the highest winter maintenance standard.

In the VSL section on the motorway in Kuopio there are four optical sensors: a sensor focused on both driving lanes on both carriageways. All sensors must indicate at least 0.30 before the highest possible speed limit (120 km/h) can be used. Also this VSL section is on the highest maintenance class Is.

It should be stated, that the optical sensor is never used as a single sensor for speed limit calculations. It is always used together with the traditional sensor. It gives great extra information, but cannot replace all the traditional sensors. According to Finnish experiences, it has been relatively easy to add the new optical sensors to the existing system. Both the new sensors and the old road weather stations are made by Vaisala.

![The new optical DSC111 sensor. It has a spectroscopic measuring principle, individually identifying the presence of water, ice, slush, snow, and frost.](image)

It seems that the new optical sensors overestimate the grip in wet road surface (it cannot detect the ice below the water layer). On the other hand, the optical sensors seem to underestimate the grip on white snow.
2.3 Research findings concerning very slippery road surface conditions

Recent studies in Finland have focused on analysing different methods to assess the road surface friction in different kinds of road weather situations, not just on very slippery surface.

2.3.1 Winter 2003-2005 tests

The first comprehensive test with the new DSC111 sensor in a real road environment was carried out on the highway VT6 in Utti near Kouvola in South-eastern Finland during the winters 2003-2004 and 2004-2005. The other testing location in Salo in Southwest Finland was used in the winter 2004-2005. The sensor DSC111 was installed on a wooden pole mast and aimed at the right wheel track on this two lane road. The testing included human observations of the road surface state and occasional measurements of friction by lock braking a vehicle equipped with a decelometer (friction is calculated on the basis of biggest deceleration measured). Test made by FINNRA (Finnish road administration) personnel showed promising results. The Utti field testing included altogether 293 and Salo 74 human observations of the surface state. These observations were done by experienced observers who did not have access to the DSC111 output at the time of the observation. Out of all the Utti observations 90.1% agreed with the DSC111 output and in 95.9% of the cases DSC111 was showing the same or worse surface state. In the Salo location the overall agreement was 91.9% (Pilli-Sihvola, 2009).

2.3.2 Winter 2005-2006 tests

During the study in winter 2005-2006, the Finnish road administration purchased 11 new DSC111 sensors from Vaisala and installed them in different test locations (road side environment) in Southwest Finland. During the winter over 300 road friction measurements were made with C-trip (friction measurement is based on the vehicle speed difference before and after braking) in those test locations in different road weather conditions. According to the measurements, the correlation between C-trip and DSC111 measurements was very weak. On the other hand, it was revealed, that on the road sections with weather controlled VSL, DSC111 measurements correlated quite well with the speed limit alterations (Figure 2.4). Also the duty officers in the road weather centres, who were able to look at DSC111 measurements during the winter, considered DSC111 to be quite promising. After all, the accuracy of the C-trip friction measurement device raised a lot of discussion (Schirokoff et al, 2006).
2.3.3 Winter 2007-2008 test

In this project a comparison between four different measurement devices had been conducted. The measurement devices were the traditional C-trip, Gripman tester by AL-Engineering Oy, Traction Watcher One (“TWO”) by Fosstech AS in Vestfold Norway, and DSC111 by Vaisala Oy in Finland (Figure 2.5). C-trip friction measurement is based on the vehicle speed difference before and after breaking. Gripman measurement is based on the acceleration sensor values during vehicle breaking. The TWO system measures the extra test wheel slip and DSC111 analyses the optical road surface parameters.

Figure 2.5 The test apparatus. TWO and DSC111 were attached on the test vehicle rear end. The small electrical devices: C-trip and Gripman were in the vehicle cabin.
The first goal was to test the repeatability of each device. There was also an option to look how the winter conditions would affect to the repeatability, but it turned out to be quite difficult to find suitable winter conditions during that winter in Southern Finland. The repeatability of each device was tested by making two runs on a test road network with 36 km of roads in the same day. The repeatability of a device was estimated by looking at the scatter plots of the pair of runs, correlation of those runs, the standard deviation of the difference of both runs, and the average of the difference of the runs. As would be expected the average values of differences were small, between 0.001 and 0.008. Standard deviations of differences of two runs were between 0.01-0.098 depending on the device and the averaging interval. The main indicator of the repeatability was the standard deviation of differences. The TWO device had the best repeatability especially when the results were averaged in a longer period. DSC111 repeatability was better during small friction values and worse in bigger values (Figure 2.6). The repeatability during low friction periods is encouraging. Naturally the weather parameters could not have been controlled between the two test runs.

![Figure 2.6 DSC111 repeatability](image)

The other goal was to study how well the results of each device fit against each other. This goal was a combination of testing between the trueness and reproducibility of measurements. First the other devices were compared with TWO and then with Gripman. This comparison was made using data of a relatively large amount of friction measurements totalling to 500 km roads.

When compared it was revealed, that both the DSC111 and TWO devices produced small friction values in low grip situations and high friction values in high grip situations, but there was a lot of separate deviations (Figure 2.7). Especially in snowy and slushy road weather conditions the differences were big. The loose snow and slush made the TWO friction wheel to show too small values. On the other hand the snow circulation and slush made DSC111 to show too high values. There were probably also interaction between TWO and DSC so that the wheels of TWO lifted some snow circulation in the area of DSC sensors and this had a negative effect on the results.
The study showed that there are still a lot of differences between the friction values given by the measuring devices which operate using different measuring methods. The friction varies considerably on the road surface depending of the cross-section of the road and also along the road. It is evident that there is not any unambiguous way to specify the correct friction value on the road surface (Virtala 2008).

### 2.3.4 Winter 2010-2011 test

A quite large friction meter comparison study was carried out in February and March 2012 in Finland. During these tests, 7 different kind of friction meters were analyzed. The devices were:

- 4 different friction meters to be used when braking:
  - 1 traditional Eltrip-45n
  - 2 pieces of Gripman (using own acceleration sensor)
  - 2 pieces of Eltrip-7k (using own acceleration sensor)
  - 2 pieces of μTEC (cellphone application to be used with those cellphones having already an acceleration sensor inside)

- 2 different optical meters:
  - 1 mobile version of Vaisala DSC111
  - 1 RCM411

- 1 mechanical meter:
  - 1 small portable T2GO

Additionally GPS-based vehicle measuring instrument Vbox (Performance Box) was used a reference meter.
The friction meters were tested both on special testing circuits and on regular highways during spot quality control testing. As a result, the differences between different friction meters and various optical road testers were much greater than expected.

Both systematic level-variation and random deviations were detected in the measurement results for friction meters. When testing those meters to be used when braking, the level-variations were highest with the μTECs and the lowest with Gripmans and the new Eltrips. Random deviations were highest with the new Eltrips and μTECs and the lowest with Gripmans. All friction meters demonstrated rather large variations in the friction values when braking time's were varied on the testing circuits. In practice, the meters’ sensitivity to braking time means that the person performing the testing must be sufficiently experienced, in order to keep the braking times reasonably similar during measurement.
μTEC and Gripman were able to compensate for the effect of gradients, allowing these meters to be used for friction testing on hills. Of the devices equipped with an acceleration sensor, only Gripman was able to generate reliable friction measurement results in the most slippery test circuit conditions.

Optical road sensors were compared to a traditional friction meter during spot quality checks. Results collected with an RCM411 sensor correlate much more closely with the results of the traditional friction meters than those collected with a DSC111 sensor. During test circuit testing on so-called artificial surfaces, the operation of both optical sensors was poorer: they gauged the most slippery conditions (light, smooth ice surface) as having the highest friction.
Figure 2.10  Optical meters RCM411 and DSC111 compared to the traditional Eltrip-45n friction on regular highways.

The portable T2GO was only tested on test tracks. The device showed quite reliable result on firm surfaces, but considered loose snow as slippery as smooth ice. Loose snow in a cold weather isn't so slippery when driving or walking.

As a result of this test serie, Gripman was approved as an official friction meter for winter maintenance quality control in Finland (the traditional Eltrip-45n was approved much earlier). After these tests, Finnish Transport Agency published demands for friction meters to be used as an official meter in winter maintenance quality control in Finland. Therefore the meter manufacturers, who couldn't get their meters approved, were able to see clear performance limits to be obtained.

A 26-page English abstract of the test can be obtained freely from the writer: mikko.malmivuo@innomikko.fi.

2.3.5 Winter 2011-2012 test

After the 2010-2011 test, both the manufacturer's of μTEC and Eltrip-7k were able to significantly improve their meters. In January and February 2012, both meter manufacturer's financed and passed their own approval tests (done by an independent party). In March 2012, Finnish Transport Agency wanted to make some additional test with these meters on a test track. In these tests, two versions of Eltrip-7kmb were tested. The μTEC were tested in 6 different cell phones, because the 2011-2012 tests indicated, that the cellphone type can have an effect on the μTEC friction values.
Figure 2.11 The meters tested in March 2012. μTEC was used in cellphones Samsung Gio, Samsung Galaxy pad, Nokia E7, Nokia 500, Nokia C6 and Nokia E52. Two version of Eltrip-7kmb’s were tested (two pieces of each). Two Gripman’s, one Eltrip-45n and one Vbox were used as an reference meter.

As a result of these tests, both μTEC and Eltrip-7kmb were finally approved as the official meters for winter maintenance quality control in Finland. μTEC has still phone model limitations, it has been only approved with the tested phone models Samsung Gio, Samsung Galaxy pad, Nokia E7, Nokia 500, Nokia C6 and Nokia E52. According the tests 2012, the tested Samsung Android devices and Nokia 500 were the best options for friction measurements.

After the tests 2011 and 2012 there are now 3 different acceleration sensor meter approved in Finland for winter maintenance quality control. Although the basic logic of these meters is the same, these meters are quite different. The main differences are:

- Gripman and μTEC can give quite reliable friction values on the hills, but Eltrip-7kmb doesn’t work on hills.
- Gripman and μTEC are sensitive for the meter position changes, but the Eltrip-7kmb values are still correct after small position changes.
- μTEC can utilize effectively the cellphone memory and GPS-information. There is no memory and GPS in Gripman and Eltrip-7kmb.
- Gripman and Eltrip-7kmb are optimized for ease of use and have very few user options. \(\mu\)TEC has much more user options.

It has been decided in Finland, that when using friction meters in winter maintenance quality control, those meters had to be calibrated to 0.29 in packed snow (-5°C). All the official meters are "braking-meters", meters to be used when braking a car. Because the measuring car is not "standardized", the type of the car and tyres can be different. Only things that has been agreed are, that these cars need to have studded tyres and ABS. Although all the measuring vehicles and meters as calibrated in packed snow, the car and tyre model and tyre wear can have an effect to the friction profile. That means, that different combinations can achieve different friction values e.g. on smooth ice, although they give same result on packed snow. When analysing the effect of tyre wear in 2011 tests, vehicle type in 2012 tests and tyre model in the basis of winter tyre test made by "Tekniikan Maailma" (World of Technique) - magazine, the effect of measuring equipment can be estimated as shown in Figure 2.12.

**Figure 2.12** A rough estimate of the effect of tyre wear, tyre model and vehicle type on friction profile when using friction meters used when braking.
2.4 On-going and future studies of road-side or in-vehicle detection sensors

2.4.1 Slippery detection in heavy road vehicles
Modern heavy road vehicles include several sensors, which measure different things as tyre speeds, motor function, vehicle position etc. VTT in Finland have studied the possibilities to get information of slipperiness using the heavy vehicle’s own sensors and own data sources. The idea is to compare the speed of driving tyres with free rolling front tyres in relation to the motor power. The information achieved could be delivered as well to the driver on board as to the road weather information centres. Because no extra sensors are needed the friction assessment devices could be very cheap and easy to install in numerous vehicles. Therefore this system could be very efficient to detect slipperiness in broad areas (Kytö et al, 2009).

According to the results, a single vehicle cannot produce very accurate data alone, but when a data from fleet of vehicles operating in same roads can be brought together, the information is clearly useful. In fact, the project leader Kimmo Erkkilä (VTT) says that they are at the moment looking for a commercial partner who can breed these results into commercial products and services. The final report of the study will be published in the beginning of 2013 in the project web-site www.transeco.fi (project "HDENIQ").

2.4.2 Continuous mechanical friction measurement
Some manufacturers of continuous mechanical friction measurement devices has shown an interest of getting Finnish meter approval for winter maintenance quality control. Therefore it seems possible, that these manufacturer's and Finnish Transport Agency together will make some tests with these devices in early 2013.

2.5 Other relevant studies

2.5.1 Extended use of variable speed limits in Finland (Ministry of transport and communications, 2005)
The aim of this study was to create an extensive estimate of the effects on traffic safety of weather controlled variable speed limits on the main road network as well as of the costs of building and maintaining such a system.

The studied road network was divided into parts of which three different sized networks were created (2100 - 4300 km). The road segments were specified according to traffic safety and traffic volumes.
In order to estimate the impacts of accidents, pre-existing research material on the effects of variable speed limit signs on injury accidents in Finland was complemented. Speed limit systems which use fibre optic or LED signs, base the control on automatic classification of road condition situations, and include variable slippery warning signs appeared to decrease the risk of accidents with injuries by an average of 10%.

The investment costs and annual maintenance costs of the variable speed limit system were approximated according to the prices of the year 2004, the building costs for divided roads was estimated to be 80 000 €/km and for undivided roads 34 000 €/km. Because there is no research data available on the traffic impacts of variable speed limits varying with the traffic situation in Finland, the building expenses were allocated separately for a weather and road condition controlled system. The impacts on traffic were estimated by possible speed changes, safety changes and the forth-coming use of the speed limits.

On the grounds of the results it seems likely that a weather and road condition controlled system of variable speed limits would be profitable in Finland. The benefit-cost ratio (gross) based on direct benefits calculated with the most likely starting values was 1.1–1.9. According to the estimates acquired, the benefit-cost ratios on different sized networks do not differ significantly. But it can be said that it is most profitable to build variable speed limit systems on heavy trafficked road segments. The systems should be used according to the same principles round the year, namely taking into account the weather and road conditions and the traffic flow. The control should be based on automated, exact and reliable monitoring and classification of the conditions (Schirokoff at al. 2005).

2.5.2 Impact study of telematics on route 1 between Lohja and Ring III (FinnRa 2008)

A variable traffic management system was taken into use on main road no 1 between Helsinki and Lohja in January 2007 (section 1 in Figure 2.1). This road section suffered from difficult congestion problems especially in rush-hours on mornings and afternoons. The system includes variable speed limit signs, variable roadside and overhead warning and information signs, weather stations, automated traffic measurement points and traffic cameras. The purpose of the system is to regulate vehicle speeds according to traffic and weather conditions using variable speed limits and provide road users with information on traffic incidents.

The purpose of this study was to determine the impact of the system on driving behaviour and traffic safety on one hand, and the attitude of road users toward the new system and its messages on the other hand. At the same time methods suitable for impact studies were developed. The material, which was used in the project, consisted of traffic studies, information produced by the system, Finnra’s traffic centre’s bulletins,
and questionnaires directed to road users. Source material was gathered both before and after the system was taken into use.

Based on this study, the traffic management system has had a minor impact on driving behaviour. There have been no significant changes in the average speed of traffic, but there has been less divergence in speeds during rush hours, which improves traffic fluency and safety. Road users notice the variable signs and react to them, but the effect weakens already after one kilometre. Based on a comparison of accidents, the system has not had an effect on traffic safety or the number of accidents on the section of highway. The system’s impact on safety is most evident during rush hours, when the flow of traffic adapts its speed to the traffic situation better than before. The short duration of the study had some effect on the results concerning driving behaviour and road safety.

The study also examined the impact of information on speeds during bad weather and speed control arranged by the police. Speeds were clearly lower during speed control when motorists were informed of the control, although some drivers still clearly exceeded the speed limit. Road users felt that informing about bad weather was unnecessary, as the weather can be observed otherwise.

For the most part, road users had a positive attitude toward the traffic management system, yet there is room for improvement. The understandability of the system suffers from the two types of messages given by the signs. On one hand they command and on the other hand they guide and inform. According to road users, the system has only a minor impact on their driving behaviour. Information given by the signs should always be correct and up-to-date so that road users’ confidence in the system is preserved.

The study also provided a wealth of knowledge about the benefit of various source materials and research methods in this type of study. Concrete recommendations were also given concerning the development and expansion of research methods (Ristikartano et al. 2008).

3 Use of WCVSL in Sweden

3.1 Trial in 2003-08

3.1.1 Weather controlled variable speed limits
 Trials with Variable Speed Limits (VSL) for different applications were carried out by the Swedish Road Administration (SRA) in 2003-08. The four weather-controlled test-
sections are still in operation. The goal was to demonstrate if and how VSL can contribute to a better speed adaption in a cost-efficient way. Road weather controlled variable speed limit sections (WCVSL) were one application area. For this type of application the maximum permitted speed limit was adjusted downwards to different levels when adverse weather and road surface conditions occur. For example:

- Reduced road grip (data from surface state sensor)
- Intense precipitation
- Low visibility
- Strong winds

The four sites with WCVSL are a 17 km section of E22 in the province of Blekinge (Åryd-Ronneby), 55 km of E6 in Halland (Skottorp–Heberg), the Uddevalla Bridge and the bridge to Öland which is 6 km long. The first mentioned two establishments are controlled based on the road weather conditions, the Uddevalla Bridge is controlled based on wind and the Öland Bridge has a multifunctional control based on road weather, wind and traffic flow. The sections differ from each other. The site in Halland is a fairly traffic intense motorway (18000 vehicles/day) while Blekinge is a three lane highway with centre crash barrier (2+1L) and average daily traffic of approximately 8500 vehicles/day. The Öland Bridge has 2+2 narrow lanes with an average traffic flow of 14 700 vehicles/day.
An important principle in Sweden has been that the VSL signs shall be lit up when conditions are deteriorating. In good conditions the highest normal permitted speed should be posted with fixed speed limit signs. This principle was abandoned on some occasions during the tests.

### 3.1.2 Resulting control principles

A common principle for variable speed limits on weather controlled road sections were proposed as a result of the trial. Three levels were suggested (good, severe and very severe driving conditions) in 20 km/h steps and the lowest at 50 km/h.

**Table 3.1 Preliminary criteria for speed limits on weather-controlled VSL sections**

<table>
<thead>
<tr>
<th>Road type</th>
<th>Good conditions</th>
<th>Severe conditions</th>
<th>Very severe conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorway</td>
<td>120</td>
<td>100</td>
<td>80</td>
</tr>
<tr>
<td>Expressway (Motortrafikled)</td>
<td>110</td>
<td>90</td>
<td>70</td>
</tr>
<tr>
<td>Other high standard 2 or 2+1-lane roads</td>
<td>100</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>Special conditions: e.g. the bridge to Öland</td>
<td>90</td>
<td>70</td>
<td>50</td>
</tr>
</tbody>
</table>

A suitable activation principle with regard to the combination of friction and wind was also proposed:

- **Good conditions**: \( f \geq 0.5 \) or wind <15 m/s
- **Severe conditions**: \( 0.3 \leq f < 0.5 \) or wind 15-20 m/s
- **Very severe conditions**: \( f < 0.3 \) or wind >20 m/s

The following recommendations were made in order to improve the performance of the weather controlled VSL:
- Introduce fully automatic control (monitored from Traffic Information Centre)
In order to achieve even better speed adaption to the prevailing road surface conditions the following measures should be considered:

- Conduct frequent speed checks. Develop automatic camera systems to handle variable speed limits. Average speed-over-distance systems (section control) might be suitable for weather controlled VSL.
- Introduce dynamic information about the reason for a lower speed limit. This is important at situations when surface conditions are difficult for the driver to detect (black ice etc.) but it is also essential for systems controlled by more than one type of condition (weather, traffic etc.).

### 3.2 First generation of weather-controlled VSL

The first generation of weather-controlled VSL used data from SRA’s Road Weather Information System (RWIS) in order to assess the weather and road surface conditions.

#### 3.2.1 Swedish RWIS

RWIS gets weather information from over 700 stations spread all over Sweden and contains parameters that include air and surface temperature, dew point, precipitation type and amount and wind speed. RWIS are supplemented by forecast data from the Swedish Meteorological Institute, SMHI. The main purpose is helping and auditing snow removal and ice control entrepreneurs but it has found many other uses in road management, where one of them is Weather Controlled VSL (WCVSL).

Slippery road alerts that can be generated every half hour are:

- **HN** Rain/mixed snow-rain on cold road
- **HT** Moist/wet carriageway that is freezing
- **H2** Heavy white frost
- **H1** Moderate white frost
- **H*** Several types of slipperiness simultaneously
- **--** No alert
- **??** Alert cannot be calculated due to missing data

Forecasts are delivered on an hour-to-hour basis:

- **PN** wet precipitation on cold surface – cannot be classified if precipitation forecast is missing
- **PT** Temperature fall and moist road surface
- **P2** Heavy white frost
- **P1** Formation of white frost
- **P*** Several forecasts of slipperiness are calculated
3.2.2 The weather model

Within the WC VSL project, an algorithm (called the Weather model) was developed to estimate road friction values based on regular RWIS data (temperature, dew-point, wind, humidity and precipitation), thermal mapping, topography data etc. During the tests five speed limit levels were used, which have later been reduced to three. The following settings are currently used in Halland (motorway):

- Friction ≥ 0.4  VSL 120 km/h, e.g. posted speed
- Friction < 0.3  VSL 100 km/h
- Friction < 0.2  VSL 80 km/h

Since remedial actions naturally have a large influence on the road friction and all regular RWIS data is measured above the surface (except for surface temperature), the WC VSL could not be fully automated based on the Weather model. The Weather model was used to indicate changes in road conditions, but the Traffic Management Centre (TMC) operators had to make the final decision and execute the increased or decreased speed limit.

(Later the VSL control was changed so that the speed limit is automatically lowered one step (20 km/h) when the weather model indicates reduced friction.)

![Diagram](image_url)

*Figure 3.3 Principal system solution for the installation during VSL tests on E22 in Blekinge (before summer 2006)*
The friction levels in the Weather model consist of a bundle of different road surface conditions. A more detailed description of friction level 0.2 is envisaged in Table 3.2.

