MOBI-ROMA

Mobile Observation Methods for Road Maintenance Assessments

Report on Data Collection, Fusion and Analysis

Deliverable Nr 2

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Executive summary

The key objectives of MOBI-ROMA are to develop, test and evaluate improved, affordable and moderate-cost road condition and performance assessment techniques for effective monitoring and assessing maintenance needs across Europe. In this second report, the data collection phase as well as data analysis and fusion are described. The use of data with the MOBI-ROMA maintenance tool is discussed for various road maintenance needs.

The development of MOBI-ROMA maintenance tool requires input data from all seasons and from varying traffic conditions. The three main data types used in MOBI-ROMA pilot are spring thaw detection, winter road conditions and pavement quality estimation. All three types are collected using the floating car data methodology. Spring thaw data is generated in the on-going project BiFi (II) and data regarding winter road conditions are collected from the SRIS project.

Project BiFi (II) - Load bearing capacity through vehicle intelligence - analyses the load bearing capacity of gravel roads, often related to surface softness or spring thaw. The floating car data is retrieved from the CAN-bus outlet or by a purpose-built hardware which is designed to imitate standard sensors equipped in modern vehicles. Floating car data together with data from fixed measuring field stations generate geographically positioned information regarding the roads surface characteristics. The same methodology is performed in another project named SRIS – Slippery Road Information System. The aim of SRIS is to estimate winter road conditions by combining data from a fleet of cars with fixed measuring stations. The project housed a pilot that took place in the Gothenburg area during the winter 2007/2008. A fleet of 100 cars was used to collect several data parameters from the CAN-bus outlet, such as ABS. The data collected during this period was fed into the MOBI-ROMA maintenance tool.

The third source of data are pavement condition measurements performed in a five-stage campaign from autumn 2011 to end of summer 2012 covering roads in Sweden, Denmark, Norway, Germany and Czech Republic. The measuring vehicle was equipped with necessary purpose-built hardware and software to record all data available on the CAN-bus. An external GPS that provides CAN-signals was added to the setup which allowed accurate positioning. The data was stored on hard drives and analyzed on a PC. To perform algorithms validation, data were collected and compared with data from laser equipped vehicles provided by the Swedish Transport Administration. The final output is a grade from zero to ten, ten being the best quality. The grade is computed by letting the vibration signal pass through several filters and algorithms.

In MOBI-ROMA the aim to collect and utilize data from surrounding projects has been achieved. Data from three external frameworks has been fed into the maintenance tool. This eases the next step: the development of the graphical user interface. The collected data is relevant and accurate enough. The amount of data is also large enough to validate the system performance and evaluate the MOBI-ROMA maintenance tool.

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List of Abbreviations

AADT	Average Annual Daily Traffic
ABS	Anti-lock Braking System
BiFi	Bearing Information Through Vehicle Intelligence
CAN	Control Area Network
CBR	California Bearing Ratio
EPS	Electronic Power Steering
FCD	Floating Car Data
FWD	Falling Weight Deflectometer
GPS	Global Positioning System
GPRS	General Packet Radio Service
GUI	Graphical User Interface
IRI	International Roughness Index
MPD	Mean Profile Depth
NVDB	Swedish National Road Database
OBD2	On-board Diagnostics 2
PMSv3	Swedish Pavement Management System version 3
RWIS	Road Weather Information System
SRIS	Slippery Road Information System

D2 Report on Data Collection, Fusion and Analysis

1 Objectives of MOBI-ROMA data collection

The objective of this research project is to introduce a new tool for cost effective road management. The approach is to combine and process available data from fixed measuring field stations with floating car data (FCD). Data from several sources therefore has to be collected and fed into MOBI-ROMA. State-of-the Art report of present methods was published as the first MOBI-ROMA Deliverable. [1]

Floating car data as such is not a new concept. It has been tested and studied for a number of years, and has mostly focused on traffic flow in and around cities. In the last decade there has been a fair bit of research in the area of utilizing floating car data. The majority of publications are on using floating car data for traffic flow, examples of this is Turksma, 2000, and Schäfer et al., 2002, the latter utilizing taxis to produce data on traffic flow. [2] [3]

Although the majority of tests have concentrated on traffic flow and travel times, there have been projects where FCD is utilized for other applications. In the United States there have been some smaller field trials using CAN-bus data; the standouts being Koller et al., 2012 and Drobot et al., 2012, both using the onboard capabilities of cars with the objective to detect slipperiness and weather conditions. However, compared to the SRIS project utilized in MOBI-ROMA, they are still relatively small scale tests. [4] [5]

The MOBI-ROMA framework encompassing database and graphical user interface is unique in its capacity to ingest and display in meaningful ways, different types of floating car data. The web based platform allows users to access the service independently from what type of hardware platform they are using, be it Windows, iOS, Android, MacOSX, Linux etc. Furthermore, the flexibility of the MOBI-ROMA framework enables easy additions of new types of data, thus expanding the utility of the tool.