<table>
<thead>
<tr>
<th>Alarm level</th>
<th>Friction</th>
<th>Legal condition</th>
<th>Alarm code in central computer (GSV)</th>
<th>Definition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.2</td>
<td>Severe road surface and weather conditions</td>
<td>3-Rain</td>
<td>Rain &gt; 4.0 mm</td>
<td>Risk of aquaplaning</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3-Freezing rain</td>
<td>Freezing rain &gt;0.2 mm</td>
<td>Road temp ≤ 1, air temp &lt; 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3-Snow</td>
<td>Snow &gt; 3.0 cm</td>
<td>-3 ≤ road temp &lt; +3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3-Snow</td>
<td>Snow &gt; 3.0 cm</td>
<td>independent of road temp</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3-Snow</td>
<td>Snow &gt; 1.0 cm and wind</td>
<td>Max wind &gt;7 m/s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3-Snow</td>
<td>Snow &gt; 0.5 cm o wind</td>
<td>Max wind&gt;12m/s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3-Spin-drift</td>
<td>Old snow and wind</td>
<td>Max wind&gt;14m/s, ack snow ≥ 15 cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3-Ice formation</td>
<td>Ice formation</td>
<td>2 consecutive alarms on one station or one alarm on several stations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3-White frost</td>
<td>White frost</td>
<td>Thick, unpolished frost, 2 consecutive alarms on one station or one on several stations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3-White frost</td>
<td>White frost</td>
<td>Moderate, polished frost, 2 consecutive alarms on one station or one on several stations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3-White frost</td>
<td>White frost</td>
<td>Moderate, moderate worn frost, 2 consecutive alarms on one station or one on several stations</td>
</tr>
</tbody>
</table>

### 3.2.3 Experiences

The validation of the manually controlled sites based on the weather model input generally showed time consumption problems. Due to several steps of the data transmission and processing procedure an alert for speed limit reduction could be delayed up to 45 minutes after the initial data registration at site. Above this the operator might want to verify the situation before acting because of lack of trust for the weather model. This means getting confirmation from field personnel which takes additional time. Altogether an hour or even more might elapse from the detection of slippery surface until the speed limit is lowered. This hour is often the most critical for the drivers since they might not be aware of the danger (black ice etc.). The Swedish
experience shows that this leads to an unacceptable variation in the setting of the speed limit.

### 3.3 Second generation of weather-controlled VSL

#### 3.3.1 Description

In the second generation of WCVSL, remote road surface state sensors were installed at E22 Blekinge and at the Öland Bridge. The remote road surface state sensor that was installed is the Vaisala Remote Road Surface State Sensor - DSC111.

In contrast to the first generation WCVSL, it was possible to actually measure the condition of the road surface. This was necessary in order to implement a fully autonomous and automatic weather control system, where the TMC not had to actively manage the speed limits.

DSC111 sends an IR beam to a point on the road surface (ca 10 cm in diameter). The signal that is reflected back to the equipment is scanned for different wave lengths. Based on the observed difference in light absorption, several layers of surface structures and the status of the road surface can be identified. The system detects if the surface is dry, moist, wet, icy, snowy, frosty or slushy. The sensor also provides a measure called ‘grip’ which is representative for the friction level on the road surface. This grip measure is calculated on the basis of an empiric model based on the status of the surface and the thickness of the surface layer (water, ice, snow).

![Figure 3.4 Road status sensor mounted on a RWIS station at Bräkne-Hoby](image)

The surface state sensors are used to automatically set the variable speed limits.
3.3.2 Main results and experiences

A comparison between the alerts from the weather model and the road surface state sensor showed that both systems activated the VSL signs during roughly the same length of time. However, the activation did seldom occur at the same time. When both systems triggered very slippery road (60 km/h), the alert signal came 2-3 hours later from the weather model compared to the surface state sensor.

Unfortunately, the friction measurement vehicle was operative only during one month at the end of the appraisal period, which in practice meant two days measurements when the road surface was slippery. The values differ in both directions from each other meaning that the comparisons in Figure 3.5 do not prove any evidence for putting one method before the other. (Note: H1 = slippery warning)

![Figure 3.5 Comparison between some measurement methods in Blekinge](image)

3.3.3 Test of additional road surface state sensor

During the end of the VSL trial project a road surface state sensor was tested at the southern part of the E6 Halland site. A simple comparison was carried out between the data delivered by the weather model and the road surface state sensor. It was noticed that the weather model indicated low grip at freezing rain conditions more often than the remote road surface sensor did. However, this does not necessarily mean that the remote road surface sensor provides wrong output. According to interviews with Traffic Management Centre operators the weather model incorrectly gives low friction alerts also when the road surface is not slippery according to other systems (RWIS).
3.4 Third generation of weather-controlled VSL

At the start of this co-operative research project in 2009, the Swedish Road Administration was working towards a third generation of WCVSL. This work has only partly been carried out, primarily by organisational reasons (merging with the Swedish Rail Administration).

The intention at the start was to develop a fully automated WCVSL that can address a number of weather-related situations such as low friction, strong precipitation, low visibility and different kinds of risk-scenarios. To achieve this continued research and improved skill to judge our road-side microclimate and detection mechanisms are necessary. Examples of issues that have to be solved are:

- Road status is today measured using remote road surface state sensors. Even if those seem to be working quite well, how can the information from a small measuring point (about 10 cm in diameter) be used to control a section of 10 km with sufficient precision? And how do we handle a road with ruts and variations in road width?
- The relation between road status (water, ice, snow) and road friction/grip? Reduced road grip is very different for different vehicles.
- Intense precipitation. How to measure intensity in an accurate way? And how to map precipitation intensity to VSL displays?
- Low visibility. Visibility is, compared to road surface status, quite easy to detect. There are many different detectors available that are developed for airports. The major issue here is that we haven’t put enough effort in mapping visibility information from a road section to display VSL. The visibility can for example be very local, and how do you map that to a VSL display that is trustworthy?
- Even if we already today have two fully automated variable speed limits sections in Sweden, the weather controlled VSL display still requires some manual supervision by operators. Therefore we also have to build a HMI that makes it possible for operators to understand what is happening and the ability to, if a situation occurs, overtake control of the VSL display process.
- The set of problems related to drivers conception that we have taken all traffic conditions into consideration and control speed limits based on multiple parameters as weather, wind, sight distance, traffic flow etc.
- The sensors are expensive and it is not affordable to install as many sensors as we want to. There is a demand for improved knowledge how to optimally provide sections with equipment.
- In Sweden, we have no weather-controlled section in the more winter-like landscapes in the middle part of the country, where we think the system is most needed. There is an urgent need for evaluations of sensors, models and driver behaviour in these conditions.
3.5 Impacts of weather-controlled VSL

3.5.1 Speed adaptation

During the large-scale demonstration of VSL in Sweden, traffic data were collected in pre and post periods during two consecutive winter seasons (Vägverket, 2008). A second follow-up were accomplished in Blekinge a year later to observe the long term effects.

The speed adaption was clearly improved by the VSL system at both sites (Halland and Blekinge). This is especially true for passenger cars. The most evident impacts occur at low speed limits. The average speed is then reduced 15-20 km/h below the level that the drivers choose spontaneously during corresponding adverse conditions with traditional fixed signs. See Figure 3.6 below.

![Figure 3.6](image-url)  
*Figure 3.6  Average speeds at Hökaslätt in Halland and Bräkne-Hoby in Blekinge (both directions) at different road surface conditions with and without VSL*

The average speed in Halland increased only by 2 km/h during dry conditions despite the fact that the highest speed limit was changed from 110 to 120 km/h. The increase of the maximum permitted speed limit in Blekinge from 90 to 110 km/h made the average speed to increase by around 4-5 km/h. This is also valid for the Uddevalla Bridge although there was no raise of the speed limit there. Thus the observance of the highest speed limit increased. In Blekinge the observance of the speed limits also improved during wet road surface or snow (displayed 100 and 90 km/h respectively). However
the observance of the lowest speed limits at severe road surface conditions decreased, but not as much as expected.

It can be concluded that the VSL system gives only a minor contribution to better speed adaption at fairly difficult conditions. At very severe conditions (snow, ice, and white frost) the VSL system gives significant extra stimuli to the drivers to adjust their speed properly.

Long-time measurements were conducted in Blekinge one year after the first measurement period with the system operational. The results show a continuing decrease of the average speed to an even lower level than during the first follow up period. This was especially evident when 60 km/h was displayed.

3.5.2 Attitudes
The drivers’ respect of the speed limits strengthened with the introduction of VSL. In total more than 90 % of the respondents in Halland and about 70 % in Blekinge consider the system to be good. The most frequent comment to why the system is good is that it contributes to a more harmonised traffic flow. About 80 % of the drivers believe that they have become more attentive regarding the road surface when passing an activated VSL sign. A majority of the respondents in both surveys also believes that displayed speed limits are in line with the current weather and road surface conditions while about one third disagree to this. Almost half of the drivers in Blekinge thus consider the signs sometimes being out of order or that the wrong speed message is displayed. Regardless of the reason behind this opinion, it is important to display speed limits that are apprehended as correct with regard to current road surface conditions. Otherwise it will be difficult to maintain public confidence.

The drivers believe that observance and speed adaption can be increased by more speed enforcement. However to an even higher degree they think that information about the reasons for decreasing the speed limits leads to better attention and observance.

3.5.3 Traffic safety
Traffic safety, represented by the difference in accident figures, was calculated using the traditional power model based on measured speeds and traffic load during different road surface conditions. The calculation revealed no difference with regard to the total number of accidents. However the number of fatalities and severely injured increased by 4% (at 80 % functional accessibility) based on speed changes.

Statistics showed, however, 11 people killed or severely injured yearly before the introduction of VSL. After the introduction the number of fatalities and severely injured decreased from 22 to 15 individuals during the first two years (July 2005 to June 2007).
This tendency was promising. An experience is therefore that calculation of safety effects from speed differences alone is not satisfactory.

For the Blekinge case figures from the accident database STRADA state that the number of accident with injuries increased from 4 to 13 during the first three years and that the number of fatalities and severely injured increased from 1 to 2 individuals after the introduction of a raised maximum permitted speed limit and VSL. However the follow-up periods were far too short. Thus it is important to continue the accident analyses over longer periods of time. (In Section 5.8.2, a revised follow-up based on four years is presented.)

3.5.4 Performance

The idea behind weather controlled variable speed limits is to be able to accept higher speeds at good conditions (dry surface) as a trade-off for differentiated speed regulations during periods with adverse weather and road surface conditions. In Halland the time consumption decreased 1.3 % by using VSL in combination with raised maximum speed limit. The corresponding figure for Blekinge was 1.4 %. Thus the impact on time consumption is minor.

3.5.5 Environment

The environmental impact from VSL is marginal. Raising the maximum speed limit in Halland from 110 to 120 km/h resulted in 0.6 % increase of carbon dioxide emissions. This is however partly compensated by a decrease in emissions during periods of lower speeds at adverse weather conditions. The resulting impact for Halland is 0.4 % increase. A conclusion is that VSL solely influence the environment positively although to a negligible degree.

4 Workshop on collaboration

4.1 Detection problems – the end of weather controlled VSL?

A workshop was organised within the project to identify possible collaboration areas in the Nordic countries, especially in Finland and Sweden, with long experience of weather-controlled variable speed limits. The invitation was sent to all Nordic countries. For different reasons, Denmark and Norway, decided not to take part in the workshop. Instead there was an interest from Lithuania to participate. The workshop was held in Stockholm on the 1 September, 2010 with 13 experts. The objective of the workshop was to:
1) disseminate experiences concerning detection of slippery road conditions – good or bad.
2) discuss how we can work together in the Nordic and Baltic countries, more systematic and co-ordinated.

Agenda of the workshop:
- Bjarne Holmgren, Swedish Transport Administration: Swedish national progress report
- Mikko Malmivuo, InnoMikko, Finland, National progress report
- Leif Ringhagen Sweden and Gintaras Cilcius Lithuania: Short presentation of the East West project and Lithuanian national progress report
- Taisto Haavasoja, Teconer, Finland: Mobile phones used for friction detection
- Patrik Jonsson, Saab, Sweden: New sensor test results from the winter 2009-2010
- Mats Galmén, Swepro, Sweden: Detection and validation, introduction to discussion concerning pros and cons of different sensors
- Pirkko Saarikivi, Foreca Consulting, Finland: Weather models and speed management, introduction to discussion concerning best practice

Discussion of common research needs and possibilities.

_Bjarne Holmgren_ presented the Swedish national progress report (Chapter 3). The second generation Weather-Controlled Variable Speed Limit system (WCVSL) has been used since 2008 in Blekinge and on the Öland Bridge with the following design:

- Based on Vaisala Remote Road Surface Sensor DSC111.
- Measures the prevailing conditions on the road, and therefore maintenance measures are taken into account.
- Autonomous control, but monitored by the TMCs.
- Deactivation is delayed due to the time it takes for maintenance vehicles to cover the entire road section.

Experiences:
- There are limited data from validations so far, but better performance than the first generation
- Questions regarding detection of freezing rain conditions.
- Faster activation, since it’s independent of manual actions.
- The measuring point is about 10 cm in diameter. Different results if we measure in or beside a wheel track.

Conclusion:
- More evaluations are needed. A step in the right direction, but not the final solution.

_Bjarne_ also presented some thoughts about the third generation:
• Doesn’t exist yet. Will probably use several sensor types, where we use each sensor’s best potential. One sensor may be good at detecting snow depth, another freezing rain etc.
• We should develop intelligent algorithms and models to combine the information.
• Next implementation in “real winter” conditions
• Handling of multiple parameters, weather, wind, visibility, traffic flow.

Mikko Malmivuo presented the Finnish national progress report (Chapter 2). There are plans in Finland to use more on-board friction measurement devices:

• At the moment the old C-trip device is the only official friction measurement device in winter maintenance quality control
• It is obvious, that in the near future, also other kind of friction measurement devices could be used in winter maintenance quality control. The other devices will obviously include devices with accelerometer sensors like μTEC.
• During the winter 2010-2011 there will be tests aiming to produce new friction tables for various winter maintenance classes when the new friction devices are used.

The RASTU project is going on since 2006

• Information of slipperiness using heavy vehicle’s own sensors
• The idea is to compare the speed of driving tyres with free rolling tyres in relation to the motor power
• Information achieved could be delivered as well to the driver on board as to the road weather information centres
• There are promising results, but still too much random variation

Extended use of variable speed limits

• Weather and road condition controlled system of variable speed limits would be profitable in Finland. The benefit-cost ratio (gross) based on direct benefits calculated with the most likely starting values was 1.1–1.9
• Calculation was based on the assumption that variable slippery warning signs appeared to decrease the risk of accidents with injuries by an average of 10%.

Gintaras Cilcius presented a short Lithuanian national progress report. Some facts:
• > 2 000 000 cars
• 370 fatalities in road accidents in 2009
• Up to 100 RWIS stations

Work is in progress to build a real-Time Traffic and Travel Information system including:

• Traffic conditions
• Road works
- Road weather
- Road accidents
- Restrictions

Next step will be to introduce VSL between Vilnius and Kaunas. They will be either traffic-controlled (yellow dots) or weather-controlled (red dots).

![Figure 4.1 Introduction of VSL between Vilnius and Kaunas](image)

Leif Ringhagen made a short presentation of the East West project. Dynamic Speed Control is an activity within the project East West Transport Corridor II - a green corridor concept within the Northern Transport Axis approach – EWTCII. It includes:
- Improvements and evaluations of the test site at the highway E22 in Blekinge
- Preparing for implementation of a test site at the section Vilnius-Kaunas-Sitkūnai on national highway A1

A follow-up workshop to the workshop in 2010 may be organised within the East-West project.

4.2 Discussion

How can the information provided by the new road surface condition and grip sensors be utilised in dynamic speed management?

According to Finnish experiences, there are not any common rules describing the methods, how new sensors should be used in dynamic speed management. In those road sections with VSL, where the old sensors seem to produce satisfactory information for VSL, there is no reason to add new sensors. In VSL-road sections, where old sensors cannot interpret difficult local weather conditions, new sensors can improve the situation significantly. The local weather conditions and the problems connected to old sensors affect the way how new sensors should be used. Normally it takes months, even years to find the best procedure to utilize new sensors.
How can more efficient data fusion methods to combine new sensor technologies and data from traditional road weather stations be developed?
It seems that the new optical sensors overestimate the grip in wet road surface (it can't detect the ice below the water layer). On the other hand, the optical sensors seem to underestimate the grip on white snow. In the future, when we know more about the behaviour of optical sensors in various weather conditions, it is probably possible to compensate the flaws by demanding different friction values in different weather conditions. The way how the values from old sensors should affect the use of new sensors can be developed when more experience of new sensors has been achieved.

How much do the new sensors improve the technical performance of the weather-related speed management systems?
It depends of the local conditions. In certain difficult conditions the new optical sensors can improve the performance significantly.

What detection rate can be expected in very slippery road conditions? What detection rate is necessary to obtain a reasonable acceptance by the road users?
Finnish tests have not focused on very slippery conditions, but presumable the detection rate is about 70-90%.

What safety and other benefits could be expected from the systems enhanced with the new sensors?
According to Finnish studies, speed limit systems which use fibre optic or LED signs including variable slippery warning signs and base the control on automatic classification of road condition situations appeared to decrease the risk of accidents with injuries by an average of 10%. Because in certain road sections new optical sensors improve the VSL control, new optical sensors have clear safety benefits. But if the accident decrease for the whole system is about 10%, the extra safety benefit because of optical sensors included, must be less than 1%.

Mats Galmén made an introduction to the discussion concerning pros and cons of different sensors.

Which weather situations do we need to detect?
- Wind
- Visibility (rain, snow, fog)
- Grip (aquaplaning, ice, black ice, white frost, hoar frost, rime, snow, polished snow, slush)

Especially complicated to detect:
- snowy/slushy roads with tracks
- narrowing lanes due to snow banks

Which weather related situations are Sweden focusing on today?
• Visibility (rain, snow)
• Grip (ice, black ice, white frost, hoar frost, rime, snow, polished snow, moist, slush)
• Wind
• Snowdrifts to a lesser extent

but not

• snowy/slushy roads with tracks

Which weather related situations are Finland focusing on today?
• Rain, visibility and surface conditions.

Traffic safety impacts are found not only in icy conditions, but also during heavy rain. Slushy road conditions are almost as severe as ice. The risk is like a hammock according to VTI. It’s higher in the beginning (Förvinter) and the end of the winter season (Senvinter) due to less experience and higher use of summer tyres.

![Figure 4.2 Risk variation during the winter period](image)

Work is on-going to define Swedish “Objectives for WCVSL-project”
This work will be finalised in September-October 2010. Can be object for discussion in a future workshop. There is no similar work going on in Finland.

Taisto warned Sweden to focus too much on freezing point estimation. It might be the answer to the wrong question. Ask instead: Is the road slippery? **Forecasting of friction is important!**

What detection rate can be expected in slippery road conditions?
The response time should be fast when it’s freezing. A better name for detection rate could be **display rate.** It can be defined as the time during severe weather conditions that the display of the speed limit is correct according to predefined criteria.

Are there new types of sensors/sensor techniques at hand that can improve the ability to detect slippery road?
Mats meant that it would be very interesting with a sweeping detector. You will get a lot of data efficiently in that way.
What could we expect from DSC111? Limitations?
*DSC111 is very good at thin layers of ice (<1mm). Thick ice is more difficult. Slush is very difficult. Water on ice is the worst challenge, but it is very rare.*

How should we handle the values from DSC111? Should we use DSC 111 grip-values, or use layer-thickness and build our own model?
*There are considerations in Sweden to adjust the basic values from DSC111 instead of using the calculated friction coefficient. Taisto recommended using the friction from DSC111 directly. New modelling will result in the same friction anyway.*

What is best practice in validating different sensors?
*How representative are point measurements for stretches of 5 km or more? Taisto meant that most sections will have the same friction; the representation is much more difficult across the road. The tracks can be either more (icy) or less (dry) slippery than the rest of the road section.*

Is there a ‘champion’ method that can produce objective friction or road surface grip values?
*It is important to find a reliable reference value. But it is important to test the reference value at first.*

How do you find the right locations for the sensors?
*Thermal mapping is used to find extreme values of friction along the road. Weather stations should be located at points with average conditions, not with extreme conditions.*

Best practice in modelling?
*Considerations are made in Finland to combine fixed and mobile measurements in order to improve the hit rate. Friction coefficient 0.15 and 0.3 are used by the Finnish Transport Agency to define very bad and bad weather conditions.*

Best practice in speed management?
*Winter speed limits are used in Finland from October. 100 km/h is the maximum speed on motorways, 80 on other national roads.*

Where do we still lack information?
*At the moment, the optical sensor friction demands in VSL-areas are not dependent on the weather conditions. According to Finnish experts, there is need for better understanding of the optical sensor behaviour before they can be used on a broader extent. Still, there are not any detailed plans how these kinds of studies should be done.*

How can we best co-operate to fill the remaining gaps?
*We can exchange experiences and maybe plan the future tests in closer co-operation.*
4.3 Implications for co-operative research

1) How can the information provided by the new road surface condition and grip sensors be utilised in dynamic speed management?

Since it measures actual road surface status, it makes it possible to fully automate WCVSL. The first generation WCVSL in Sweden based on the weather model had no ability to measure the effect of remedial actions such as ploughing and salting, and WCVSL were therefore dependent on the TMC operator’s decisions. Those decisions are difficult to make and therefore highly depend on the operator’s experience and knowledge. Our experience shows that this leads to an unacceptable variation in the display of speed limits.

The Swedish experience is similar to the Finnish experience from the beginning of the 2000’s (Rämä and Schirokoff, 2004).

Today VSL at Blekinge and on the Öland Bridge are fully automated, based on grip estimations from the Vaisala DSC111 sensors. This solution seems to be working better than the first generation of WCVSL.

The road surface status sensors will however not solve all problems. The measurement zone is small, 10 cm inside or outside the tracks. The position across and along the road is sensitive. How representative is the point of measurement? Is the friction value relevant? The road surface state sensor is considered to exaggerate thin layers of snow and has difficulties in detection on roads with ruts. Below -6 centigrade, the operators of the winter maintenance are allowed to leave snow on the roadway; ruts will often arise in this situation. It is also difficult to measure snow volume (intensity of precipitation).

2) How can more efficient data fusion methods to combine new sensor technologies and data from traditional road weather stations be developed?

We have no experience of data fusion yet in Sweden. The weather model is considered to be unreliable. It has been a ‘black box’ that is difficult to manage and evaluate. The goal is now to develop flexible and transparent algorithms, which is possible to assess and check for quality. The operators must be informed of the probable result when input data is changed.

It is not only road surface state sensors that are interesting for VSL. An infrared camera has been installed to register how the temperature varies across the road section, and different sensors have been placed in the roadway. Researchers from Mittuniversitetet and KTH participate in the realization of the tests. One sensor cannot solve all problems. Sight distance, friction, strong winds, heavy rains are also interesting for weather control.
Further development is now made on e.g. E22 and the Öland Bridge. There are several control models. Wind model, road surface state model and traffic model. These are today ‘singular models’; the model that results in the lowest speed limit will be used. The first generation weather model has been abandoned, because of its character as a ‘black box’. The operators must understand the display of VSL and also be able to anticipate the consequence of a change in input data. There is also a goal that the same integrated control model should be used in all regions in Sweden. It consists of the sub systems above, but should also work if e.g. a wind sensor not is installed. The simple ‘singular models’ will be used in parallel. They give redundancy and will be used whenever one of the sub systems is out of control.

In the third generation VSL, a weather model will be developed, that probably involves ‘data fusion’. In this case, also other sensors beside road surface state sensors will be utilised.

3) How much do the new sensors improve the technical performance of the weather-related speed management systems?

A decisive question is how the sensors are validated. In order to estimate the hit rate, the friction must be measured by another and more reliable method than by the road surface state sensor. This method might be to use a friction measuring vehicle, but this is not either considered as fully reliable. In the validation in Blekinge, the accordance seemed to be sufficient during good surface conditions, but insufficient during bad surface conditions.

The precision of friction should not be exaggerated. It is not at all possible to measure friction with two decimals. We are in fact talking about friction classes. It refers to a way of bundling road surface states. The most dangerous road surface conditions are packed snow or thick ice with friction around 0.2 and thin ice or white frost with friction around 0.1. The problem is that nobody knows what the true friction is! Friction can in fact not be measured! It is estimated based on a number of measured secondary parameters. It might be better to bundle road surface states instead, that give more accurate descriptions of different road surface conditions.

4) What detection rate can be expected in very slippery road conditions? What detection rate is necessary to obtain a reasonable acceptance by the road users?

The share of severe slipperiness that is detected by RWIS was estimated by Per-Olof Sjölander, SRA, to 50% for Sweden in the SRIS project. The road surface state sensor ought to increase the detection rate. In the final report in the VSL project, it was estimated that correct set speed limits must be attained during 80% of the time with bad weather conditions in order to obtain a reliable system that can produce the intended traffic safety benefits.
The confidence of the drivers in the VSL system on E22 in Blekinge was low in 2005 during the trial. Several technical problems have been solved afterwards.

5) What safety and other benefits could be expected from the systems enhanced with the new sensors?
We don’t know yet. There is a need to follow up equipped sections and compare with control sections. No such study has yet been undertaken.

6) Where do we still lack information?
Data on validated road surface conditions to be used in evaluation of different sensors and weather models. Feed-back concerning the drivers’ confidence in the more efficient second-generation system. Feed-back concerning the change from 5 to 3 speed limit levels in Sweden. Feed-back concerning traffic safety from the improvement in rapidity and accuracy. Feed-back on single carriageway roads and on the northern climate zones (Middle Sweden, Lower North Sweden and Upper North Sweden).

At the moment, the demands on the optical sensor in VSL areas are not dependent on the weather conditions. According to Finnish experts, there is need for better understanding of the optical sensor behaviour before they can be used on a broader extent.

7) How can we best co-operate in the Nordic and Baltic countries to fill the remaining gaps?
We can exchange experiences and maybe plan the future tests in closer co-operation. There is experience from single carriageway roads in Finland that is lacking in Sweden. Finland has also more and longer experience from severe winter conditions than we have got in Sweden from our test roads in Halland and Blekinge.

We have still difficulties in motivating weather controlled VSL in Sweden. It would be interesting to be informed of how the investment in VSL has been motivated in Finland.

It would be interesting to exchange experiences concerning the display of the speed limits differs between Finland and Sweden. How would the Swedish system work in Finland and the Finnish in Sweden?

Tests of the Vaisala DSC111 sensor have been undertaken in all three countries. Several different sensors will be tested in Sweden. Exchange of test results and experiences would be fruitful. Which other types of sensors are used in Finland?

Which weather and control models are used in Finland? We are going to start the development of the third generation control models. Which is the best way to integrate several sensors and weather data into one single model?
We should also be able to compare the views of the road users, and impacts on vehicle speeds and traffic safety in all three countries. A synthesis of results can be made. Which differences in efficiency between road types, traffic flows and climate zones can be detected from our common results? Which strategies are there in Sweden, Norway and Finland to invest in weather controlled VSL in the future?

Is there any description of the goals for WCVSL in other countries, which describes what conditions the systems should detect and what they want to achieve regarding i.e. traffic safety and speed limit observance?

The following activities will continue in Sweden:
- Sensor tests will continue, but no plans for additional sensor test at Myggsjön next winter
- Objectives for WCVSL will be finalised
- We lack information about the relation between the sensor measured friction and the behaviour (speed) on the road; tests may be carried out

The following activities will continue in Finland:
- There are no plans for tests of fixed sensors
- Tests with hybrid systems: devices connected to mobile systems
- How to influence the drivers to drive cautiously in severe weather conditions?

The following areas were identified for co-operation
- Exchange of test results for new sensors
- Common strategy for display of speed limits
- Continuous measurement of friction and speed along a stretch for a long period (winter season). More data is needed for better modelling
- Best practice of modelling. There are new development in projects as Coldspot and Roadidea.
- Safety and behaviour effects

4.4 Seminar conclusions and proposed actions
- VSL should focus on weather conditions the driver can’t be aware of
- Multiple sensors (hybrid monitoring) are necessary to improve detection rates
- Validation of sensors is a key question
- More behaviour data is needed to motivate extended use of VSL

The Swedish organisers were asked to propose actions for continued co-operation:

1) The Swedish Transport Administration and the Finnish Transport Agency form a working group aiming at a common strategy for management of WCVSL. The co-operation efforts should be included in the agenda of the Nordic Road Association.
The strategy should include:

- Objectives for WCVSL management
- Considerations concerning extended use of WCVSL (road types, traffic volume, climate zone)
- Considerations concerning WCVSL management (speed levels, VMS, instrumentation, models)
- Common research program for extended validation of sensors
- Common research program for extended speed measurements

2) The participants in the workshop form a WCVSL group for information exchange and networking

3) A new workshop should be held within 12 months, it might be organised within the Nordic Road Association, the East-Way Project or Easyway

4) Efforts should be made to include Norway and Denmark in the cooperation.
5 Further studies

5.1 Mobile phones used for friction detection

5.1.1 The concept

Taisto Haavasoja, presented in the workshop experiences with cell phones used for friction detection. Many modern cell phones have a 3D accelerometer. Friction can be calculated with a software application measuring vertical and lateral forces during a test braking.

\[ \mu \]

\( \mu \)TEC is software, an application for certain mobile phones (Figure 5.1). When we later talk about \( \mu \)TEC-friction, we mean the friction measured by a cell phone using the \( \mu \)TEC application. \( \mu \)TEC can only be used in cell phones, which have already an acceleration sensor inside. When the cell phone is attached firmly to the vehicle, the \( \mu \)TEC application will register the cell phone deceleration during the braking and calculates the friction. If desired, the results can be sent immediately to the map (can be seen on the internet) in the form of phone GPS coordinates. The results can also be saved on the cell phone memory. More information:

http://www.teconer.fi/index_tiedostot/Page478.htm

Figure 5.1 \( \mu \)TEC user interface in a cell phone. The \( \mu \)TEC application license was about 500 € + VAT in the year 2010.

Advantages:

- communication, GPS, camera, voice
• absolute calibration against gravity
• easy to use: a few seconds and go!
• very short braking is enough!
• any position
• vehicle independent

A real time map interface to data (MµMS) has been made, where results from braking tests all over Finland can be followed.

Figure 5.2 Real time map of friction data

Several tests have been made by technical journals. The system (µTEC) has turned out to be as reliable as other friction measurement methods.

5.1.2 Conclusions
There are problems to measure friction on an extended road link:

• Freezing of solutions of salt and snow results in
  – both soft and hard ice with varying friction
• Friction coefficient
  – is an absolute measure of slippery surfaces
• Measuring friction
  – there are easy, reliable and cost effective ways to measure friction on highways

5.2 Sensor tests in Sweden

5.2.1 Objectives
Six different sensors were tested in Sweden during the winter 2009-10 (Trafikverket, 2010). The main purpose with the project was to evaluate different sensors, find their
strengths and weaknesses and examine how they could be utilized in applications that are of interest for the Swedish Transport Administration, with a focus on variable speeds and RWIS. The different sensors were evaluated individually with aspect to their different characteristics. Research prototypes in pre-product stage have been evaluated under real-world conditions, and products from the market (non-intrusive sensors and road surface mounted sensors) have been evaluated, mainly with respect to their ability to properly detect road status.

For weather controlled speed limits the current road surface state is of high interest. The speed limits could be lowered due to reduced friction, wind, reduced visibility and precipitation. Road surface state sensors can calculate an estimated friction value which is reduced due to snow, ice or moisture. The requirements of sensor accuracy are very high since the measurements are the basis of the speed recommendations or limits. Furthermore, a sensor which is too sensitive or send “false warnings” will lower the confidence in the VSL system.

For winter road maintenance the sensors are used for better knowledge of the current situation on the roads, improved forecasting, and planning of salting and ploughing. Freezing point temperature sensors can help maintenance personnel to indicate if there is residual salt on the road or not and thus save the environment by not spreading more de-icing fluids than necessary and perform de-icing tasks at the right occasions. Road surface state sensors can complement camera pictures for detecting road surface states.

5.2.2 Test site

The tests have been carried out on the test site Myggsjön, immediately south of Borlänge in mid-Sweden. The climate changes often during winter-time when the temperature can be everything from +10 to -30 degrees centigrade. Most interesting from a research point of view is when the weather is changing fast and it is freezing and thawing indiscriminately. With precipitation in different forms, the situation is even more critical.

5.2.3 Sensors

Six sensors were tested and evaluated, see Table 5.1. In addition to these a number of research sensors an infrared camera were used at the site during the test period. The DSC111, OpticQ and LIWAS are all non-contact road surface sensors using spectroscopy to measure water, ice or snow on the surface. Through a numerical approximation the friction can be estimated based on the road surface measurements. IRS31, ARS31 and Frensor are installed in the road surface. IRS31 is measuring temperature, moisture and conductivity of the moisture which can be recalculated to a freezing point temperature. ARS31 and Frensor are both active sensors which cool and heat the road surface moisture to measure at which temperature the moisture freezes.
Table 5.1  Sensors and suppliers

<table>
<thead>
<tr>
<th>Sensor type</th>
<th>Supplier</th>
<th>Output data</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSC 111</td>
<td>Vaisala</td>
<td>Road surface state, friction</td>
</tr>
<tr>
<td>Optic Q</td>
<td>Quixote</td>
<td>Road surface state, friction</td>
</tr>
<tr>
<td>LIWAS</td>
<td>Mercon</td>
<td>Road surface state, friction</td>
</tr>
<tr>
<td>IRS 31</td>
<td>Lufft</td>
<td>Freezing point, ice, water quantity</td>
</tr>
<tr>
<td>ARS 31</td>
<td>Lufft</td>
<td>Freezing point temperature</td>
</tr>
<tr>
<td>Frenson</td>
<td>Saab Security</td>
<td>Freezing point temperature</td>
</tr>
</tbody>
</table>

In addition to the sensors which were tested, several other sensors were available at the test site. Some sensors were installed on the monitoring station and others were installed separately.

5.2.4  Realization

All output data was collected with high frequency (every minute). As there was a wealth of data, the measurements were saved on a local PC situated at Myggsjön. The existing RWIS station (VViS) did also deliver information of air temperature, humidity, dew point, wind speed, wind direction, precipitation type and surface temperature.

Figure 5.3  System description
5.2.5 Evaluation results

The conclusions from the tests of road surface sensors are summarized in Table 5.2.

Table 5.2 Summary of conclusions from tests of road surface sensors

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Accessibility</th>
<th>Road status detection</th>
<th>Friction estimations</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vaisala DCS111</td>
<td>Good few error codes</td>
<td>Good High degree of proper response to changes in road status conditions</td>
<td>Good Indicates levels of road friction well in line with measurements and observations</td>
<td>Recommended for further testing and use.</td>
</tr>
<tr>
<td>Quilose OpticQ</td>
<td>Poor -50% error codes</td>
<td>Very poor Indicates more or less constant road status entire season</td>
<td>Very poor Indicates friction levels that contradict measurements and observations</td>
<td>Not recommended for use without further testing</td>
</tr>
<tr>
<td>Amfitech Liwas</td>
<td>Poor Much data missing</td>
<td>Ok Some degree of proper indication of road status, however too much data missing to draw motivated conclusions</td>
<td>Ok Friction levels in line with measurements, but too much data missing to make good conclusions</td>
<td>Further testing needed to establish sensor performance</td>
</tr>
</tbody>
</table>

The Vaisala DSC111 sensor is mature for operational use even though further testing would be useful to assure performance under some circumstances which were less common during these test, black ice and frost. The sensor would be well suited both for variable speed and at road weather stations; however the problem with the small spot size in relation to the vast road must be further evaluated. There is a risk that data will be misinterpreted depending on where the sensors are “looking”. OpticQ is not recommended for further testing in its current version. LIWAS requires more testing with longer time periods with continuous data to be further evaluated.

The results from the road mounted sensors IRS31, ARS31 and Frensor were ambiguous in aspect to measuring freezing point temperature. ARS31 and Frensor corresponded quite well in their performance of detecting a freezing point temperature while the magnitude of the freezing point depression differed significantly. It can’t be determined which sensor that is truer than the other without a more detailed study with an accurate reference. The reported salt actions are to some degree uncertain; it is likely that at least two salt actions were not reported. Freezing point temperature sensors should first be tested in a controlled environment with pre-prepared solutions with known freezing point. This method would screen out many of the uncertainties related to sensor instalments in roads. After measuring the sensors accuracy in a controlled environment it would be easier to conclude which errors that are sensor related and which are related to the complex road surface environment.
Both the optical sensors and the road mounted sensors monitor a very small spot on the road. The optical sensors have a larger spot area than the road mounted sensors and the Frensor has tried to overcome this problem by using four sensor heads. Neither of these sensors gives a picture of a larger road area, why the sensor installation must be done carefully and directed to road sections of most interest for the specific site and application. Naturally, the more sensors used the better will the estimation of the road condition be.

5.2.6 Experience

For future work it is important to define for what purpose the sensor will be tested and what the requirements are. Laboratory tests should be performed before the sensor is installed at the road to ensure that the sensor is functional and accurate in a controlled environment. Logging equipment must be redundant to survive power outages with secured communication. All data should be logged at the station or at an accessible server controlled by the Swedish Transport Administration. The data and logging procedures must be transparent and several mid-season checks should assure that data are collected properly and the sensors are functioning. Visual observations are very important and should be documented in an objective manner. The test site should be chosen so that all above criteria are fulfilled.

5.3 Friction Meter Comparison Study in Finland

5.3.1 Background

The friction requirements are an essential part of the winter maintenance quality requirements in public roads in Finland, Sweden and Norway. The idea behind these frictions requirements are that all the main roads don’t need to be bare, as far as the friction on the road surface is sufficient. This policy minimizes the need of various environmentally unfriendly anti-icing materials and chemicals.

In Finland, the road authorities, quality control consultants and the private winter maintenance contractors measure the road friction. The Finnish Transport Agency (= road authority) specifies the instruments and methods to be used in public roads friction measurements.

In Finland, during last 25 years, the road friction measurement is based on the method, where a small electrical in-car accessory determines the deceleration during braking and thereby estimates the friction. Those accessories are intended to be used in ordinary passenger cars or SUV's (Sport Utility Vehicles). When measuring friction, driver brakes the car with full force about 1-2 seconds and then releases the pedal. During the
braking, the car speed decreases, but the car won’t stop. The measuring cars have been equipped with studded tyres and they have ABS-brakes.

The measurements should be taken on a flat road section and the driver should carefully be aware, that no one neither is behind the car, nor driving from the opposite direction. The measurements should be carried out with passenger cars or SUV’s, and we haven’t heard of any serious accidents connected to that kind of friction measurement during the last 25 years. On the contrary, we only know about one fatal rear-end accident, when obviously a rather non-experienced user tried to measure friction with a lorry.

Because the tyre condition, air drag and brake system of the measuring vehicle has an effect on the friction value, the friction meters have to be calibrated during so called ”calibration days” several times during a winter. During those calibration days, the drivers make sure, that all the friction meters give the same results in the same place and at the same time. If the friction value is not satisfactory, the driver adjusts the calibration coefficient until the result is agreeable. According to the Finnish guidelines, the friction value should be 0.29 on packed snow, when the temperature is -5°C.

The traditional friction meters, used since the 1980’s, get their measuring impulses from the vehicle speedometer sensor and brake light wire. The speedometer sensor gives the vehicle speed before and after the braking. The brake lights tell the duration of the braking. This information is enough for the friction meter to calculate the friction value.

These traditional friction meters have one remarkable shortage: the meter installation needs professional expertise and becomes more difficult when electrical systems in the new vehicles are getting more complicated. That’s why new friction meters utilizing acceleration sensors are today so interesting. For these new meters, it’s enough to install them firmly near or on the dashboard. If the installation is firm enough, the deceleration measured by the acceleration sensor is same as the deceleration of the vehicle during braking. And the friction value displayed is relative to the deceleration.

Thus, the object of this study was to assess if the new friction meters with the acceleration sensors are so reliable and accurate, that these meters can be utilized in winter maintenance quality control in Finland. Furthermore, the object was to determine quality requirements for friction meters, so that the meter manufacturers can directly see, if their meter is suitable for winter maintenance quality control. In the future, when a manufacturer wants his meter to be used in quality control, he must present a report card of the conformity, made by an independent research organization.

This friction meter comparison study included several friction meters intended to use in winter maintenance quality control, as well as some other types of friction meters. The devices compared in the study have been classified in Table 5.3. The two uppermost
classes represent meters that are intended to be used in the winter maintenance quality control. All the devices, except T2GO and VBOX, have been developed and manufactured in Finland.

Table 5.3 The devices (compared in the study) classified in the basis of the operational principle (this is not any "official" classification).

<table>
<thead>
<tr>
<th>Device class</th>
<th>Operational principle</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Traditional friction meters&quot;</td>
<td>Calculates the friction in the basis of vehicle wheel spinning speed and braking time.</td>
<td>Eltrip-45n</td>
</tr>
<tr>
<td>Friction meters using acceleration sensor</td>
<td>Calculates the friction in the basis of deceleration measured by acceleration sensor.</td>
<td>µTEC, Gripman, Eltrip-7kmB</td>
</tr>
<tr>
<td>Optical friction meters</td>
<td>Estimates the friction and road condition in the basis of the reflectivity of the road surface.</td>
<td>DSC111, RCM411</td>
</tr>
<tr>
<td>Mechanical friction meters</td>
<td>Needs additional measuring wheel or wheels, which have a constant or variable slip. The friction is calculated in the basis of slip or forces affecting to the measuring wheel.</td>
<td>T2GO</td>
</tr>
<tr>
<td>Vehicle measurement instrument</td>
<td>Measures the vehicle speed and braking distance in the basis of accurate GPS. The instrument doesn’t display any friction values, but it can be easily calculated in the basis of speed and braking distance.</td>
<td>VBOX</td>
</tr>
</tbody>
</table>

5.3.2 Results from the tests on public roads

During this study, the consultant doing the winter maintenance spot check quality control, used all the test devices (except VBOX and T2GO) when making his work. Thus, this part of the test was done by accompanying normal measuring routines and no one needed to wait for suitable road conditions because of the study.

The results of the acceleration sensor meters from public roads were quite consistent with the results from the test tracks. When the two meters of each manufacturer were compared, it was revealed again, that the values of Gripman’s were most consistent. You can also find in Figure 5.5, that the deviation between two meters of the same manufacturer was always higher on the small friction levels.
Figure 5.4  The portion of the measurements, when the difference between 2 meters of the same manufacture was smaller than 10%. The devices are not calibrated and are used with factory settings.

The measurements with optical sensors were much more fruitful on public roads than on artificial test tracks. The RCM411 were better also in these tests, although the deviation of both devices were so extensive, that those devices couldn’t be used in the wintertime quality control.

5.3.3  Conclusions for individual devices
The objective of this research was to study the reliability and accuracy of various friction meters and assess their suitability in winter maintenance quality control in Finland.

Eltrip-45n, "Old Eltrip"
While the Old Eltrip was intended to be used as a reference device only, it was also revealed, that the accuracy of the Old Eltrip is still so good, that there is no reason to abandon this device, if it can be found on the vehicle. The Old Eltrip’s sensitivity for braking time was smallest, but on the other hand, this device is not suitable when measuring friction on a hill.

μTEC
μTEC was the most multifunctional application compared, but the deviation was quite large compared to the most accurate devices. While Gripman was designed to be used only in one position in a car, the position of the μTEC could be changed when ever
needed, if so called ”position calibration” was made at the same time. The problem with that was that the position calibration changed μTEC’s friction level ± 0.06. Because the application demanded the position calibration in the beginning of each test day, this position calibration weakened μTEC’s reliability and accuracy considerably. μTEC didn’t give any results in the most slippery test track condition (smooth ice). μTEC gave unintentional results on bumpy roads. The deviation was remarkably weaker when μTEC was used with Nokia 5230 than with Nokia E52. The application has been further developed after the tests.

Gripman
The two Gripman’s gave very consistent results and the results were also parallel to the reference device (Old Eltrip, VBOX) results. Gripman was the only acceleration sensor meter, which gave reliable results also on the most slippery test track condition (smooth ice). Gripman also operated on the hill faultlessly. Like other acceleration sensor meters, Gripman was quite sensitive for the variation of the braking time.

Eltrip-7kmb, New Eltrip
The extraordinary calibration logic complicated the use of New Eltrip in the tests, and the manufacturer changed the logic to the traditional method soon after the tests. The new Eltrip didn’t operate on the hill and gave unreliable results on the most slippery test track conditions. The accuracy in other road conditions wasn’t at the same level as the best devices. New Eltrip gave also unintentional results on bumpy road conditions.

Mobile DSC111
The Vaisala’s mobile DSC111 seemed to give quite illogical results across the whole study, and the performance didn’t become any better, although the device was examined in the Vaisala headquarters in the middle of the study. Although the device has the same name as the fixed roadside DSC111, the test results of the mobile DSC111 are not applicable to the fixed DSC111.

RCM411
RCM411 was the best optical device for the friction measurement in the test. The deviation of the RCM411 results was still so large, that the device is not suitable for the winter maintenance quality control. If the user however is able to interpret the results correctly, the device may give support to the winter maintenance and winter traffic management.

T2GO
T2GO was the only device suitable for the measurement of road markings and sidewalks. According to the tests, T2GO gave indicative results on the solid and hard surfaces, but T2GO considered loose snow much more slippery than observed when walking or driving.
VBOX
VBOX was used as a reference instrument in the study. Although the accuracy of the VBOX wasn't studied, the device convinced with the reliability and ease of installation. We are waiting for the model intended for friction measurement.

5.4 Weather modelling and speed management

5.4.1 Weather modelling today

Pirkko Saarikivi made an introduction to the discussion concerning best practice in the co-operative workshop.

How to forecast main risks?