The development of the maintenance tool requires input from data collected during various times of a year and in various traffic conditions. Due to this, data from other on-going projects are continuously ingested into MOBI-ROMA, used to ease both development and evaluation of the maintenance tool.

One of the on-going research projects is BiFi (II)[1]. The project aims to compute the load bearing capacity of gravel roads, often related to surface softness or spring thaw. The floating car data is retrieved from the CAN-bus outlet or by a purpose-built hardware, which is designed to imitate standard sensors equipped in modern vehicles. The purpose-built hardware is developed due to the restrictions car manufacturers add on CAN-bus[2] data. Floating car data together with data

[1] Load bearing capacity through vehicle intelligence. More information, reports and presentations available on the project web page: http://bifi.se.

[2] Controller Area Network, a vehicle bus standard, which allow microcontrollers, sensors, etc. to communicate without a host computer.

from fixed measuring field stations generate geographically positioned information regarding the roads surface characteristics. All data collected during BiFi (II) will be fed into MOBI-ROMA and used to develop and evaluate the maintenance tool. [7]

The same methodology is performed in another framework named SRIS[3]. The aim of SRIS is to estimate winter road conditions by combining data from a fleet of cars with fixed measuring stations. The project housed a pilot that took place in the Gothenburg area during the winter 2007/2008. A fleet of 100 cars was used to collect several data parameters from the CAN-bus outlet, such as ABS. The data collected during this period will be ingested and used to develop and evaluate the MOBI-ROMA maintenance tool. [8]

The above mentioned research project BiFi (II) includes a functionality to determine whether the vehicle is located on a gravel road. The algorithm has been re-developed to also determine the roads pavement quality. The system is partly broken out of its original project and aims to use floating car data to provide, amongst others, several road administrations with spatially distributed pavement quality information. Collection of data, used to further develop the pavement analysis algorithms, was performed parallel with MOBI-ROMA and fed into the maintenance tool.

Data is thereby collected and fed into the MOBI-ROMA maintenance tool from three different projects/frameworks, each estimating a specific problem area. Namely: spring thaw detection, winter road conditions and pavement quality estimation.

The objective of the data collection is to format data sets suitable for validating the pavement quality algorithms and to test performance of the MOBI-ROMA web base maintenance tool.

A short time table stating the time of measurement for the different data sources is shown in Figure 1.

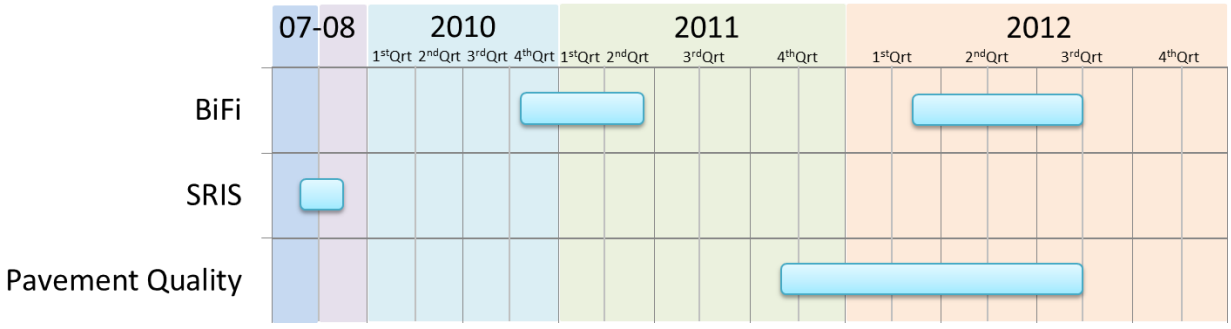


Figure 1 Data sources time table

[3] Slippery Road Information System, more information and a final report available on http://www.sris.nu.

2 Data collection plan

2.1 Measurement devices and techniques

A modern car has a whole range of sensors and systems that can be utilized to analyze specific road characteristics. Depending on what one wishes to measure there are systems and sensors like the traction control systems, EPS, ABS, air temperature, air quality, air pressure, accelerometers etc. available via the CAN-bus system of a modern car. Due to access restrictions it is sometimes easier to install external, purpose-built, sensors to vehicles. Measurements are connected spatially via GPS, and the information transmitted via either the vehicles onboard communication systems or an external system such as 3G/GPRS.