- Weather models work well for snow fall and heavy rainfall, strong winds and low visibility due to snowfall or heavy rain
- Large synoptic (coherent) situations: no problem
- Small local variations: problematic, may be dangerous
- Slipperiness, fog and freezing rain are the most difficult parameters to forecast
- Mobile observation and fog and friction models are developed in the ColdSpots and ROADIDEA projects

New development: Hybrid monitoring = fixed + mobile

- Fixed network has \textbf{50-100 km} spatial density
- Mobile measurements have \textbf{50-100 m} spatial density!
- Challenge 1: how to combine the two for further use
- Challenge 2: reliable and fast delivery and processing of mobile data to warning and other services

Validation results:

An example of modelled vs. observed road surface friction when snow/ice is on the surface is illustrated in Figure 5.5.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{validation_results.png}
\caption{Validation results. The correlation is 0.86.}
\end{figure}
Friction model results:
The present model simulates cases of poor friction well, but…
• The model produces typically too low friction values for a too long time
  – The road weather model has too big storages for ice
  – The road weather model lacks information about road maintenance actions, which are necessary input data for a well-functioning model!

5.4.2 Conclusions and future needs
Results today are not quite as good as expected, but the shortcomings are identified:
• Further development, testing and evaluation is needed, especially comparisons and compilations with mobile and fixed observations
• Station specific relationships at all computation points must be specified
• Probabilistic approach to friction/slipperiness forecasting may be the best solution

5.5 Candidate links for future weather-controlled VSL
A study has been made in Sweden during 2011 as a basis for the discussion of the future deployment of weather-controlled VSL (Trafikverket, 2012a). The objective with the study has been to map road links and places where there is a need for weather-controlled road-side ITS equipment. Road-side localized weather-controlled ITS is defined as variable speed limits (VSL) controlled by weather (road surface, wind, visibility etc.) but also warning systems in adverse weather conditions that may influence traffic safety.

The work included generation of a method and general criteria for identification of places where weather-controlled ITS can improve traffic safety and a compilation of these places. The resulting priority between road links and shorter stretches is based on weather data (RWIS) and accident data (STRADA).

The method is divided into the following work packages
• Interviews with Project leaders Operation and Maintenance
• Identification of places or stretches that the Project leaders Operation and Maintenance have pointed out.
• Collection of weather (RWIS) and accident (STRADA) data.
• Generation of a method to map the location of a RWIS station to accident data.
• Analysis of places pointed out by Project leaders Operation and Maintenance concerning accidents and weather.

Based on the places that were pointed out and available STRADA and RWIS data, the following places have been given the highest priority:
Table 5.4 Locations with highest priority based on the list of designated locations and available STRADA and RWIS data.

<table>
<thead>
<tr>
<th>Region</th>
<th>O&amp;M area</th>
<th>Road</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitt</td>
<td>Avesta</td>
<td>N80</td>
<td>Falun- Hofors</td>
</tr>
<tr>
<td>Väst</td>
<td>Norra Värmland</td>
<td>E45</td>
<td>Vägsjöfors-Stöllet</td>
</tr>
<tr>
<td>Väst</td>
<td>Falkenberg, Hylte</td>
<td>E6</td>
<td>Broen VVIS</td>
</tr>
<tr>
<td>Öst</td>
<td>Mjölby, Norrköping</td>
<td>E4</td>
<td>Brahehus</td>
</tr>
<tr>
<td>Öst</td>
<td>Nyköping, Flen, Eskilstuna</td>
<td>E20</td>
<td>Barva-Lappen</td>
</tr>
<tr>
<td>Syd</td>
<td>Växjö</td>
<td>N23/37</td>
<td>Nottebäck</td>
</tr>
</tbody>
</table>

These locations have an accident outcome that relates to weather. Further detailed studies must be made on each location to determine if weather-controlled VSL or another type of ITS based warning system is suitable.

The analysis is based on:
- Interviews with project leaders Operation & Maintenance, which have pointed out more than 100 locations that can be interesting from a weather and accident point of view.
- STRADA data from the years 2003-2010, almost 140 000 police reports
- RWIS data from the years 2006-2010, almost 900 RWiS stations

It has not been possible despite the great data material to carry out a traditional statistical analysis of the relation between accidents and weather at these locations. The accident outcome is too sparse for single locations (RWIS stations). Criteria in traditional meaning have not been created. The method to analyse the locations has been a multi-stage analysis where weather and accident data result in a ‘picture of indices’. A shortage in this analysis is that exposure (traffic flow) and speed data have not been available.

5.6 Accident analysis on E6 and E22

An accident analysis based on police reported injury accidents (PIA), which has occurred on a 130 km stretch of E6 in Halland and a 30 km stretch of E22 in Blekinge during the period from 2000-07-01 to 2011-06-30 has been carried out (VTI, 2012). The objective was to find out whether the changes in risk are statistically significant or only accidental.

The link between Skottorp in the south and Heberg to the north is the test stretch (TS) on E6, while Heberg-Kungsbacka is the control stretch (CS).
Figure 5.6  E6 in Halland, control stretch to the north, test stretch to the south. Red = 120 km/h, green = 110 km/h, speed limits after 15 September 2008.

The link Ronneby–Åryd is the test stretch (TS) on E22, while Åryd–Mörrum is the control stretch (CS).

Figure 5.7  E22 in Blekinge, control stretch to the west, test stretch to the east, both with 100 km/h after 15 September 2008.

The Chi-2-tests that are reported here give statistically significant results on the 95-percent level (Chi-2 = 3.84). If Chi-2 is greater than the indexed ratio TS/CS in Table 5.5, significant results are achieved.

On E6 there has been an increase in accidents on the control stretch, but a decrease on the test stretch. On E22, on the contrary, there has been a greater increase in accidents on the test stretch than on the control stretch.

The before period on both roads is 5 years, the after period is 6 years.
Table 5.5  Number of PIAs on the test and control stretches on E6

<table>
<thead>
<tr>
<th>Road link</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>E6, test</td>
<td>164</td>
<td>157</td>
</tr>
<tr>
<td>E6, control</td>
<td>173</td>
<td>204</td>
</tr>
</tbody>
</table>

Table 5.6  Number of PIAs on the test and control stretches on E22

<table>
<thead>
<tr>
<th>Road link</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>E22, test</td>
<td>9</td>
<td>24</td>
</tr>
<tr>
<td>E22, control</td>
<td>14</td>
<td>24</td>
</tr>
</tbody>
</table>

The control stretch on E6 consists of two parts according to Figure 5.6. The speed limit was increased in 2008 to 120 km/h on the southern part. The accident trend has for the whole after period been significantly better on the test stretch when comparing with the northern part of the control stretch, which has had a speed limit of 110 km/h during both the before and after period. Also when the comparison is made for the whole control stretch but limited to the after period 1, there is an accident reduction on the test stretch.

Table 5.7  E6 full year, different control stretches

<table>
<thead>
<tr>
<th>Selection</th>
<th>Lowest</th>
<th>After/before</th>
<th>Standardized</th>
<th>H0 = similar development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total, C north, after period 1+2</td>
<td>T 0,96</td>
<td>1,51</td>
<td>0,64</td>
<td>6,16</td>
</tr>
<tr>
<td>Total, C whole, after period 1</td>
<td>T 0,54</td>
<td>0,68</td>
<td>0,80</td>
<td>1,53</td>
</tr>
</tbody>
</table>

On the E22 2+1-road, there has been a greater increase in accidents on the test stretch than on the control stretch, contrary to the E6 motorway. The observed difference is however not statistically significant for the total outcome and the null hypothesis of the same development cannot be rejected. For “non-winter” the development is also similar on the test and control stretches.

The hypothesis can however be rejected if the analysis is limited to the winter period. Please observe again that the control stretch, not the test stretch, has had the most favourable development.
Table 5.8  E22 full year, winter and no winter respectively

<table>
<thead>
<tr>
<th>Selection</th>
<th>Ratio</th>
<th>Test</th>
<th>Control</th>
<th>TS/CS</th>
<th>Chi-2</th>
<th>H0 = similar development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>CS</td>
<td>2.67</td>
<td>1.71</td>
<td>1.56</td>
<td>0.74</td>
<td>no</td>
</tr>
<tr>
<td>Winter</td>
<td>CS</td>
<td>11.00</td>
<td>1.75</td>
<td>6.29</td>
<td>4.55</td>
<td>yes, control better</td>
</tr>
<tr>
<td>Non-winter</td>
<td>TS</td>
<td>1.63</td>
<td>1.70</td>
<td>0.96</td>
<td>0.01</td>
<td>no</td>
</tr>
</tbody>
</table>

5.6.1  Winter and non-winter conditions
Division in winter/non-winter conditions show that it is during non-winter that the relative accident reduction on the test stretches on both E6 and E22 can be observed.

Data from the accident reports concerning road surface condition, weather and light conditions are used to get a closer look on the development on the test and control stretches respectively. It is primarily in these situations that a reduced speed limit can be supposed to be effective.

Table 5.9  Classification of road surface, weather and light conditions

<table>
<thead>
<tr>
<th>Road surface</th>
<th>Weather</th>
<th>Light conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>Cloudy weather</td>
<td>Daylight</td>
</tr>
<tr>
<td>Wet/humid</td>
<td>Haze/fog</td>
<td>Darkness</td>
</tr>
<tr>
<td>Thick ice / packed snow</td>
<td>Rain</td>
<td>Dawn/dusk</td>
</tr>
<tr>
<td>Thin ice, carriageway visible</td>
<td>Mixed snow/rain</td>
<td>Unknown</td>
</tr>
<tr>
<td>Loose snow / slush</td>
<td>Snow fall</td>
<td>Unknown</td>
</tr>
<tr>
<td>Unknown</td>
<td>Unknown</td>
<td></td>
</tr>
</tbody>
</table>

In the following sections, situations are discussed where road surface, weather and light conditions have influenced the difference between test and control stretches in such a way that the null hypothesis can be rejected.

5.6.2  Road surface
The test stretch on E6 show during periods with dry road surface in non-winter conditions a positive accident trend compared to the control stretch. In winter-time with the road surface condition “thin ice, road surface visible”, the relative accident development is advantageous for the test stretch, but without rejection of the null hypothesis.
The accident development has on E22 only during the road surface condition “wet/humid” in the winter been such that the hypothesis of similar change on the test and control stretches can be rejected (Chi-2 = 7.62 > 3.84). The significant decrease in accidents has occurred on the control stretch. This result is however based on a few accidents only, 0 before and 5 after on the test stretch and 3 before and 2 after on the control stretch.

5.6.3 Weather

The null hypothesis can be rejected on E6 in one weather situation only - clear, non-winter. The test stretch has had the relatively best accident trend.

None of the weather conditions reported in the accident reports for E22 give rise to rejection of the null hypothesis of similar development on test and control stretches.

5.6.4 Light conditions

The null hypothesis can be rejected in one case only on E6. It is in daylight during non-winter time that the test stretch compared to the control stretch has had the most favourable accident development.

None of the light conditions reported in the accident reports give rise to rejection of the null hypothesis of similar development on test and control stretches on E22.

5.6.5 Discussion and conclusions

The accidents that have occurred on the test stretches during the after period where the speed limit according to STRADA has been lower than 120 km/h on E6 and 100 km/h on E22 (VSL) has been identified.

On E22, there is only one single accident during daylight, snowfall and loose snow/slush. According to the accident description “very difficult road surface conditions were prevailing caused by snowfall”. The variable speed limit was set to 60 km/h.

On E6, the selection results in 44 accidents. In one single accident report only, it is mentioned in the accidents description that the speed limit was reduced. An accident on E6 2006-07-31 was reported to have occurred in conditions when the speed limit was 110 km/h (daylight and rain, ”Got aquaplaning after heavy rainfall and slipped off the road. In the accident situation the speed limit was reduced from 120 km/h to 110 km/h.”).

For E6, a positive effect of VSL on traffic safety has been validated. It is during the non-winter season (16 March – 14 November) that the effect can be found, and especially in conditions with dry road surface or clear weather or daylight, i.e. conditions that give no reason to presume that the speed limit has been reduced as a consequence of the VSL.
system. The result seems to lead to the suspicion that the VSL system influences the drivers positively when it is not active, but only marginally or even slightly negatively when it is active.

A hypothesis can be that drivers expect that speed limits are controlled to a higher degree on roads that are equipped with variable speed limits. This might result in lower vehicle speeds than expected on roads with variable speed limits. The resulting increase in speed on E6 was in fact only 2 km/h instead of the expected 4 km/h, when the maximum speed limits were increased from 110 km/h to 120 km/h. If the VSL system per se influences the drivers – whether the speed limit is reduced or not – this might result in a traffic safety effect also in other conditions concerning road surface etc. than those which lead to a reduced speed limit.

Drivers might on the other hand have to high confidence in the warnings from the VSL system in bad driving conditions. As we can see from the description of the VSL systems and the sensor tests, the technical performance of the system is not perfect. This can result in a too high speed limit compared to the weather situation, which in turn can result in higher vehicle speeds than the spontaneous speed without VSL.

Based on the reported accident analysis, the weather-controlled VSL system seems not to have any significant traffic safety effect on E22. Quite the contrary seems to be the case. The control stretch is significantly better during the winter-time. As can be found in the user survey in Section 5.7, drivers still have the feeling that the speed limits sometimes are not in accordance with the road conditions. The relatively poorer performance of the system in Blekinge might be a partial explanation of the relatively negative safety outcome, especially compared to E6 in Halland. Another explanation can be that the vertical alignment is very complex with steep hills and valleys, which results in largely differing road conditions along the road.

5.7 User survey on E22 in Blekinge

A new survey of user attitudes was carried out in March 2012, around eight years after the deployment of VSL in Blekinge (Trafikverket, 2012b). The sample in the user survey consisted of drivers that have been passing the weather controlled road link. Limitations have been made such that only private car users from Blekinge, southern Småland and north-western Skåne were included in the sample. A sample of 600 drivers that passes the test stretch has been selected. The goal has been to get 300 useful answers to the survey. When the collection was finished after one reminder there were 280 answers. In this situation, the decision was made not to send out a second reminder in order to limit the cost.
5.7.1 Travel habits and attention

The majority of the questioned road users drive daily or several times a week on the test stretch, and almost all, 96%, know the test stretch well. Almost all, 97%, have observed that variable speed limits are used on the test stretch.

5.7.2 Experience concerning technical function

Drivers agree in particular with the positive statements that the speed signs can be clearly seen in darkness and daylight. Among negative statements, drivers agree most with the statement that the distance between signs are too far. The majority, 62% of the interviewed, have experienced that the signs have been out of order. Most of these (45% per cent units) have only made this experience once. Almost half, 48% of the interviewed have felt uncertain on which speed limit that was valid during a specific time. Most of these (32% per cent) have only felt this way once.

People are aware of the meaning of variable speed limits. They disagree that the road holder can guarantee that speed limit results in a low injury risk. They agree most with the statement that speed limits are set with regard to the most difficult road surface and weather conditions on the stretch. When it comes to all other statements, 18-31% does not think that the statements are correct. This can be interpreted as the fact that a clear and relatively large minority still do not fully understand the concept of variable speed limits.

A clear majority, 67%, are of the opinion that the concept of variable speed limits is good or very good on the test stretch, but every tenth (10%) mean that it is bad or very bad. The motivation behind positive answers is primarily that one gets more attentive on the road surface condition and that it creates a calmer and safer traffic.

Negative comments are that speed signs seldom are in accordance with the current weather and road surface condition and that they mean that drivers themselves should adapt the vehicle speed to the circumstances.

5.7.3 Experiences concerning driving behaviour

The attitudes tend to give support to the opinion that the stretch has been calmer, less dangerous and slower than before. However, the opinions divert among drivers, concerning how accessibility and the traffic tempo have been influenced by the variable speed limits.

The majority, 58%, experience that the speed limit always or usually is in accordance with variations in road surface and weather conditions. 11% experience that the limits seldom or never are correct. The majority means that the speed limits are reasonable by snowfall, slush or slipperiness. They are more doubtful concerning rain or fog.
A relatively great share experience that they have changed their driving behaviour. 49-62% experience that they have been more attentive on the road surface and other vehicles, and that they keep longer distances and do not overtake other vehicles as often as before. Most drivers do not test the road surface more often to investigate the slipperiness, but 27% say that they in fact test the friction more often than before.

5.7.4 Attitudes to speed limits and speed signs

More drivers state that they almost never exceed the allowed speed limit when the variable speed sign is activated compared to when it is not activated (36% activated = VSL compared to 27% not activated = fixed speed limit). Somewhat more drivers answer to the same question that they often or very often exceed the speed limit at these occasions (14% activated = VSL compared to 11% not activated = fixed speed limit).

The most common causes to driving too fast are that drivers experience speed limits as being set too low compared to the road standard, that they only follow the tempo in traffic, that they feel to be in control of the situation and/or that they mean that the road surface and weather conditions allow a higher speed than the posted speed limit.

52% of the interviewed drivers think that they respect the speed limit more when it is variable compared to the normal fixed speed limit. 31% of the interviewed drivers experience that the speed limits in general are kept more often when they are supplemented by variable speed limits. Drivers are of the opinion that the greatest influence on attention/compliance would be attained if there also was an explanation/motivation to the speed limit (82% have this opinion). They also mean that the effect would be smallest if the variable speed sign always was activated/lit (showing fixed or variable speed limit).

A clear majority, 76%, feel that they would be somewhat or very supported by a warning sign (pictogram) that is shown together with the speed sign. Studying different proposed designs of such warning signs (Figure 6.1), drivers were able to give relevant answers to the meaning of the different layouts of the pictograms.

5.7.5 Comparison with 2005

The results in the new user survey in 2012 are surprisingly similar to the results in the first survey in 2005. The question “What is your opinion of Variable Speed Limits on E22 in Blekinge” was answered almost exactly the same as in the survey from 2005. 21% found VSL very good and 46% good.
Since 2005 there have been technical improvements of the system. In spite of this, slightly more drivers are of the opinion that the VSL signs is out of order more often in 2012 than in 2005. Slightly more are also uncertain of the set speed limit in 2012. These unexpected results explain why almost the same share (57% compared to 54%) finds that the variation of speed limits is in accordance to the weather and road surface conditions.

The conclusion from the user survey is that drivers find the VSL system useful, but the share that score good or very good (65%) is significantly lower than for the system in Halland. The response to WCVSL in Halland (92%) is even better than for e.g. VSL at intersections (ca 80%) or travel time information (78%).

A probable reason to the low figure in Blekinge can be that drivers find the set speed correct to a lower degree, that the number of VSL signs are too small, and maybe most important that the topography results in road surface conditions that can vary heavily between hills and valleys.

More information (in Swedish) about the comparison between 2005 and 2012 can be found in Appendix 1.

#### 5.8 A hypothesis on behaviour and safety benefits on WCVSL

##### 5.8.1 Safety benefits of traffic management on motorways

A research project concerning safety effects of traffic management measures on motorways was carried out in 2011. It consisted of a literature survey, synthesis of safety effects and validation by simulation studies (Movea and VTI, 2012). From the
literature survey, it is evident that five characteristics of the traffic flow are especially important from a traffic safety perspective:

- **vehicle speed**, which is important for accident frequency and crash violence
- differences between drivers’ individual desired speeds and kept distances, which represents the aggressiveness of the drivers and influences i.e. the number of overtaking and rear end situations
- **instability/harmonisation** of the traffic flow, which increases/reduces the risk of disturbances and in the worst case accidents
- **response readiness** and driving skill, which influence the response time and the propensity to react to active traffic management measures
- **relative speed** compared to the road standard, which is important for the lane and road keeping ability

### 5.8.2 Follow-up of safety benefits

The impact of weather-controlled variable speed limits (WCVSL) depends i.e. on how often the system is active. The share of bad or severe road surface conditions amounts to ca 10-15% of the vehicle mileage in the southern part of Sweden. Guided by measured reductions of average speeds in different road surface conditions, the impact was estimated to the magnitude of 10% in connection with the VSL trials (Vägverket, 2008).

**Finland**

A study was conducted already in 2004 on the impacts of weather-controlled variable speed limit systems on injury accidents (Rämä and Schirokoff, 2004). The high quality systems which based the control on automatic classification of road condition situations and which used fibre optic or LED signs decreased the injury accident risk in winter by 13% and in summer by 2%. For the other group of systems with manual control and electromechanical signs the safety was reduced. The length of the follow-up periods was up to 12 years. The results were not statistically significant.

The evaluation study included eight variable speed limit systems controlled by weather and road condition data. The lengths of the equipped sections varied from 8 km to 41 km. Systems were implemented on two-lane roads. On this road type 80 km/h is usually the highest speed limit permitted in wintertime. Variable speed limit systems used three alternative limits: 100 km/h for good conditions, 80 km/h for moderate or normal conditions and 60 or 70 km/h for adverse conditions.

This study investigated the effects of the variable weather-controlled speed limits on injury accident risk. Because variable speed limits were used to both increase and decrease the speed of the traffic flow it was difficult to anticipate the safety effects of the system. The suggestive results showed that the high quality systems with elaborate control system seemed to decrease the injury accident risk especially in winter. The
system seemed to improve traffic safety even though it was also used to improve the fluency of traffic flow. The positive effects are based first, on the efficient recognition of hazardous weather and road conditions, second, on the use of the variable slippery road signs to support the variable speed limit system, and third, on the moderate use of the highest speed limit (100 km/h). Without these qualities the variable speed limits seemed to reduce traffic safety.

**Sweden**

A simple follow-up study was made in 2010, based on reported accidents four years before and four years after the installation of WCVSL on E6 in Halland (STRADA, 2010). The study indicated far greater safety impacts than the 10% expected impacts according to the Swedish VSL trial (Vägverket, 2008). The number of personal injury accidents (PIAs) was reduced with 17% and the number of killed or severely injured (KSI) was reduced by 45%. During the very same period the number of injury accidents in Sweden was increased with 5% while the number of severely injured has dropped by 14%. Remaining is a 20-30% relative change.

**Table 5.10 Follow-up of accidents on E6 in Halland**

<table>
<thead>
<tr>
<th>Period</th>
<th>Number of PIAs</th>
<th>Fatalities</th>
<th>Severely injured</th>
<th>Slightly injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before (July 2001-June 2005)</td>
<td>141</td>
<td>8</td>
<td>30</td>
<td>206</td>
</tr>
<tr>
<td>After (July 2005-June 2009)</td>
<td>117</td>
<td>3</td>
<td>18</td>
<td>179</td>
</tr>
<tr>
<td>Difference</td>
<td>-17%</td>
<td>-63%</td>
<td>-40%</td>
<td>-13%</td>
</tr>
</tbody>
</table>

An attempt was also made to differentiate the effects on summer/wintertime and different road surface conditions. At the time of the study, road surface conditions were only available for two years in the before period, which complicated the comparison. Another problem is that the road surface of course differs between different years.

The problems can however not hide the fact the study show surprisingly positive results in dry conditions and during the summer period. It seems therefore motivated to modify the hypothesis of the impacts of weather controlled VSL. Besides the speed reduction in bad weather and road surface, it is probable that attention rising effects in shape of focus and activation of the driver also occur.

Based on the problems with comparable data from the before and after period, it was decided to initiate a new study with comparable test and control stretches using the same periods. This study, which is reported in Section 5.6, confirms that safety impacts also occur in dry conditions and during the summer.
**England**

An ambitious evaluation, which was made of homogenisation (VSL) and hard shoulder running (HSR) on the M42 at Birmingham, strengthens this hypothesis (Highways Agency, 2011). M42 was before rearranging the lanes provided with three lanes and a hard shoulder. The traffic volume was 120,000 veh./24h. By disposing the hard shoulder temporarily as an extra lane, the capacity is increased in the rush hour. This will result in a reduction of around half of the share of dense traffic. One should therefore expect that the number of rear-end accidents will be reduced, which was also the case.

The result of the detailed accident analysis is that both variable speed limits and hard shoulder running heavily reduces the number of accidents and the severity of accidents. The number of single accidents is however surprisingly reduced more than the number of rear end accidents that the measures are focusing on. A further result is that accidents during the morning peak are generally unchanged, while accidents were mainly reduced in medium and low traffic. There was also an increase in the share of side collisions and the share of accidents during peak traffic and in low speed conditions (stop-and-go). Another observation was that the share of accidents with heavy vehicles increased.

A possible explanation of the reduction of accidents in low and medium traffic might be that the traffic management system is most efficient to reduce rear-end collisions when the relative speed differences are greater, which occurs in less dense traffic conditions. It is also possible that the drivers are influenced by the fact that the stretch is equipped with a traffic management system, which might lead to greater awareness and shorter response time. To the point belongs also that the automatic speed control increased both in low traffic and in situations with VSL.

An explanation for the increased share of side collisions might be that the vehicles are driving closer together in the HSR regime. The share of accidents with heavy vehicles involved is often increased with VSL, as these vehicles try to avoid slowing down in dense traffic, which in turn leads to more critical situations. This problem is often mitigated by an overtaking ban for trucks in rush hour traffic.

### 5.8.3 Probable behavioural effects

Based on the experience concerning vehicle speed, accident analysis and user attitudes, the following adaptation of driver behaviour seems plausible:

1) The WCVSL system leads to recognition of the driver that the road link is more complex than other links. This feeling results in a somewhat lower vehicle speed and possibly also a somewhat shorter response time than for other similar links. A contributing cause might be that the drivers suspect that the speed control is increased on the regulated link. This effect will occur already with a passive, not
activated control system. This behaviour explains why the vehicle speed often is lower than expected in sparse traffic.

2) When the system is activated, this leads to an increase in the preparedness and the response time will decrease. The drivers place greater emphasis on surrounding traffic and the road surface. This behaviour explains the fact that the accident risk will decrease also with only marginal changes in vehicle speed.

3) After the first reaction upon the activation of the system, adaption of the vehicle speed and distance keeping will continuously take place as a response to further control measures and changing traffic conditions.

The first focus effect means that the driver gets a higher preparedness to handle risks on the designated road. He/she understands that the speed limit can be changed in bad weather. The second activation effect occurs at the first illuminated variable sign, when the speed limit is changed from the fixed maximum level. In that moment, the attention on the road surface conditions increases and the response time of the driver reduces. This leads to a more active driving style, which gives a contribution to safety in addition to real speed changes. We will therefore get the following relationship:

\[ \text{Safety impact of WCVSL} = x(\text{focus}) + y(\text{activation}) + z(\text{speed adaptation}) \]

Already in the Finnish WCVSL trial, attention was drawn to the fact that traffic safety effects not only occurred in the winter, but also in the summer (Rämä and Schirokoff, 2004). The analysis of E6 Heberg-Skottorp gave the corresponding indications that the safety is increased also in summertime and during dry road surface conditions. This result must be interpreted as an elevated preparedness of the drivers that difficult road surface may occur on roads with variable speed limits. These roads are specially designated and should therefore have a greater risk in bad road conditions than other roads. A similar focus effect will probably occur as a result of the general weather forecast in radio and TV. During days when difficult weather conditions are expected, drivers will be more focussed on the road surface conditions and this will probably lead to fewer accidents. On other days when slipperiness is not expected, systems for local slip warnings will thus have greater potential to influence the drivers and increase the road safety. Another reason for safety benefits in the summertime is that slippery road conditions in that period are especially surprising. In the research project, this focus effect was estimated to at least 5-10% of the number of personal injury accidents.

In acute situations when the road surface conditions are difficult, a spontaneous adaptation of the vehicle speed will occur. This behavioural adaptation probably amounts to 10-15 km/h in icy conditions that are visible for the driver. In white frost and thin ice conditions, the driver cannot always see that it is very slippery. The vehicle speed is then often higher than on thick ice. When the illuminated speed or warning sign is lit,
the attention to the road surface conditions will increase even more. Even if the speed limit is not reduced further, traffic safety benefits would accrue by reduced response time at increased slip risk. In the research project, this activation effect was preliminary estimated to 10-15% of the number of personal injury accidents.

During the Swedish WCVSL trial, reduced vehicle speeds of 15-20 km/h were measured in severe road surface conditions (very slippery). The relative injury risk for different road conditions has been calculated in the SRIS\(^1\) project (Movea, 2008). Warning is only expected in severe or very severe road surface conditions.

![Table 5.11 Relative injury risk in different road surface conditions with and without slippery road warning](image)

<table>
<thead>
<tr>
<th>Relative injury risk (KSI)</th>
<th>Without warning</th>
<th>With warning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry road surface</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Moist or wet road surface</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Loose snow or slush</td>
<td>13.0</td>
<td>13.0</td>
</tr>
<tr>
<td>Packed snow or thick ice</td>
<td>10.8</td>
<td>4.4</td>
</tr>
<tr>
<td>Thin ice or white frost</td>
<td>18.6</td>
<td>5.4</td>
</tr>
</tbody>
</table>

From the speed reductions in Halland one should expect an increase in traffic safety of up to 60-70% in difficult (packed snow or thick ice) and severe (thin ice or white frost) road surface conditions. The accident analysis indicates quite the contrary that the slippery road accidents have changed only marginally while the effect in dry road conditions is surprisingly great and positive. A plausible explanation is that the precision in slippery road warnings is poor in combination with the drivers showing too high confidence in the system. Moreover, the speed control system has been changed in such way that 80 km/h compared to earlier 60 km/h is now displayed in very slippery road conditions. Just as in Finland, one can imagine that compensation effects accrue when the signs indicate that the conditions are good. Drivers will in this case believe that they can drive faster than the spontaneous speed that will result without any variable signs. The remaining effect during the winter will therefore be the increased focus on the road surface conditions.

If the precision in detection of slippery roads in Sweden could be improved, the corresponding results as in the Finnish trials would however be expected. It could also be recommended to limit the information to very slippery conditions in order to get sufficient effects. The influence on vehicle speed will probably decline the more often the reduced speed limit is shown. Another improvement may also be to show symbols (pictograms) to a greater extent in order to stimulate the drivers even more. Today, there is no information at all about the cause of the speed reduction. Information is

---

\(^1\) SRIS = Slippery Road Information System
especially important when conditions are changing. Pictograms should therefore be at hand for local slipperiness on spots, varying road surface conditions, risk for aquaplaning etc. With these improvements it is estimated in the research project that the speed adaptation effect of best practice will amount to 15-20% on the number of personal injury accidents.

A conservative hypothesis based on the literature review and the Swedish and Finnish trials of WCVSL will lead us to the following estimation of safety benefits at a speed limit of 120 km/h:

Table 5.12  Effects of weather-controlled VSL during different seasons (person injury accidents)

<table>
<thead>
<tr>
<th>Season</th>
<th>Increase in safety (PIAs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus effect all year also in dry conditions</td>
<td>5-10%</td>
</tr>
<tr>
<td>Extra activation effect during slipperiness and rainy days</td>
<td>10-15%</td>
</tr>
<tr>
<td>Extra speed adaptation in slippery road conditions</td>
<td>15-20%</td>
</tr>
</tbody>
</table>

The impacts will be somewhat reduced on roads with lower speed limits. The hypotheses above are based on experienced effects and behavioural considerations. The relationship is however uncertain. More studies are necessary to validate the logic and the preliminary hypotheses.

As stated above, we believe that focusing on the road and the activation caused by the first illuminated variable speed sign together will have greater importance for the road user behaviour and response time than the size of the change of the speed limit. We also assume that the vehicle speed is crucial in severe conditions and that the power model can be used to estimate the effects of speed adaptation.

Table 5.13  Probable impact on PIAs from WCVSL

<table>
<thead>
<tr>
<th>Change in speed limit</th>
<th>Focus</th>
<th>Activation</th>
<th>Adaptation</th>
<th>Effect with 15% active system of which 5% very slippery road conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>120 km/h → 100, 80 km/h</td>
<td>10%</td>
<td>15%</td>
<td>20%</td>
<td>13%</td>
</tr>
<tr>
<td>110 km/h → 90, 70 km/h</td>
<td>8%</td>
<td>12%</td>
<td>15%</td>
<td>10%</td>
</tr>
<tr>
<td>100 km/h → 80, 60 km/h</td>
<td>6%</td>
<td>9%</td>
<td>12%</td>
<td>8%</td>
</tr>
<tr>
<td>90 km/h → 70, 60 km/h</td>
<td>4%</td>
<td>6%</td>
<td>8%</td>
<td>6%</td>
</tr>
<tr>
<td>80 km/h → 60 km/h</td>
<td>3%</td>
<td>4%</td>
<td>6%</td>
<td>4%</td>
</tr>
</tbody>
</table>

The main additional feature in WCVSL is warning signs that motivate the driver to comply with the variable speed limit. Based on the results from Sweden, it seems that the control strategy in the VSL trials can be questioned. It appears most important that the driver focus on the varying road conditions.
An alternative control principle is to only slow down one step (20 km/h) and to complement the reduced speed limit with warning signs representing increasing degrees of bad weather and road conditions. If we assume that this leads to 10% higher activation effect, but the other behavioural effects are unchanged, we obtain the following speculative safety impact:

Table 5.14 Probable impact on PIAs of warning signs and WCVSL

<table>
<thead>
<tr>
<th>Change in speed limit</th>
<th>Focus</th>
<th>Activation</th>
<th>Adaptation</th>
<th>Effect with 15% active system of which 5% very slippery road conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>120 km/h → 100 km/h + warning</td>
<td>10%</td>
<td>25%</td>
<td>20%</td>
<td>15%</td>
</tr>
<tr>
<td>110 km/h → 90 km/h + warning</td>
<td>8%</td>
<td>19%</td>
<td>15%</td>
<td>11%</td>
</tr>
<tr>
<td>100 km/h → 80 km/h + warning</td>
<td>6%</td>
<td>14%</td>
<td>12%</td>
<td>9%</td>
</tr>
<tr>
<td>90 km/h → 70 km/h + warning</td>
<td>4%</td>
<td>11%</td>
<td>8%</td>
<td>6%</td>
</tr>
<tr>
<td>80 km/h → 60 km/h + warning</td>
<td>3%</td>
<td>7%</td>
<td>6%</td>
<td>4%</td>
</tr>
</tbody>
</table>

WCVSL has the biggest impact on road user behaviour in difficult weather and road conditions at high vehicle speeds. In dense traffic, the driver will be forced to adjust his speed to the surrounding traffic and the effects will be more limited. On the other hand, the risk of multiple vehicle accidents will be greater if the speed is not adjusted further.

Table 5.15 Influence on driver behaviour of WCVSL

<table>
<thead>
<tr>
<th>Traffic characteristic</th>
<th>Adaption to weather and road surface</th>
<th>Traffic characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active traffic management in sparse traffic (Traffic load 10-40%)</td>
<td>Heavy reduction in severe slipperiness</td>
<td>Vehicle speed</td>
</tr>
<tr>
<td></td>
<td>Moderate reduction in severe slipperiness</td>
<td>Speed variance</td>
</tr>
<tr>
<td></td>
<td>Activates the driver, moderate influence</td>
<td>Response time</td>
</tr>
<tr>
<td></td>
<td>No influence</td>
<td>Instability, harmonisation</td>
</tr>
<tr>
<td>Active traffic management in dense traffic (Traffic load 80-90%)</td>
<td>Moderate reduction in severe slipperiness</td>
<td>Moderate decrease with active system</td>
</tr>
<tr>
<td></td>
<td>Small decrease with active system</td>
<td>Activates the driver, small influence</td>
</tr>
<tr>
<td></td>
<td>Marginal influence</td>
<td></td>
</tr>
</tbody>
</table>

5.9 Review of benefits and costs

The socio-economic calculations for Halland in 2008 based on the Swedish VSL trial reveal a (gross) benefit cost ratio of +1.6 (Vägverket, 2008). Thus the investment was beneficial provided that correct speed limits are displayed during the assumed 80% of the time when adverse weather conditions occur. This accessibility level was however not sufficient to make the investment in Blekinge beneficial (benefit cost ratio +0.8).
Analysis of different isolated measures for Blekinge indicated that raising the maximum speed limit from 90 to 110 km/h alone results in significant negative safety consequences. However the introduction of VSL when the maximum speed limit is 110 km/h was indicated to be a very profitable measure (benefit cost ratio >3) according to the power model. The analysis also indicated that a decrease of the maximum permitted speed limit to 100 km/h in combination with a reduction of the number of alert or speed display levels of the VSL system to three levels, which has been suggested, is a very valuable measure. The speed limit was in accordance with the results later changed to 100 km/h.

A hypothesis for the future made in 2008 was that weather-controlled VSL may be more profitable on single carriageway roads with relatively high traffic volume (around 10000 veh./day) and low vertical alignment in the middle part of Sweden where there are more winter days with adverse road conditions.

Now, four years later, we have got indications that the safety impacts are more complex. There seems to also be a focus effect and an activation effect beside the originally assumed speed adaptation effect. We can also notice that the drivers still experience poor functionality in Blekinge, which may explain why the safety effects are smaller than expected. The safety effects on E6 in Halland have on the other hand already since the opening of the WCVSL motorway been quite larger than expected. Results are still confusing, but we have anyway been asked to make a new analysis of costs and benefits based on the analysis and assumptions in Section 5.8.

The new calculations are made for three different road categories, adapted to the Swedish winter maintenance classes VVK1-VVK3. This will give indications of the use of WCVSL for different traffic volumes and slippery road conditions.

Table 5.16 Type roads

<table>
<thead>
<tr>
<th>Class</th>
<th>Type</th>
<th>Traffic volume (veh./24h)</th>
<th>Free flow speed (km/h)</th>
<th>Accident risk (police rep./M veh.km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VVK1</td>
<td>Motorway</td>
<td>30000</td>
<td>110,2</td>
<td>0,25</td>
</tr>
<tr>
<td>VVK2</td>
<td>2+1L, expressway</td>
<td>10000</td>
<td>108,4</td>
<td>0,425</td>
</tr>
<tr>
<td></td>
<td>2L, &gt;11,5 m</td>
<td>10000</td>
<td>90,2</td>
<td>0,28</td>
</tr>
<tr>
<td>VVK3</td>
<td>2L, 8-11,5 m</td>
<td>4000</td>
<td>92,7</td>
<td>0,30</td>
</tr>
</tbody>
</table>

VVK2 consists in the calculation of the average of a 2+1 lane expressway and a wide (>11.5 m) single carriageway road.
5.9.1 Safety model

In order to estimate the safety impact, basic data as risk indices (accident and severity rate) for different road types, speed limits and road surface conditions are needed.

In relatively good conditions, the safety effect is based on the figures in Section 5.8. When the system is not active there is only a focus effect. When the system is active in winter (or heavy rain) conditions, there seems to be only marginal speed adaptation effects, but activation of the driver is assumed to reduce the response time and hence increase safety anyway.

<table>
<thead>
<tr>
<th>Road class</th>
<th>Change in speed limit</th>
<th>Focus</th>
<th>Activation</th>
<th>Adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td>VVK1</td>
<td>110 km/h → 90 km/h + warning</td>
<td>8%</td>
<td>19%</td>
<td>15%</td>
</tr>
<tr>
<td>VVK2</td>
<td>100 km/h → 80 km/h + warning</td>
<td>6%</td>
<td>14%</td>
<td>12%</td>
</tr>
<tr>
<td>VVK3</td>
<td>90 km/h → 70 km/h + warning</td>
<td>4%</td>
<td>11%</td>
<td>8%</td>
</tr>
</tbody>
</table>

In relatively bad conditions, the change in accident outcome due to speed adaptation has been estimated by means of an adjusted power model. Starting with the traditional model, a speed reduction from 100 km/h to 90 km/h means that the risk for killed and severely injured is reduced to \((90/100)^3 \approx 68\%\). In the calculations, the power factor has been set to 4.5 for killed persons, 3 for severely injured and 1.5 for light injured according to the latest research.

In order to calculate the average impact, we have to get data of speed changes in all road surface conditions and the number of vehicles that travel on the road in different conditions. We have based the calculations on the work by VTI on the ‘Winter model’ (VTI, 2006). Results indicate that the accident risk is around 10-20 times higher in bad
road surface conditions for the road class VVK1 in Central Sweden. The corresponding figures have been calculated for other road types and road surface conditions in Sweden.

Assumed values of slippery road warnings, based on measurements in the VSL project, shown in Table 5.18 below. For dry, moist or wet road surface it is assumed that no slippery road warnings are posted. Warnings in case of loose snow and slush are of doubtful value. In the VSL project, no significant effects were shown. The calculations of the improvements by speed adaptation due to slippery road warnings are therefore limited to packed snow, thick or thin ice and frost.

The results below refer to Central Sweden. In the calculations, we use all accidents as a reference instead of only PIAs. It was estimated in the research project (Movea and VTI, 2012) that the impact on PIAs should be multiplied with 0.415 to reflect changes for all accidents. This figure is used to transfer effects in Table 5.17 to influence on accident ratios in Table 5.18.

Table 5.18  Average speed, accident risk and severity (Sev) for various winter standard classes with non-slip warnings in the form of variable speed limit in Central Sweden

<table>
<thead>
<tr>
<th>Risk VVK1</th>
<th>Without warning</th>
<th>With warning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Speed</td>
<td>Risk abs</td>
</tr>
<tr>
<td>packed snow or thick ice</td>
<td>106.1</td>
<td>3.4</td>
</tr>
<tr>
<td>thin ice or white frost</td>
<td>97.7</td>
<td>5.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk VVK2</th>
<th>Without warning</th>
<th>With warning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Speed</td>
<td>Risk abs</td>
</tr>
<tr>
<td>packed snow or thick ice</td>
<td>91.7</td>
<td>2.8</td>
</tr>
<tr>
<td>thin ice or white frost</td>
<td>93.3</td>
<td>3.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk VVK3</th>
<th>Without warning</th>
<th>With warning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Speed</td>
<td>Risk abs</td>
</tr>
<tr>
<td>packed snow or thick ice</td>
<td>78.8</td>
<td>0.74</td>
</tr>
<tr>
<td>thin ice or white frost</td>
<td>86.2</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Risk = accidents per million vehicle-km  
Severity = killed or severely injured persons per accident

5.9.2 Share of traffic in different road conditions

During a whole winter in central Sweden on average around 40 slippery road days occur, corresponding to around 15% for the entire year. With slippery road days we mean days when snow removal or de-icing is necessary. It therefore means that the road surface is loose snow, slush, packed snow, thick ice, thin ice or frost. Divided into the various winter classes taking into account differences in quality of de-icing the following allocation of traffic in different road surface conditions is expected:
Table 5.19 Yearly division of vehicle-kilometres on different road surface conditions

<table>
<thead>
<tr>
<th>Road surface</th>
<th>VVK1</th>
<th>VVK2</th>
<th>VVK3</th>
</tr>
</thead>
<tbody>
<tr>
<td>dry</td>
<td>63,6%</td>
<td>61,7%</td>
<td>56,6%</td>
</tr>
<tr>
<td>damp or wet</td>
<td>23,0%</td>
<td>21,3%</td>
<td>12,0%</td>
</tr>
<tr>
<td>loose snow or slush</td>
<td>11,9%</td>
<td>13,1%</td>
<td>26,3%</td>
</tr>
<tr>
<td>packed snow or thick ice</td>
<td>0,6%</td>
<td>0,8%</td>
<td>1,4%</td>
</tr>
<tr>
<td>thin ice or white frost</td>
<td>1,0%</td>
<td>3,1%</td>
<td>3,8%</td>
</tr>
</tbody>
</table>

The focus effect in Table 5.17 applies to dry, damp or wet road conditions. The focus and activation effect in Table 5.17 apply to loose snow or slush. The adaptation effect is not taken from Table 5.17, instead Table 5.18 is used, which applies only to packed snow, thick or thin ice and white frost.

5.9.3 Safety benefit

The total accident reduction can then be calculated by multiplying the impacts with the yearly share of vehicle-kilometres in different road surface conditions.

The values used (2010 year prices) follow the Swedish Transport Administration's new socio-economic guideline ASEK 5 (Trafikverket, 2012c):

- Killed: 23 739 000 SEK
- Severely injured: 4 412 000 SEK
- Light injured: 217 000 SEK

Table 5.20 Safety impacts for three road types during a year

<table>
<thead>
<tr>
<th>Type road</th>
<th>Accidents number</th>
<th>Injured persons</th>
<th>Accident cost MSEK/year</th>
<th>Benefit MSEK/accident</th>
</tr>
</thead>
<tbody>
<tr>
<td>VVK1</td>
<td>-12,6</td>
<td>-10,3</td>
<td>-22,0</td>
<td>1,7</td>
</tr>
<tr>
<td>VVK2</td>
<td>-11,4</td>
<td>-7,6</td>
<td>-15,6</td>
<td>1,4</td>
</tr>
<tr>
<td>VVK3</td>
<td>-1,5</td>
<td>-1,8</td>
<td>-4,6</td>
<td>3,1</td>
</tr>
</tbody>
</table>

The benefit per accident is higher in the two-lane road in VVK3. This is because more lives are saved and serious injuries are more relieved when the speed is reduced as a result of slip warnings on these roads.

5.9.4 Impact on travel time

Travel time changes have been calculated on the basis of assumed values of Table 5.18 and 5.19. No speed differences are assumed in good conditions. Speed changes have been converted into travel time effects on the basis of calculations that follow STA's economic model (EVA).
Table 5.21  Travel time impacts for three road types during a year

<table>
<thead>
<tr>
<th>Type road</th>
<th>Travel time 1000 veh.-hours</th>
<th>Time costs MSEK/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>VVK1</td>
<td>+16</td>
<td>+3,2</td>
</tr>
<tr>
<td>VVK2</td>
<td>+25</td>
<td>+5,0</td>
</tr>
<tr>
<td>VVK3</td>
<td>+13</td>
<td>+2,6</td>
</tr>
</tbody>
</table>

The time value is assumed to be 202 SEK / vehicle hour at an average truck percentage of 12%.

5.9.5 Secondary effects on the environment
Calculation of exhaust emissions have been estimated by the VETO model developed at VTI and is implemented in STA: s EVA program. Here are only estimates of carbon dioxide carried out based on fuel consumption and average speed. 1-12% extra fuel consumption is assumed in bad weather conditions, based on the ‘Winter model’ (VTI, 2006).

Table 5.22  Change in emissions for three road types during a year

<table>
<thead>
<tr>
<th>Type road</th>
<th>Emissions ton CO₂</th>
<th>Environmental costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>VVK1</td>
<td>-124</td>
<td>-0,1</td>
</tr>
<tr>
<td>VVK2</td>
<td>-183</td>
<td>-0,2</td>
</tr>
<tr>
<td>VVK3</td>
<td>-88</td>
<td>-0,1</td>
</tr>
</tbody>
</table>

The exhaust value is assumed to be 1.08 SEK / kg of carbon dioxide. The effects are relatively small.

5.9.6 Investment and maintenance costs
Based on experience from the VSL-trials the assumed investment in the WCVSL is 0.7 MSEK per km for a motorway, 0.6 MSEK/km for 2+1L expressway and 0.5 MSEK per km for a single carriageway road. Operational costs (service and maintenance) have been assumed to be 7% of investment cost per year.

5.9.7 Socio-economic profitability
The total benefits and costs for VVK1 (i.e. motorway with 30000 f/24h) are shown in Figure 5.10. Road safety benefits are overwhelming. Estimates are based on an amortization of 20 years for equipment, a cost of capital (adjusted for inflation) of 3.5% and a traffic growth of 1.5%.
The results of calculations including VVK2 and VVK3 are shown in Table 5.23 below.

Table 5.23 Total socio-economic benefit for three road types with WCVSL

<table>
<thead>
<tr>
<th>Road type</th>
<th>VVK1</th>
<th>VVK2</th>
<th>VVK3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>+22.0</td>
<td>+15.6</td>
<td>+4.6</td>
</tr>
<tr>
<td>Travel time</td>
<td>-3.2</td>
<td>-5.0</td>
<td>-2.6</td>
</tr>
<tr>
<td>CO2</td>
<td>+0.1</td>
<td>+0.2</td>
<td>+0.1</td>
</tr>
<tr>
<td>Total benefit</td>
<td>19</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>Total (rounded) benefit during 20 years, MSEK</td>
<td>310</td>
<td>177</td>
<td>32</td>
</tr>
<tr>
<td>Basic investment</td>
<td>35</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>Operation (7%, 20 years)</td>
<td>35</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>Total cost during 20 years, MSEK</td>
<td>70</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>Benefit/cost ratio (gross)</td>
<td>4.4</td>
<td>3.0</td>
<td>0.6</td>
</tr>
</tbody>
</table>

The highest Benefit-Cost-ratio (4.4) applies for VVK1 and the lowest (0.6) for VVK3. The profitability can according to European experience be classified as illustrated in Figure 5.11. The classification takes into consideration that Benefits and Costs are based on
many parameters, which all are in turn based on assumptions. There is therefore always a certain uncertainty connected with such calculations.

Figure 5.11  Classification of Benefit-Cost results

<table>
<thead>
<tr>
<th>Benefit / cost-ratio (gross)</th>
<th>&gt;3</th>
<th>1-3</th>
<th>&lt;1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very profitable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Probably profitable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardly profitable</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The resulting conclusion is that WCVSL definitely is profitable on motorways, but hardly profitable on single carriageway roads with average traffic volume.

A sensitivity analysis has also been made in order to adapt to the Swedish guideline for socio-economic analysis of infrastructure investment. This will make the comparison easier between ITS and infrastructure investment. In the sensitivity analysis the calculation period is set to 40 years, a reinvestment is assumed after 20 years and the economic values are increased with 1.75% per year.

Table 5.24  Net benefit/cost-ratio for three road types with WCVSL according to Swedish guidelines (ASEK 5)

<table>
<thead>
<tr>
<th>Road type (Sweden)</th>
<th>VVK1</th>
<th>VVK2</th>
<th>VVK3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net BC-ratio</td>
<td>4.3</td>
<td>2.5</td>
<td>1.0</td>
</tr>
</tbody>
</table>

5.9.8  Discussion

The results show that weather-controlled VSL on a motorway with 30,000 veh/day is socio-economically viable if it can achieve the effects measured for E6 in Halland. The profitability increases with increasing traffic volumes. Particularly, it should be justified with WCVSL on parts of the motorway network with lower standard. The visibility is assumed to be worse (class II) on about 5% of motorways in Sweden. With high traffic volumes, some of these have already been provided with traffic controlled VSL due to heavy traffic or exposure to sudden queues. In these cases, lower costs can be expected for weather control. Control algorithms, sensors and additional warning signs are then all that is required. The most profitable application of weather-controlled VSL should therefore be on managed motorways with poor alignment. We therefore recommend that WCVSL is primarily considered in connection with the establishment of traffic-controlled VSL on motorways.

On 2+1L or single carriageway roads with high traffic volume (around 10,000 veh/day), the profitability is also likely to be sufficient if the system works well and provides good guidance as on the E6 Halland and not perceived by many to be inadequate as on the E22 in Blekinge. This requires that the speed limits shift quickly enough at changing
road conditions, adapted to the road alignment that the road has warning signs indicating the reasons for the speed reduction and enough variable speed signs such that no uncertainty arises.

In the case of the two-lane road, the profitability is generally not sufficient at 4000 veh/day with the assumptions about speed changes from the ‘Winter model’. The profitability may be higher for certain roads with more traffic, where the alignment is poor and where fast deterioration of the grip occurs during icy episodes. The visibility is assumed to be worse (class II or III) on more than 20% of these roads. A profitable implementation of WCVSL requires most likely that the traffic is greater, the proportion of accidents in poor weather conditions is higher than average, and that the speed limit in severe road conditions is exceeded. Careful investigation should be conducted to establish that this is the case.

6 Best practice

The recommendations in this section reflects the view of the authors and not necessarily the view of the Swedish and Finnish authorities.

6.1 Application of WCVSL

6.1.1 Control principles
Weather-controlled VSL has as its objective to motivate users to reduce speed in bad road conditions, enhance response preparedness for abnormal conditions and to create conditions for more homogenised traffic. This can be done through the following overall governing principles:

- Make drivers pay attention to worse weather and road conditions by application of variable speed limits
- Motivate more spontaneous speed reductions by variable road signs (pictograms) in particularly difficult conditions
- Make drivers pay attention to deviations from the general weather situation through the information on VMS and in on-board systems
- Ensure that homogenization, and speed reduction is achieved through regular or automatic control of speed when the system is active

6.1.2 Motorways
On motorways with high traffic volume, WCVSL gives sufficiently large effects to also result in high socio-economic profitability.
The first priority to introduce WCVSL lies on roads with poor alignment, where the worst conditions are often found in a frost hollow. Roads with heavy traffic, with introduced or planned traffic-controlled VSL show the highest profitability. The traffic control and weather control can in this situation share the costs, which results in higher profitability.

Traffic-controlled VSL should according to suggested Swedish Guidelines (Trafikverket, 2011) be applied at about 50,000 veh. / day or more. A side-effect of traffic control systems is that they contribute to calmer traffic, also in off-peak periods when speeds often are too high. Expectations of users are that monitoring is improved by the VSL system, leading to lower vehicle speeds. This impression would be reinforced if speed cameras are used regularly, something which experience show will lead to lower average speed and a higher degree of homogenization. With weather-controlled VSL speed cameras should particularly be used to increase the compliance to speed limits when the VSL system is active.

Compliance with the recommended slowdown of speeds in adverse conditions should also be promoted with information boards. Road users are likely to have knowledge of the average conditions through weather reports, etc. The goal of this information should be to inform the road users about conditions that they cannot be expected to be aware of. 'Patchy very slippery road' and 'Icing at junction X' are examples of informative message that road users will benefit from beyond the general knowledge of the weather situation.

The detection of slippery road conditions should focus on discovering worst occurring conditions, which deviate from the road user expectations. Fixed sensors are preferably located on weather-sensitive stretches of the road. On-board sensors should be used to reveal local abnormal conditions.

The project has shown that detection is not good enough in difficult conditions, unless the distance between the measuring stations is short enough and optical sensors are used. Road users must experience that the speed is 'right' in current conditions at least two times out of three in order to trust the system. The target of 80% hit rate from the Swedish VSL demonstrations can therefore still be recommended. The belief in Finland is that this target level already is achieved with the support of optical sensors.

Measurements in the VSL demonstrations show that it can be difficult to motivate users to reduce the speed by more than 20 km / h in adverse conditions. Larger reductions give deteriorating compliance and greater variation in speeds. We therefore recommend increasing the homogenization by motivating variable warning road signs. Pictograms should be developed for 'very slippery conditions' and other circumstances where larger reductions than 20 km / h are desirable.
Summary of the recommended approach of WCVSL on motorways:

- Weather-controlled VSL are imposed where traffic-controlled VSL already are installed or planned (mostly roads with 50,000 f / day or more).
- WCVSL are considered at lower traffic volume if the alignment is particularly bad (Swedish visibility class II or lower). More sensors can be required to increase the reliability, which the initially very high profitability would tolerate.
- Information is provided by VMS of abnormal conditions.
- The speed is reduced by poor road conditions (black ice, heavy rain, fog), but should be limited to no more than 10% of vehicle-mileage, to reduce the risk that road users are affected by over-exposure, which reduces compliance.
- The speed limit compliance should be checked when the system is active.

6.1.3 Expressways and other 2+1 lane roads

In rare cases when traffic is relatively heavy and the alignment is uniform, VSL can also be justified on expressways and two plus one lane roads.

Calculations show that the cost of the equipment must be low to make the system profitable. This is problematic because the measurements show that the effect differs between the two and one lane sections. It is normally specified, based on the Finnish results that sensors are needed at every 8th km, but at varying alignment, density should increase to at least every 5th km to make the hit rate satisfactory.

The example E22 Blekinge shows that it is difficult to obtain sufficient precision of detection in hilly terrain where road conditions vary. The hit rate becomes low and does not provide the support for road users as desired. Even after the technical problems were resolved, the confidence in the system is relatively low in Blekinge compared to Halland.

Opportunities for better detection may be increased by on-board system (SRIS, μTEC). Thus, deviations in time and distance can be detected. With increased hit rate, the profitability increases of WCVSL, which conveys serious, slip warnings to all motorists. In addition, the skid prevention will be more effective. There will probably also be a focusing effect if the reliability is high enough, which means that the response time in critical situations decreases.

Until further notice, however, the profitability is expected to be greatest on roads with a uniform alignment, where a small number of detectors is sufficient.

Summary of the recommended approach of WCVSL on expressways and 2+1L roads:

- Weather-controlled VSL should be considered where alignment is uniform, the traffic volume significantly above average (more than 10000 f / d), and there is
documented evidence showing that the slippery conditions are common and that the velocity is not adapted to the road conditions.

- The speed limit compliance should be checked when the system is active, in order to make the traffic more homogeneous in practice.
- Tests should be conducted to determine whether the hit rate can be increased and the costs limited by vehicle-mounted detection systems.

### 6.1.4 Two-lane, single carriageway roads

Two-lane roads often do not have enough traffic to make the socio-economic profitability of WCVSL to be well achieved. Opportunities should be sought to reduce the cost of equipment and operation. Measurements show that the traffic is less homogenous at lower speeds. The effect of VSL is therefore deteriorating at common speeds of 80 km / h or less, especially because the compliance of truck traffic in these conditions is extremely poor.

The project shows that the effort should focus on days when the risk of severe slippery road conditions are higher and on stretches that can be more slippery than normal. Information about the increased risk of slipping on certain days can be done by VMS (and the corresponding slip warnings in the navigation system). Information about the increased risk of slipping locally on certain routes may be provided through fixed road signs. This already exists, but its use may need to be revised to be more consistent. In this case, information relating to increased risk of slipping should be limited to a maximum of 10% of days and 10% of road network to avoid overdose of information, which could result in reduced efficiency.

Sensors should at varying alignment be placed at least at every 5 km for the hit ratio to be sufficiently high. This cost can normally not be justified in the CBA for two-lane roads. We therefore recommend that the information to the drivers is based on vehicle-mounted sensor systems, which means lower collection costs.

Within a five year period, it can be expected that sensors will be available on cars and trucks that can be utilized for detection of local slippery road conditions. Already today, however, the Finnish application μTEC can be used on vehicles from the Swedish Transport Administration and the Finnish Transport Agency. We recommend using this application as a means of accelerating the progress.

Summary of the recommended approach of WCVSL on two-lane roads:

- WCVSL is currently not recommended in general on two-lane roads
- The overall VMS system should be further developed to ensure that slip warnings can be given everywhere on the main national road network
- Sensitive stretches of the network should be mapped and fitted with permanent information signs
• The vehicles of the Transport Administration should be equipped with sensors that can provide a basis for slipping alerts
• Test of WCVSL should be carried out on a few links to investigate the speed and safety effects

6.2 User interface

During the large-scale trials with variable speed limits in Sweden 2005-08 the focus was on the speed limits only. Propositions to test VSL in combination with symbols (pictograms) were because of this rejected at the time. The trial resulted however in experienced problems to estimate the friction correctly and thus display a suitable speed limit adapted to the real road surface conditions.

A simpler and also more reliable solution based on this experience may be a user interface concerning speed limits that is supported by pictograms showing the reason behind the reduction of the speed limit. The objective behind showing pictograms in combination with variable speed limits is of course to improve the efficiency of and compliance to the speed control.

The difficulty to exactly define the status of the road surface by sensors is foremost valid for severe and very severe road surface conditions. The optimal vehicle speed in every situation is therefore difficult to predict. A better solution can, based on this experience, be to start with a moderate reduction (20 km/h) which is supplemented in dangerous road surface and weather conditions by warning signs/pictograms that illustrate why the speed limit is reduced. The driver will with this solution be slightly more forced to be active himself and his own ability to pay attention to the road conditions and adapt vehicle speed can be utilized. Speed control will in this way be replaced by speed management.

Traffic safety studies in Finland and also on E6 in Halland show that improved safety not only is attained in slippery road conditions, but also during autumn and spring and even during summertime. Most important seems to be to alert the driver of abnormal weather and road surface conditions. The driver’s focus on the road surface will in this way be reinforced, which has been stated by many drivers in the road user survey.

The Transport Authorities in Sweden and Finland quote three reasons for lowering the variable speed limit:
A) Risk for slippery road conditions (ice or snow in the winter)
B) Strong precipitation (heavy rain, risk for aquaplaning or slipperiness)
C) Reduced visibility (haze/fog)
One of the objectives is to enhance the efficiency of VSL. It would therefore be suitable within the framework of a possible continuation of the Easyway project to test the new user interface, which is illustrated in Figure 6.1.

Figure 6.1  Variable speed limits with additional road sign

Advantages:

- It is easier to understand. The reduced variable speed limit to 80 km/h means that the traffic situation demands extra attention.
- The pictogram indicates the type of problem. The driver must himself adjust the vehicle speed to varying conditions on the link.
- The VSL and pictogram together will probably improve the efficiency as the driver will understand the motive better, and he will himself focus on the road surface conditions and will take more own responsible for the speed adaptation.
- The reduced speed limit means that the reduction of speed, when it occurs, should be taken seriously by the driver. The system should therefore not be over-utilized. Reduced speed should be shown 10-15% of the time at the most. The confidence of the drivers to the system will otherwise fade.
- The accurate speed limit does not need to be calculated, which evidently is very demanding.
- The detection of the road surface conditions on the stretch will be relaxed. The correct friction etc. needs not to be calculated; only that the risk of difficult conditions is sufficiently increased.
- The costs for variable speed limit signs will be reduced as fewer speed limits are used.
Disadvantages:

- Higher costs for pictogram. The costs may possibly be limited by prism signs if the number of causes that triggers a reduction of the speed limit is three or fewer.

6.3 System design

Fixed stations with optical sensors for detection of bad road conditions should be available at least every 8 km on weather-controlled roads. Stations should be closer in varying alignment. The Vaisala DSC 111 optical sensor works best at low friction, when it is most important. Other sensors require more testing before they are operational.

The weather control should be based on automated, exact, fast and reliable monitoring and classification of the conditions. Tests resulting in an alert signal 2-3 hours later from the weather model compared to the surface state sensor is unacceptable. This means that the driver usually already has experienced the slipperiness before he gets the information.

Thermal mapping should be used to find extreme values of friction along the road. Weather stations should be located at points with average conditions, not with extreme conditions.

Vehicle sensors can be used to measure the current friction over distance. Equipment should be mounted on the Transport Authority and contractor vehicles, especially for winter maintenance. The road weather models may be enhanced by the combination of mobile and fixed friction measurements.

The representativeness is much more difficult across the road than along the road. The tracks can be both more (icy) and less (dry) slippery than the rest of the road section. Further research should be conducted to find suitable methods to tackle this problem.

Many road users feel that informing about bad weather often is unnecessary, as the weather can be observed otherwise. Information given by the signs should therefore always be correct and up-to-date so that road users’ confidence in the system is preserved.

Frequent speed checks should be conducted so often that speed limits are respected, especially when establishing the system. Automatic camera systems to handle variable speed limits should be developed. Average speed-over-distance systems (section control) might be suitable for weather controlled VSL.

The performance of the system should be followed-up. There should be focus on the display rate instead of detection rate. The display rate can be defined as the time during
6.4 Organisation

To set a correct speed limit depending on weather/road surface conditions is a challenging task. The two first generations of WCVSL are earlier described (Chapter 3). During the work with these generations, the understanding of the weather/road surface problems has grown significantly within the Swedish Transport Administration. In pace with increased knowledge, we have more and more understood the complexity of the task. To automatically detect the current weather/road surface conditions with sufficient precision and reliability to a reasonable cost is a considerable challenge that demands significant development resources.

The ambition within the Swedish Transport Administration was to work with the development of the third generation of WCVSL. The activity would connect to a greater development project, with the aim to find an efficient and cost-effective concept for WCVSL. We experience now that this development project not has been carried out as foreseen, it has therefore not been possible to reach the objectives that initially were defined. Some development of the current road link on E22 in Blekinge has been made. Algorithms to handle precipitation have i.e. been developed and deployed. But first of all the knowledge of WCVSL has grown significantly. We have today a better understanding of as well technical challenges as the potential traffic safety effect and social benefit that WCVSL contributes to.

The experiences up till now can be summarized as:

- Drivers pay more attention to the road surface condition with VSL
- It is difficult to correctly estimate the friction in severe road surface conditions
- It is unavoidable that the system sometimes show the “wrong” speed
- Road signs/pictograms can motivate drivers better to keep the speed limit and would lead to improved compliance

In the current situation, it is uncertain if the Swedish Transport Administration will initiate any further ventures within WCVSL. The reasons for this are i.e.:

- **Organisational.** The Swedish Road Administration has been merged with the Swedish Rail Administration into the Swedish Transport Administration. Weather-controlled VSL has no obvious client and driving force in the new organisation.

- **Lack of evident demand.** The survey of potential WCVSL links has not revealed any powerful pressure to deploy VSL on further road links.

- **Resources.** The cost of new VSL links will be too high. The weak improvement of traffic safety in Blekinge gives, in spite of big positive results in Halland, not sufficiently strong arguments for further deployment.
Problem-oriented. The discussion has resulted in a reorientation of the problem to sensitive road surface conditions in general (white frost, black ice) especially in the beginning and in the end of the winter season instead of designated links with winter problems. A solution is therefore demanded, that can be used on an extensive road network, not only on a few road links.

Development-oriented. Hopes are tied to the dissemination of slippery road warnings in combination with recommended speeds directly into the car, which can be reached by all drivers with suitable equipment. The big challenge is however to achieve real changes of the vehicle speeds at bad road surface conditions, without this resulting in increased speed difference, which can result in an increase of the number of accidents.

If the development of the third generation of WCVSL is resumed, success factors will be:

- A clear objective in the work to develop detection and modelling techniques. It must be defined which weather/road surface conditions that should be detected and which reliability that is needed to reach a sufficient quality in speed settings. These definitions demand interaction and consensus among expertise in sensor technology and traffic safety.

- Significant development resources and calendar time. The single greatest challenge in the development work is to verify real road surface conditions to be able to compare these to indications from sensors and models. This is resource consuming as it requires personnel to be at hand during long periods. The estimated resources for the development work are 1 to 1.5 mill. Euro during a period of three years.

The future of WCVSL in Blekinge is uncertain. Without any further initiatives, the system will probably be dismantled in connection with the decision to reinvest or not. If the system should be maintained, there is however potential for further improvement and simplifications on the basis of experiences from detection, user behaviour and accident analysis.

The cooperation between Sweden and Finland should continue in order to make accurate and informed decisions. The Swedish Transport Administration and the Finnish Transport Agency should form a working group aiming at a common strategy for management of WCVSL. The co-operation efforts should be included in the agenda of the Nordic Road Association.

The strategy should include:

- Objectives for WCVSL management
- Considerations concerning extended use of WCVSL (road types, traffic volume, climate zone)
- Considerations concerning WCVSL management (speed levels, VMS, instrumentation, models)
• Common research program for extended validation of sensors
• Common research program for extended speed measurements

The Swedish Transport Administration and the Finnish Transport Agency should also form a WCVSL group for information exchange and networking. Efforts should be made to include Norway and Denmark in the cooperation.

A new workshop should be held within 12 months, it might be organised within the Nordic Road Association, the East-West Project or Easyway.
References

Trafikverket (2012c) Samhällsekonomiska principer och kalkylvärden för transportsektorn: ASEK 5.
Appendix 1 - Olycksanalys

Fördjupad trafiksäkerhetsanalys för teststräckorna på E6 i Halland och E22 i Blekinge

Urban Björketun
1 Bakgrund
Trafikverket har gett MOVEA i uppdrag att följa upp "användning av nya sensorer för bättre styrning av variabla väderstyrda föreskrivna hastighetsgränser". I det projektet ingår ett delprojekt "Fördjupad olycksanalys" och där har MOVEA anlitat VTI.

2 Syfte
Syftet med projektet är att primärt att undersöka om systemet med variabla, väderstyrda hastighetsgränser haft någon effekt på trafiksäkerheten. Sekundärt kartläggs vid vilka väglags-, väder- och ljusförhållanden systemet främst påverkat olycksutfallet.

3 Data
Olycksdata
Samtliga tre angivna källor finns som Acces-databaser på VTI, men kommer från Vägverkets/Transportstyrelsens system med polisrapporterade personskadeolyckor i vägtrafiken.
Tabell 1 Antal polisrapporterade personskadeolyckor som inträffat på respektive vägavsnitt.

<table>
<thead>
<tr>
<th>Vägavsnitt</th>
<th>Före</th>
<th>Efter</th>
<th>Efter period 1</th>
<th>Efter period 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>E6, test</td>
<td>164</td>
<td>157</td>
<td>89</td>
<td>68</td>
</tr>
<tr>
<td>E6, kontroll, söder</td>
<td>94</td>
<td>85</td>
<td>51</td>
<td>34</td>
</tr>
<tr>
<td>E6, kontroll, norr</td>
<td>79</td>
<td>119</td>
<td>66</td>
<td>53</td>
</tr>
<tr>
<td>E22, test</td>
<td>9</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E22, kontroll</td>
<td>14</td>
<td>24</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Vägdata


I tabell 2 redovisas de aktuella avsnitten i vägnätet 2011. Ändring av hastighetsgräns på E6 har för kontrolldelen skett under efterperioden vilket gör att delarna med 110 respektive 120 km/h måste särskiljas i analysen.

Tabell 2 Vägavsnitt behandlade i olycksanalysen. Data från NVDB 2011-06-30. Samtliga avsnitt hade hastighetsgräns 110 km/h under föreperioden. Längder i km

<table>
<thead>
<tr>
<th>Vägavsnitt</th>
<th>HG efter</th>
<th>Längd alla vägposter</th>
<th>Väglängd</th>
</tr>
</thead>
<tbody>
<tr>
<td>E6, test</td>
<td>120</td>
<td>113,5</td>
<td>56,7</td>
</tr>
<tr>
<td>E6, kontroll, söder</td>
<td>120</td>
<td>75,9</td>
<td>38,1</td>
</tr>
<tr>
<td>E6, kontroll, norr</td>
<td>110</td>
<td>76,2</td>
<td>38,0</td>
</tr>
<tr>
<td>E22, test</td>
<td>100</td>
<td>32,4</td>
<td>16,2</td>
</tr>
<tr>
<td>E22, kontroll</td>
<td>100</td>
<td>30,4</td>
<td>15,2</td>
</tr>
</tbody>
</table>

Vid beräkning av Väglängd i tabellen ovan har grenar exkluderats och syskonlänkars längd halverats, detta för att ge de väglängder som normalt används för att ange avstånd.

I tabell 3 redovisas ändpunkterna för alla studerade vägavsnitt. Figur 1 och Figur 2 visar samma avsnitt i dumpar från GIS.

Tabell 3 Ändpunkter för de aktuella avsnitten på E6 och E22. ÅDT avser trafikflödet i en riktning.

<table>
<thead>
<tr>
<th>E6 Halland</th>
<th>Trafikplats</th>
<th>ÅDT axelpar 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teststräcka, startpunkt</td>
<td>Tpl 40 Skottorp</td>
<td>12 800</td>
</tr>
<tr>
<td>Teststräcka, slutpunkt</td>
<td>Tpl 49 Heberg</td>
<td></td>
</tr>
<tr>
<td>Kontrollsträcka, startpunkt</td>
<td>Tpl 49 Heberg</td>
<td>11 800 södra delen</td>
</tr>
<tr>
<td>Kontrollsträcka, slutpunkt</td>
<td>Tpl 59 Kungsbacka S</td>
<td>13 800 norra delen</td>
</tr>
<tr>
<td>E6 Blekinge</td>
<td>Trafikplats</td>
<td></td>
</tr>
<tr>
<td>Teststräcka, startpunkt</td>
<td>Tpl 54 Åryd</td>
<td>4 800</td>
</tr>
<tr>
<td>Teststräcka, slutpunkt</td>
<td>Tpl 56 Ronneby V</td>
<td></td>
</tr>
<tr>
<td>Kontrollsträcka, startpunkt</td>
<td>Tpl 50 Mörrum Ö</td>
<td>5 500</td>
</tr>
<tr>
<td>Kontrollsträcka, slutpunkt</td>
<td>Tpl 54 Åryd</td>
<td></td>
</tr>
</tbody>
</table>
Vägavsnitten sträcker sig mellan + tecknen.

Figur 1 E6 i Halland, teststräckan i söder och kontrollsträckan i norr. Rött för 120 km/h, grönt för 110 km/h, hastighetsgränser efter 15 september 2008.

Figur 2 E22 i Blekinge, kontrollsträckan i väster och teststräckan i öster, båda med 100 km/h efter 15 september 2008.
4 Metod

Förändringen i antal personskadeolyckor från före- till efterperioden på de två teststräckorna jämförs med motsvarande förändringar på respektive kontrollsträckor. Eftersom test- och kontrollsträcka ligger i direkt anslutning till varandra antas att väderförhållanden varit likartade. Dessutom kan insatser för halkbekämpning antas ha varit desamma för sträckorna i respektive par.

Olycksutvecklingen analyseras i en fyrfältstabell där ett Chi-2-test används för att avgöra om nollhypotesen om lika utveckling för test- och kontrollsträckan kan förkastas eller ej.

<table>
<thead>
<tr>
<th></th>
<th>Test</th>
<th>Kontroll</th>
<th>Summa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Före</td>
<td>a</td>
<td>c</td>
<td>(a+c)</td>
</tr>
<tr>
<td>Efter</td>
<td>b</td>
<td>d</td>
<td>(b+d)</td>
</tr>
<tr>
<td>Summa</td>
<td>(a+b)</td>
<td>(c+d)</td>
<td>a+b+c+d=N</td>
</tr>
</tbody>
</table>


Alla aktuella vägavsnitt är europavägar. För beräkning av olyckskvoter krävs uppskattning av trafikarbetet TA på de olika sträckorna. I NVDB finns uppgift om ÅDT i axelpar och mätar för ÅDT. Därigenom är det möjligt att med Trafikverkets schabloner för förändringar på europavägar räkna ut exponeringen för varje kalenderår som studeras. Eftersom schablonvärdet är detsamma för test- och kontrollsträckor får förändringskvoterna för olyckor och olyckskvot samma värden.

Med beteckningarna $O$ för olyckor, $TA$ för exponering, $t$ för teststräcka, $k$ för kontrollsträcka, $f$ för föreperiod och $e$ för efterperiod erhålls

$k$ kvot för olyckor: $\frac{O_{te}}{O_{fk}}$ och kvot för olyckskvoter: $\frac{k_{TA}}{t} \cdot \frac{k_{TA}}{k}$

Efter förkortning är uttrycken för olyckor respektive olyckskvot identiska. Jämförelserna mellan test och kontroll har därför begränsats till antal personskadeolyckor och nollhypotesen är att olycksutvecklingen varit densamma på test- och kontrollsträckan.
5 Resultat


Redovisade Chi-2-tester är med något undantag de som ger statistiskt signifikanter resultat på 95-procentsnivån (Chi-2 = 3,84).

Totalt


Tabell 4  E22 helår respektive vinter och ej vinter

<table>
<thead>
<tr>
<th>Urval</th>
<th>Lägst</th>
<th>Efter/före</th>
<th>Kontroll</th>
<th>T/K</th>
<th>Chi-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Totalt</td>
<td>K</td>
<td>2.67</td>
<td>1.71</td>
<td>1.56</td>
<td>0.74</td>
</tr>
<tr>
<td>Vinter</td>
<td>K</td>
<td>11.00</td>
<td>1.75</td>
<td>6.29</td>
<td>4.55</td>
</tr>
<tr>
<td>Ej vinter</td>
<td>T</td>
<td>1.63</td>
<td>1.70</td>
<td>0.96</td>
<td>0.01</td>
</tr>
</tbody>
</table>

På E6 har olycksutvecklingen för hela efterperioden varit klart bättre på teststräckan när jämförelse görs mot kontrolsträckans norra del som haft hastighetsgränsen 110 km/h under både före- och efterperioden. Även vid jämförelse mot hela kontrolsträckan men begränsat till efterperiod 1 erhålls en olycksminskning på teststräckan. Dock kan nollhypotesen inte förkastas.

Tabell 5  E6 helår olika kontrolsträckor

<table>
<thead>
<tr>
<th>Urval</th>
<th>Lägst</th>
<th>Efter/före</th>
<th>Kontroll</th>
<th>T/K</th>
<th>Chi-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Totalt, K norr, efterperiod 1+2</td>
<td>T</td>
<td>0,96</td>
<td>1,51</td>
<td>0,64</td>
<td>6,16</td>
</tr>
<tr>
<td>Totalt, K hela, efterperiod 1</td>
<td>T</td>
<td>0,54</td>
<td>0,68</td>
<td>0,80</td>
<td>1,53</td>
</tr>
</tbody>
</table>
Vinter respektive ej vinter

Uppdelning på vinter/ej vinter visar att det är under ej vinter som den relativa olycksminskningen på teststräckorna erhålls. Det gäller för båda de kontrollmaterial som används.

Tabell 6  E6, kontroll norr, hela efterperioden (e1+e2)

<table>
<thead>
<tr>
<th>Urval</th>
<th>Lägst</th>
<th>Efter/före</th>
<th>Normerat</th>
<th>H0=lika utveckling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vinter</td>
<td>T</td>
<td>1,00</td>
<td>1,12</td>
<td>0,89, 0,11</td>
</tr>
<tr>
<td>Ej vinter</td>
<td>T</td>
<td>0,94</td>
<td>1,69</td>
<td>0,56, 7,23</td>
</tr>
</tbody>
</table>

Tabell 7  E6, hela kontrollsträckan, efterperiod 1 (e1)

<table>
<thead>
<tr>
<th>Urval</th>
<th>Lägst</th>
<th>Efter/före</th>
<th>Normerat</th>
<th>H0=lika utveckling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vinter</td>
<td>K</td>
<td>0,58</td>
<td>0,49</td>
<td>1,18, 0,24</td>
</tr>
<tr>
<td>Ej vinter</td>
<td>T</td>
<td>0,53</td>
<td>0,76</td>
<td>0,69, 2,95</td>
</tr>
</tbody>
</table>

Olycksrapporternas uppgifter om väglag, väderlek och ljusförhållanden används för att närmare jämföra utvecklingen på test- respektive kontrollsträckorna. Det är ju i några av dessa situationer som en sänkt hastighetsgräns kan förmodas ha varit gällande.

Väglag

<table>
<thead>
<tr>
<th>Väglag</th>
<th>Väderlek</th>
<th>Ljusförhållanden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vägbanan torr</td>
<td>Uppehållsväder</td>
<td>Dagsljus</td>
</tr>
<tr>
<td>Vägbanan våt/fuktig</td>
<td>Dis/dimma</td>
<td>Mörker</td>
</tr>
<tr>
<td>Tjock is / packad snö</td>
<td>Regn</td>
<td>Gryning/skymning</td>
</tr>
<tr>
<td>Tunn is, vägbanan synlig</td>
<td>Snöblandat regn</td>
<td>Okänt</td>
</tr>
<tr>
<td>Lös snö / snömodd</td>
<td>Snöfall</td>
<td></td>
</tr>
<tr>
<td>Okänt</td>
<td>Okänt</td>
<td></td>
</tr>
</tbody>
</table>

I de följande avsnitten redovisas de situationer beträffande väglag, väder respektive ljusförhållanden då olycksutvecklingen varit olika på test- och kontrollsträckorna och då nollhypotesen kan förkastas. Samtliga olycksdata finns i bilagorna 1 (E6) och 2 (E22).

Väglag

E22

Endast vid väglagsförhållandet ”vägbanan våt fuktig” på vintern har olycksutvecklingen varit sådan att hypotesen om lika förändring på test- och kontrollsträckorna kan förkastas (Chi-2 7,62) och då är det på kontrollsträckan som olycksminskningen har inträffat. Dock baseras detta på få olyckor – 0 före och 5 efter på teststräckan och 3 före och 2 efter på kontrollsträckan.
E6
Med vägbanan torr under ej vinter uppvisar teststräckan en jämfört med kontrollsträckan positiv olycksutveckling, det gäller båda kontrollvarianterna. För vinterperioden med väglag tunn is, vägbanan synlig är den relativa olycksutvecklingen till teststräckans fördel jämfört med norra kontrollsträckan, dock utan att nollhypotesen kan förkastas.

Tabell 8 E6, vägbanan torr, ej vinter

<table>
<thead>
<tr>
<th>Urval</th>
<th>Lägst</th>
<th>Efter/före</th>
<th>Normerat</th>
<th>H0=lika utveckling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kontroll norr, hela efterperioden (e1+e2)</td>
<td>T</td>
<td>0,78</td>
<td>2,09</td>
<td>0,37</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10,65 ja, test bättre</td>
</tr>
<tr>
<td>Hela kontroll, efterperiod 1 (e1)</td>
<td>T</td>
<td>0,46</td>
<td>0,82</td>
<td>0,56</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4,61 ja, test bättre</td>
</tr>
</tbody>
</table>

Tabell 9 E6, tunn is, vägbanan synlig, vinter

<table>
<thead>
<tr>
<th>Urval</th>
<th>Lägst</th>
<th>Efter/före</th>
<th>Normerat</th>
<th>H0=lika utveckling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kontroll norr, hela efterperioden (e1+e2)</td>
<td>T</td>
<td>0,54</td>
<td>1,75</td>
<td>0,31</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3,65 nej</td>
</tr>
</tbody>
</table>

Väderlek

E22
Inget av olycksrapporternas väderleksförhållanden ger anledning att förkasta nollhypotesen.

E6
Endast för en vädersituation – uppehållsväder, ej vinter och norra kontrollsträckan – kan nollhypotesen förkastas och då är det teststräckan som haft den relativt sett bästa olycksutvecklingen.
Tabell 10  E6, uppehållsväder, ej vinter

<table>
<thead>
<tr>
<th>Urval</th>
<th>Lägst</th>
<th>Efter/före</th>
<th>Normerat</th>
<th>H0=lika utveckling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kontroll norr, hela efterperioden (e1+e2)</td>
<td>T</td>
<td>0,83</td>
<td>1,67</td>
<td>6,55 ja, test bättre</td>
</tr>
</tbody>
</table>

**Ljusförhållanden**

**E22**

Inte vid något av olycksrapporternas ljusförhållanden ger anledning att förkasta nollhypotesen.

**E6**

Endast i ett fall kan nollhypotesen förkastas. Det är vid *dagsljus* och då under *ej vintertid* som teststräcka jämfört med kontrollsträckans norra del har den mest gynnsamma olycksutvecklingen.

Tabell 11  E6, dagsljus, ej vinter

<table>
<thead>
<tr>
<th>Urval</th>
<th>Lägst</th>
<th>Efter/före</th>
<th>Normerat</th>
<th>H0=lika utveckling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kontroll norr, hela efterperioden (e1+e2)</td>
<td>T</td>
<td>1,00</td>
<td>1,97</td>
<td>6,65 ja, test bättre</td>
</tr>
</tbody>
</table>

**Diskussion och slutsatser**

Olyckorna som inträffat på teststräckorna under efterperioden och där hastighetsgränsen enligt STRADA varit lägre än 100 km/h på E22 eller lägre än 120 km/h på E6 har identifierats. På E22 är det en enda olycka vid dagsljus, snöfall och lösnö/snömodd. Enligt olycksbeskrivningen ”råde mycket besvärligt väglag p g a snöfall”. Hastighetsgränsen var 60 km/h.

På E6 ger selektionen 44 olyckor med följande STRADA-information.

<table>
<thead>
<tr>
<th>Väglag</th>
<th>Antal</th>
<th>Väderlek</th>
<th>Antal</th>
<th>Ljusförhållanden</th>
<th>Antal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lösnö / snömodd</td>
<td>5</td>
<td>Dis/dimma</td>
<td>2</td>
<td>Dagsljus</td>
<td>29</td>
</tr>
<tr>
<td>Okänt</td>
<td>1</td>
<td>Okänt</td>
<td>1</td>
<td>Gryning/skymning</td>
<td>4</td>
</tr>
<tr>
<td>Tjock is / packad snö</td>
<td>2</td>
<td>Regn</td>
<td>15</td>
<td>Mörker</td>
<td>11</td>
</tr>
<tr>
<td>Tunn is, vägbanan synlig</td>
<td>7</td>
<td>Snöblandat regn</td>
<td>15</td>
<td>Mörker</td>
<td>11</td>
</tr>
<tr>
<td>Vägbanan torr</td>
<td>10</td>
<td>Snöfall</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vägbanan våt/fuktig</td>
<td>19</td>
<td>Uppehållsväder</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summa</td>
<td>44</td>
<td>Summa</td>
<td>44</td>
<td>Summa</td>
<td>44</td>
</tr>
</tbody>
</table>
Endast i en av de 45 olyckorna (inklusive den på E22) står det nämnt i olycksbeskrivningen att hastighetsgränsen varit sänkt. Det gäller en olycka på E6 2006-07-31 då hastighetsgränsen var 110 km/h (dagsljus och regn, ”Fick vattenplaning efter kraftigt regnväder och körde av vägen. Vid olyckstillfället var hastigheten sänkt från 120 km/h till 110 km/h.”).

## Bilaga 1 Olycksdata E6

### Totalt

<table>
<thead>
<tr>
<th>Test</th>
<th>före</th>
<th>efter</th>
<th>Kontroll-norra</th>
<th>före</th>
<th>efter</th>
<th>Kontroll-södra</th>
<th>före</th>
<th>efter</th>
<th>Kontroll-norra</th>
<th>före</th>
<th>efter</th>
<th>Kontroll-södra</th>
<th>före</th>
<th>efter</th>
<th>Kontroll-södra</th>
<th>före</th>
<th>efter</th>
<th>Kontroll-södra</th>
<th>före</th>
<th>efter</th>
<th>Kontroll-södra</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P-ol</td>
<td>D</td>
<td>SS</td>
<td>LS</td>
<td>AF</td>
<td>P-ol</td>
<td>D</td>
<td>SS</td>
<td>LS</td>
<td>AF</td>
<td>P-ol</td>
<td>D</td>
<td>SS</td>
<td>LS</td>
<td>AF</td>
<td>P-ol</td>
<td>D</td>
<td>SS</td>
<td>LS</td>
<td>AF</td>
<td>P-ol</td>
</tr>
<tr>
<td>Totalt</td>
<td>164</td>
<td>8</td>
<td>34</td>
<td>245</td>
<td>0,256</td>
<td>89</td>
<td>3</td>
<td>12</td>
<td>142</td>
<td>0,169</td>
<td>68</td>
<td>1</td>
<td>13</td>
<td>82</td>
<td>0,206</td>
<td>79</td>
<td>5</td>
<td>16</td>
<td>110</td>
<td>0,266</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Väg</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vägbanan torr</td>
<td>115</td>
<td>4</td>
<td>38</td>
<td>152</td>
<td>0,319</td>
<td>57</td>
<td>2</td>
<td>11</td>
<td>112</td>
<td>0,201</td>
<td>40</td>
<td>2</td>
<td>9</td>
<td>42</td>
<td>0,216</td>
<td>40</td>
<td>2</td>
<td>9</td>
<td>42</td>
<td>0,216</td>
<td>29</td>
</tr>
<tr>
<td>Vägbanan våt/fuktig</td>
<td>109</td>
<td>3</td>
<td>27</td>
<td>117</td>
<td>0,293</td>
<td>52</td>
<td>2</td>
<td>11</td>
<td>110</td>
<td>0,201</td>
<td>29</td>
<td>1</td>
<td>6</td>
<td>23</td>
<td>0,300</td>
<td>18</td>
<td>1</td>
<td>4</td>
<td>11</td>
<td>0,367</td>
<td>11</td>
</tr>
<tr>
<td>Tjock is / packad snö</td>
<td>104</td>
<td>3</td>
<td>27</td>
<td>117</td>
<td>0,293</td>
<td>52</td>
<td>2</td>
<td>11</td>
<td>110</td>
<td>0,201</td>
<td>29</td>
<td>1</td>
<td>6</td>
<td>23</td>
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P-ol: antal personskadeolyckor, D: antal dödade personer, SS: antal svårt skadade personer, LS: antal lindrigt skadade personer, AF: (D+SS)/P-ol

---

**Test**
- **före**: 2000-07-01 - 2005-06-30
- **efter 1**: 2005-07-01 - 2008-09-15
- **efter 2**: 2008-09-16 - 2011-06-30

---

**Typer**
- **Norr-a**: 1
- **Söder-a**: 2

---

**Tidsperiod**
- **1993-01-01 - 2001-06-30**
- **2002-01-01 - 2011-06-30**

---

**Resultat**
- **Totalt**
  - **P-ol**: 164
  - **D**: 8
  - **SS**: 34
  - **LS**: 245
  - **AF**: 0,256
| Test | före | efter | P-ol | D | SS | AF | P-ol | D | SS | AF | P-ol | D | SS | AF | P-ol | D | SS | AF | P-ol | D | SS | AF | P-ol | D | SS | AF | P-ol | D | SS | AF | P-ol | D | SS | AF |
|------|------|-------|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|----|------|---|---|--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P-ol: antal personskadeolyckor, D: antal dödade personer, SS: antal svårt skadade personer, LS: antal lindrigt skadade personer, AF: (D+SS)/P-ol
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| Väglag | | | | |
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| Vägbanan våt/fuktig | 2 | 1 | 0 | 0 |
| Tjock is / packad snö | 0 | 0 | 0 | 0 |
| Tunn is, vägbanan synlig | 1 | 0 | 0 | 0 |
| Lös snö / snömodd | 0 | 0 | 0 | 0 |
| Okänt1 | 0 | 0 | 0 | 0 |
| 9 | 1 | 1 | 13 |

| Väder | | | | |
|--------| | | | |
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| Ds/dimma | 1 | 0 | 0 | 0 |
| Regn | 0 | 0 | 0 | 0 |
| Snöblandat regn | 0 | 0 | 0 | 0 |
| Snöfall | 0 | 0 | 0 | 0 |
| Okänt2 | 0 | 0 | 0 | 0 |
| 9 | 1 | 1 | 13 |

| Luzförhållanden | | | | |
|-----------------| | | | |
| Dagsljus | 5 | 1 | 8 | 0,083 |
| Mörker | 3 | 0 | 0 | 0 |
| Gryning/skymning | 1 | 0 | 0 | 0 |
| Okänt3 | 0 | 0 | 0 | 0 |
| 9 | 1 | 1 | 13 |

| före | 2000-07-01 - 2005-06-30 |
|after| 2005-07-01 - 2011-06-30|

P-ol: antal personskadeolyckor, D: antal dödade personer, SS: antal svårt skadade personer, LS: antal lindrigt skadade personer, AF: (D+SS)/P-ol
### Olycksdata E22
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P-ol: antal personskadeolyckor, D: antal dödade personer, SS: antal svårt skadade personer, LS: antal lindrigt skadade personer, AF: (D+SS)/P-ol
Olycksdata E22

Ej vinter

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P-ol: antal personskadeolyckor, D: antal dödade personer, SS: antal svårt skadade personer, LS: antal lindrigt skadade personer, AF: (D+SS)/P-ol
Bilaga 3  VVFS 2008:212

Vägverkets författningsamling
VVFS 2008:212

Vägverkets föreskrifter
om hastighetsbegränsning på väg E6 i Hallands län;

beslutade den 22 augusti 2008.


1 § I stället för hastighetsbegränsning enligt 9 kap. 1 § första stycket 6 trafikförordningen (1998:1276) ska den högsta tillåtna hastigheten på väg E6 i Hallands län vara 120 kilometer i timmen på nedan angivna vägsträckor.

Vägdelen för trafik i sydlig färdriktning
Vägsträcka
mellan och km/tim

<table>
<thead>
<tr>
<th></th>
<th>km/tim</th>
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</thead>
<tbody>
<tr>
<td>100 meter norr om korsningen med väg 659 i trafikplats nummer 48, enligt Vägverkets föreskrifter (VVFS 2005:42) med förteckning över trafikplatsnummer</td>
<td>120</td>
</tr>
<tr>
<td>4 500 meter norr väg 41 trafikplats nummer 55, enligt Vägverkets föreskrifter (VVFS 2005:42) med förteckning över trafikplatsnummer</td>
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Vägdelen för trafik i nordlig färdriktning
Vägsträcka
mellan och km/tim

Utkom från trycket den 29 augusti 2008
18

4 200 meter norr väg 659
4 200 meter söder väg 120
i trafikplats nummer 41 i trafikplats nummer
48, enligt Vägverkets föreskrifter (VVFS 2005:42) med förteckning över trafikplatsnummer
55, enligt Vägverkets föreskrifter (VVFS 2005:42) med förteckning över trafikplatsnummer


Samtliga på- och avfartsvägar till och från väg E6 i trafikplats nummer 49 – 54, enligt Vägverkets föreskrifter (VVFS 2005:42) med förteckning över trafikplatsnummer, och trafikplats Himle.

Östra avfartsvägen från väg E6 till väg 41 i trafikplats nummer 55, enligt Vägverkets föreskrifter (VVFS 2005:42) med förteckning över trafikplatsnummer.

Västra påfartsvägen till väg E6 från väg 41 i trafikplats nummer 55, enligt Vägverkets föreskrifter (VVFS 2005:42) med förteckning över trafikplatsnummer.

________
Dessa föreskrifter träder i kraft den 15 september 2008.

INGEMAR SKOGÖ

Åsa Anderzén
<table>
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<tr>
<th>Vägsträcka i kilometer</th>
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<td>100 meter öster väg</td>
<td>väg 669 Björköpstorp</td>
<td>väg 678 trafikplats Närträby</td>
<td>90</td>
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</tbody>
</table>

ISBN 91-85-2135
Vägsträcka

mellan och km/lkm

väg 736/745 cirklutionsplats Lösten 100 meter väster väg 100 E22,08 Karlskrona Öst
väg 736/745 cirklutionsplats Lösten Kalmar län 90

2 § Hastighetsbegränsningen till 100 km/h samt om enligt 1 §.o. enbart inom påkostade sträckor
- från väg 621 från 120 meter norr om väg 621 till väg E22,
- från väg 641 från 120 meter väster om väg 641 till väg E22,
- för trafik i västlig riktning från respektive väg av dock från väg E22 till väg E22,
- för trafik i östlig riktning från respektive väg av dock från väg E22 till väg E22.

Dessa förordningar träder i kraft den 15 september 2008, då Vägverket (Förordning (VVES 2004:51) om hastighetsbegränsning på väg E22 i Blekinge län)ska upphöra att gälla.

INGEMAR SKOGÖ

Åsa Andersén
Appendix 2 - Användarstudie

Attityder till väderstyrd variabel hastighet på E22 i Blekinge

- Jämförelse av användarundersökningar genomförda 2005 och 2012
1 Deltagarnas erfarenhet av vägen


Figur 1  Hur ofta man kör den aktuella sträckan

2 Möjligheten att se VH-skyltarna

Figur 2 VH skyltarnas synbarhet

3 Skyltarnas driftsäkerhet


Figur 3 Har VH-skyltarna varit ur funktion?
4 Vilken hastighet gäller


![Diagram](image_url)

Figur 4 Hur ofta man är osäker om vilken hastighetsgräns som gäller?

5 Vad innebär de variabla hastighetsgränserna?

6 Hur upplevs sträckan med VH?

I figuren nedan redosivas hur de tillfrågade bedömt vägsträckans karakteristik genom att markera svar på en femgradig skala med två motpoler. De som har neutral uppfattning har markerat mitt i skalan dvs 3,0.

7 Hastighetsgränsens överensstämmelse med väder och väglag


Fördelningen av de olika åsikterna om variabel hastighetsgräns på sträckan är förvånansvärt lika mellan de båda mättaillfällena. Vid båda tillfällena anser två tredjedelar att VH är mycket bra eller bra!

Figur 7 Åsikt om hastighetsgräns stämmer med variationen av väder och väglagsförhållanden

8 Åsikt om variabel hastighetsgräns på sträckan

Fördelningen av de olika åsikterna om variabel hastighetsgräns på sträckan är förvånansvärt lika mellan de båda mättaillfällena. Vid båda tillfällena anser två tredjedelar att VH är mycket bra eller bra!
8

Figur 8 Åsikt om variabel hastighetsgräns på sträckan

Av de som lämnat kommentarer menar den största andelen (vid båda mätningarna) att man blir mer uppmärksam av VH eller att VH ger en bra påminnelse om att ta det försiktigt pga väglaget.

9 Ändrat körbeteende

En något större andel av bilisterna i 2012 års undersökning anser att de ändrat sitt körbeteende vad gäller såväl uppmärksamhet som agerande än de som svarade 2005. En möjlig delförklaring skulle kunna vara att trafikanterna med tiden lärt känna VH och då bättre kunna anpassa sitt körsätt till förhållandena.

Figur 9 Ändrat körbeteende efter införande av VH

10 Överskridande av hastighetsgräns

Svaren på frågan om hur ofta man överskrider hastighetsgränsen på VH-sträckan är inte jämförbara mellan de båda undersökningarna. 2005 avsåg frågan hastighetsgränsen
generellt på sträckan. 2012 var frågan uppdelad på tillfällen då VH var släckt och fast skyltad hastighetsgräns gällde respektive tillfällen då VH-skyltad hastighetsgräns gällde.

Figur 10 Hur ofta överskrids hastighetsgränsen?


Figur 11 Anledningar till att hastighetsgränsen överskrids

Fördelningen av varför man överskriver hastighetsgränsen är likartad mellan de båda undersökningarna för fem av åtta anledningar. Störst skillnad finns avseende "Orealistiskt låg hastighetsgräns".
listisk låg hastighetsgräns” och att man “Har kontroll ändå) som förhållandevis fler framhåller i 2012 års undersökning (nästan hälften av deltagarna). Detta antyder att förarna har lärt sig använda VH-budskapen. Man blir mer aktiv när skyltarna tänds

11 Respekt för hastighetsgräns med VH


![Respekt för hastighetsgräns med VH](image)

**Figur 12** Respekt för visad hastighetsgräns. Cirka 38% anser att respektien inte påverkas.

![Respekt för hastighetsgräns med VH](image)

**Figur 13** Hur håller bilisterna hastighetsgränsen där det finns VH jämfört med på vägar som saknar variabel hastighetsvisning?
12 Högre uppmärksamhet

Figur 14 Tillvägagångssätt för att påkalla uppmärksamhet (de som svarat Ja, något och Ja, mycket).

Föreskriften om varierande högsta tillåtna hastighet

- E22 i Blekinge län och E6 i Hallands län
Vägverkets föreskrifter om varierande högsta tillåten hastighet på väg E6 i Hallands län;

beslutade den 24 november 2008.

Vägverket föreskriver följande med stöd av 3 § förordningen (2002:713) om försöksverksamhet med varierande högsta tillåtna hastighet.

1 kap. Inledning

1 § På de sträckor av väg E6 med tillhörande på- och avfartsvägar i Falkenbergs kommun, Halmstads kommun respektive Laholms kommun som anges i 2 § och som framgår av bilagan till föreskrifterna får bedrivas försöksverksamhet enligt förordningen (2002:713) om försöksverksamhet med varierande högsta tillåtna hastighet.

2 § I dessa föreskrifter betecknas trafikplatser med de nummer som anges i Vägverkets föreskrifter (VVFS 2005:42) med förteckning över trafikplatser. Beteckningar på vägsträckor längs väg E6 och längs på- och avfartsvägar till den används i den betydelse som anges nedan.

Nordlig huvudriktning

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<th>Sträcka</th>
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<tbody>
<tr>
<td>N1</td>
<td>mellan 150 meter söder om länsväg 516 och 150 meter norr om länsväg 516 i trafikplats 40,</td>
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<td>N2 – N4</td>
<td>sammanlagd utsträckning av delsträckorna N2 – N4</td>
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Delsträcka Utsträckning

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<tr>
<td>N3</td>
<td>mellan 380 meter norr om riksväg 24 i trafikplats 41 och enskild väg N 799 vid vägport vid Gullbranna,</td>
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</table>
N4 mellan enskild väg N 799 vid vägport vid Gullbranna och 750 meter norr om väg E6.04 i trafikplats 43,

N5 mellan 750 meter norr om väg E6.04 i trafikplats 43 och 30 meter norr om väg E6.06 i trafikplats 45,

N6 – N9 sammanlagd utsträckning av delsträckorna N6 – N9

Sträcka Utsträckning
N6 mellan 30 meter norr om väg E6.06 i trafikplats 45 och 420 meter väster om länsväg 601 i trafikplats 46,

N7 mellan 420 meter väster om länsväg 601 i trafikplats 46 och 30 meter öster om länsväg 625 i trafikplats 47,

N8 mellan 30 meter öster om länsväg 625 i trafikplats 47 och 270 meter väster om länsväg 659 i trafikplats 48 och

N9 mellan 270 meter väster om länsväg 659 i trafikplats 48 och 4200 meter norr om länsväg 659 i trafikplats 48

På- och avfartsväg

Sträcka Utsträckning
N1pö mellan länsväg 516 och väg E6 i trafikplats 40,

N2aö mellan väg E6 och riksväg 24 i trafikplats 41,

N2pö mellan riksväg 24 och väg E6 i trafikplats 41,

N3aö mellan väg E6 och 200 meter söder om väg 540.02 i rastplats Snapparp,

N3pö mellan 200 meter norr om väg 540.02 och väg E6 i rastplats Snapparp,

N4aö mellan väg E6 och väg E6.04/länsväg 117 i trafikplats 43,

N4pö mellan 80 meter norr om Hagelvägen ovh väg E6 i trafikplats 43,

N5aö1 mellan väg E6 och väg E6.05/riksväg 25 i trafikplats 44,

N5pö1 mellan väg E6.05/riksväg 25 och väg E6 i trafikplats 44,

N5aö2 mellan väg E6 och väg E6.06/riksväg 26 i trafikplats 45,

N5pö2 mellan väg E6.06/riksväg 26 och väg E6 i trafikplats 45

N6an mellan väg E6 och länsväg 601 i trafikplats 46,
N6pn mellan länsväg 601 och väg E6 i trafikplats 46,
N7an mellan väg E6 och länsväg 625 i trafikplats 47,
N7pn mellan länsväg 625 och väg E6 i trafikplats 47,
N8aö mellan väg E6 och 60 meter söder om södra anslutningsvägen i rastplats Susedalen,
N8pö mellan 20 meter norr om norra anslutningsvägen i rastplats Susedalen och väg E6,
N8an mellan väg E6 och länsväg 659 i trafikplats 48,
N8pn mellan länsväg 659 och väg E6 i trafikplats 48 och
N9an mellan väg E6 och 135 meter nordväst om väg E6 i trafikkontrollplats Heberg

Sydlig huvudriktning

Sträcka      Utsträckning
S1            mellan 4500 meter norr om länsväg 659 i trafikplats 48 och 4200 meter norr länsväg 659 i trafikplats 48,
S2-S5         sammanlagd utsträckning av sträckorna S2 – S5.

Delsträcka   Utsträckning
S2            mellan 4200 meter norr om länsväg 659 i trafikplats 48 och 30 meter väster om länsväg 659 i trafikplats 48,
S3            mellan 30 meter väster om länsväg 659 i trafikplats 48 och 400 meter öster om länsväg 625 i trafikplats 47,
S4            mellan 400 meter öster om länsväg 625 i trafikplats 47 och 620 meter öster om länsväg 601 i trafikplats 46,
S5            mellan 620 meter öster om länsväg 601 i trafikplats 46 och 70 meter söder om väg E6.06 i trafikplats 45,

Sträcka      Utsträckning
S6            mellan 70 meter söder om väg E6.06 i trafikplats 45 och 460 meter söder om väg E6.04 i trafikplats 43,
S7 – S9       sammanlagd utsträckning av delsträckorna S7 – S9.

Delsträcka   Utsträckning
S7            mellan 460 meter söder om väg E6.04 i trafikplats 43 och enskild väg N 799 vid vägport vid Gullbranna,
S8 mellan enskild väg N 799 vid vägport vid Gullbranna och 320 meter söder om riksväg 24 i trafikplats 41 och
S9 mellan 320 meter söder om riksväg 24 i trafikplats 41 och 150 meter norr om länsväg 516 i trafikplats 40

**På- och avfartsväg**

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<th>Sträcka</th>
<th>Utsträckning</th>
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<td>S2as</td>
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<td>S2ps</td>
<td>mellan länsväg 659 och väg E6 i trafikplats 48,</td>
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<td>S3av</td>
<td>mellan väg E6 och 220 meter norr om norra anslutningsvägen i rastplats Susedalen,</td>
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<td>S3pv</td>
<td>mellan 20 meter söder om södra anslutningsvägen i rastplats Susedalen och väg E6,</td>
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<tr>
<td>S3as</td>
<td>mellan väg E6 och länsväg 625 i trafikplats 47,</td>
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<td>S3ps</td>
<td>mellan länsväg 625 och väg E6 i trafikplats 47,</td>
</tr>
<tr>
<td>S4as</td>
<td>mellan väg E6 och länsväg 601 i trafikplats 46,</td>
</tr>
<tr>
<td>S4ps</td>
<td>mellan länsväg 601 och väg E6 i trafikplats 46,</td>
</tr>
<tr>
<td>S5av</td>
<td>mellan väg E6 och väg E6.06 i trafikplats 45,</td>
</tr>
<tr>
<td>S5pv</td>
<td>mellan väg E6.06 och väg E6 i trafikplats 45,</td>
</tr>
<tr>
<td>S6av1</td>
<td>mellan väg E6 och väg E6.05 i trafikplats 44,</td>
</tr>
<tr>
<td>S6pv1</td>
<td>mellan väg E6.05 och väg E6 i trafikplats 44,</td>
</tr>
<tr>
<td>S6av2</td>
<td>mellan väg E6 och väg E6.04 i trafikplats 43,</td>
</tr>
<tr>
<td>S6pv2</td>
<td>mellan väg E6.04 och väg E6 i trafikplats 43,</td>
</tr>
<tr>
<td>S8av1</td>
<td>mellan väg E6 och 75 meter norr om väg 540.01 i rastplats Snapparp,</td>
</tr>
<tr>
<td>S8pv1</td>
<td>mellan 250 meter söder om väg 540.01 och väg E6 i rastplats Sapparp,</td>
</tr>
<tr>
<td>S8av2</td>
<td>mellan väg E6 och riksväg 24/länsväg 522 i trafikplats 41,</td>
</tr>
<tr>
<td>S8pv2</td>
<td>mellan riksväg 24/länsväg 522 och väg E6 i trafikplats 41 och</td>
</tr>
<tr>
<td>S9av</td>
<td>mellan väg E6 och länsväg 516 i trafikplats 40</td>
</tr>
</tbody>
</table>

3 § 1 dessa föreskrifter används nedan angivna väderbeteckningar i betydelsen nederbörd som ger friktion enligt nedan.

<table>
<thead>
<tr>
<th>Beteckning</th>
<th>Betydelse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Måttligt regn</td>
<td>Friktion</td>
</tr>
<tr>
<td>Kraftigt regn</td>
<td>nedsatt</td>
</tr>
<tr>
<td>Måttligt snöfall</td>
<td>låg</td>
</tr>
<tr>
<td>Kraftigt snöfall</td>
<td>nedsatt</td>
</tr>
<tr>
<td>Måttlig rimfrost</td>
<td>låg</td>
</tr>
<tr>
<td>Kraftig rimfrost</td>
<td>nedsatt</td>
</tr>
</tbody>
</table>
Måttlig isbildning nedsatt
Kraftig isbildning låg

När beteckningarna ovan används i dessa föreskrifter, baseras de på värden som uppmätts i Vägverkets mätstationer längs sträckan.

2 kap. Nordlig huvudriktning

1 § På den del av väg E6 som är avsedd för trafik i nordlig färdriktning får fordon på sträckorna N1 – N9 inte föras med högre hastighet än 120 kilometer i timmen om inte annat följer av 2 eller 3 §§.

Något besvärliga och besvärliga väglags- eller väderförhållanden

2 § Vid något besvärliga och besvärliga väglags- eller väderförhållanden vid måttligt regn, måttligt snöfall, måttlig rimfrost eller vid måttlig isbildning, eller vid risk för detta, på någon av sträckorna N2-4, N5 eller N6-9 får fordon där inte föras med högre hastighet än 100 kilometer i timmen.

Svåra och mycket svåra väglags- eller väderförhållanden

3 § Vid svåra och mycket svåra väglags- eller väderförhållanden vid kraftigt regn, kraftigt snöfall, kraftig rimfrost eller kraftig isbildning, eller vid risk för detta, på någon av sträckorna N2-4, N5 eller N6-9 får fordon där inte föras med högre hastighet än 80 kilometer i timmen.

3 kap. Sydlig huvudriktning

1 § På den del av E6 som är avsedd för trafik i sydlig färdriktning får fordon på sträckorna S1 – S9 inte föras med högre hastighet än 120 kilometer i timmen om inte annat följer av 2 eller 3 §§.

Något besvärliga och besvärliga väglags- eller väderförhållanden

2 § Vid något besvärliga och besvärliga väglags- eller väderförhållanden vid måttligt regn, måttligt snöfall, måttlig rimfrost eller måttlig isbildning, eller risk för detta, på någon av sträckorna S2-5, S6 eller S7-9 får fordon där inte föras med högre hastighet än 100 kilometer i timmen.
Svåra och mycket svåra väglags- eller väderförhållanden

3 § Vid svåra och mycket svåra väglags- eller väderförhållanden vid kraftigt regn, kraftigt snöfall, kraftig rimfrost eller kraftig isbildning, eller risk för detta, på någon av sträckorna S2-5, S6 eller S7-9 får fordon där inte föras med högre hastighet än 80 kilometer i timmen.

4 kap. På- och avfartsvägar

1 § På de sträckor av på- och avfartsvägar till väg E6 som anges i 1 kap. 2 § får fordon inte föras med högre hastighet än 120 kilometer i timmen om inte annat följer av 2 eller 3 §§.

Nordlig huvudriktning

2 § Om den högsta tillåtna hastigheten är, 100 eller 80 kilometer i timmen enligt 2 kap. 2 eller 3 §§ på någon av sträckorna N2-4, N5 eller N6-9 gäller den högsta tillåtna hastigheten även på de tillhörande avfartsvägarna och del av påfartsvägarna som anges nedan.

Avfartsväg
N2aö, N3aö, N4aö, N5aö1, N5aö2, N6an, N7an, N8aö, N8an och N9an.

Del av påfartsväg
N3pö mellan 260 meter norr om väg 540.02 och väg E6 i rastplats Snapparp.
N5pö1 mellan 250 meter sydväst om väg E6/riksväg 25 och väg E6 i trafikplats 44.

Sydlig huvudriktning

3 § Om den högsta tillåtna hastigheten är 100 eller 80 kilometer i timmen enligt 2 kap. 2 eller 3 §§ på någon av sträckorna S2-5, S6 eller S7-9 gäller den högsta tillåtna hastigheten även på de tillhörande avfartsvägarna och del av påfartsvägarna som anges nedan.

Avfartsväg
S2as, S3av, S3as, S4as, S5av, S6av1, S6av2, S8av1, S8av2 och S9av.

Del av påfartsväg
S3pv mellan 100 meter söder om södra anslutningen i rastplats Susedalen och väg E6.
S6pv1 mellan 240 meter nordost om väg E6.05 och väg E6 i trafikplats 44.

Dessa föreskrifter träder i kraft den 8 januari 2009, då Vägverkets föreskrifter (VVFS 2005:57) om varierande högsta tillåten hastighet på väg E6 i Hallands län ska upphöra att gälla.

INGEMAR SKOGÖ

Lena Erixon
Bilaga till Vägverkets föreskrifter
(VVFS 2008:309) om varierande högsta tillåten hastighet på väg E6 i Hallands län
Vägverkets föreskrifter om varierande högsta tillåtna hastighet på väg E22 i Blekinge län;

beslutade den 17 februari 2009.

Vägverket föreskriver följande med stöd av 3 § förordningen (2002:713) om försöksverksamhet med varierande högsta tillåtna hastighet.

1 kap. Inledning

1 § På de sträckor av väg E22 i Ronneby och Karlshamns kommuner som anges i 2 kap. 1 § och 3 kap. 1 § får bedrivas försöksverksamhet enligt förordningen (2002:713) om försöksverksamhet med varierande högsta tillåtna hastighet.

2 kap. Östlig huvudriktning

1 § På väg E22 mellan 400 meter öster om väg 633 i trafikplats Åryd och 60 meter väster om väg 27 i trafikplats Ronneby Väst får fordon på den del som är avsedd för trafik i östlig färdriktning inte föras med högre hastighet än 100 kilometer i timmen om inte annat följer av 2 eller 3 §§.

Om det på någon del av sträckan föreligger förhållanden enligt 3 §, gäller den föreskrivna hastigheten i den paragrafen.

Besvärliga väglags- eller väderförhållanden

2 § Vid besvärliga väglags- eller väderförhållanden på grund av regn, snö, rimfrost eller isbildning, eller risk för detta, får fordon inte föras med högre hastighet än 80 kilometer i timmen.

Mycket svåra väglags- eller väderförhållanden

3 § Vid mycket svåra väglags- eller väderförhållanden på grund av regn, snö, rimfrost eller isbildning, eller risk för detta, får fordon inte föras med högre hastighet än 60 kilometer i timmen.
3 kap. Västlig huvudriktning

1 § På väg E22 mellan 600 meter väster om väg 27 i trafikplats Ronneby Väst och 320 meter väster om väg 633 i trafikplats Åryd får fordon på den del som är avsedd för trafik i västlig färdriktning inte föras med högre hastighet än 100 kilometer i timmen om inte annat följer av 2 eller 3 §§.

Om det på någon del av sträckan föreligger förhållanden enligt 3 §, gäller den föreskrivna hastigheten i den paragrafen.

Besvärliga väglags- eller väderförhållanden
2 § Vid besvärliga väglags- eller väderförhållanden på grund av regn, snö, rimfrost eller isbildning, eller risk för detta, får fordon inte föras med högre hastighet än 80 kilometer i timmen.

Mycket svåra väglags- eller väderförhållanden
3 § Vid mycket svåra väglags- eller väderförhållanden på grund av regn, snö, rimfrost eller isbildning, eller risk för detta, får fordon inte föras med högre hastighet än 60 kilometer i timmen.

Dessa föreskrifter träder i kraft den 3 mars 2009, då Vägverkets föreskrifter (VVFS 2008:311) om varierande högsta tillätna hastighet på väg E22 i Blekinge län ska upphöra att gälla.

INGEMAR SKOGÖ

Lena Erixon