The area of interest is also affected by the kind of vehicle fleet that is used. The fleet must provide the spatial and temporal coverage that is needed to detect the sought after phenomenon. For example the spring thaw needs a temporal resolution range of between 12-24 hours for the data collected to be of use; therefore, the area of interest must be covered at least once within that time span. This means that the fleet can be small in relation to the area covered. However, if the objective is to pinpoint slippery conditions, the demands on both spatial and temporal resolution increases which in turn increases demands on the size of the fleet.

In the scope of this project, data has been collected in several different ways:

BiFi - Due to the restricted CAN-bus communication protocol of the FIAT Fiorino's that the Swedish Postal Service uses, an external sensor equipped with GPS, 3G/GPRS and accelerometers was installed in the postal vans (hardware is described in greater detail in chapter 3.2). This external unit has the capability to register, process, store and send data. In the area that the postal vans are operating the connectivity to the mobile network is limited and therefore data was sent when the postal vans where back at the post office. This results in data transfer 1-2 times per day from the postal vans.

Pavement quality - Data has been gathered using a Volvo V70 from which the CAN-bus could be read and the information processed. The data was manually ingested from the test car into the MOBI-ROMA maintenance tool, and was not for the majority of the project seen as real-time data. However there were tests done with specialized versions of the BiFi (II) hardware.

SRIS - The SRIS project utilized the onboard hardware of at most 100 vehicles, 60 Volvos and 40 SAABs. The car models used in the test were Volvo V70s and Saab 9-5s. The vehicles were both company cars and taxis to get a high frequency of usage and driving distance of the cars. The project was operative in the winters of 2006-2007 and 2007-2008; consequently the data is not seen as real-time and has therefore been ingested off-line. However, if SRIS were to go operational at a later date, the floating car data would be transmitted in real time to a database were the data could be utilized for modeling and visualization. For SRIS, a short response time is critical for the system to be as effective as possible. Slippery situations can appear quickly and therefore minimizing the time from vehicle measurement to responsible road authorities and other drivers must be as short as possible.

The strength of the systems above is that drivers who carry out the data collection do not need any specific system knowledge. This allows for people unrelated to the technicalities to collect data during weekend trips, daily commute, etc.

For further information regarding previous projects BiFi and SRIS see referenced reports [7] and [8].

2.2 Pavement condition measurements

The pavement condition measurements were performed with focus on validation of both the pavement quality algorithms and the web based maintenance tool.

To perform algorithms validation, data were collected and compared with data from laser equipped vehicles provided by the Swedish Transport Administration. This limits the possibility to choose specific road stretches and seasons, but provides an accurate data set suitable for validation of the algorithms.

Validating the maintenance tool demands a different type of data set with focus on quantity. This data set does not have any restrictions regarding road stretches or season. Data could therefore be collected in several countries in all four seasons.

The measurements are therefore divided into two categories and were measured according to the measurement schedule, seen in Figure 2.

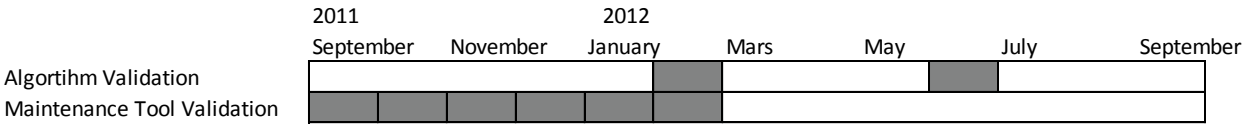


Figure 2, Pavement measurements time plan

2.2.1 Algorithms Validation Measurements

Validation of the pavement quality algorithms was done against data from laser equipped measuring vehicles, provided by the Swedish Transport Administration. Parameters available for validation were:

- International Roughness Index, IRI (mm/m)
- Rutting depth (mm)
- Macro texture, MPD, Right (mm)
- Macro texture, MPD, Center (mm)
- Macro texture, MPD, Left (mm)

Four stretches containing the above mentioned parameters were selected to validate the algorithms. One of these stretches was used in an early stage of the project, for algorithm development, and easy access of was important at this stage of the project. This initial validation stretch was not seen as part of the final validation data set. Measurement details of this initial validation stretch are shown in

Table 1 and a map showing the stretch are seen in Figure 3.

Table 1, Algorithm validation measurements, used in an early stage of the project

Stretch	Measurement date		Length	Conditions
	Swedish Transport Administration	MOBI-ROMA		
Norrleden	2011-05-17 2011-05-30	2012-03-06	3x28 km	Dry

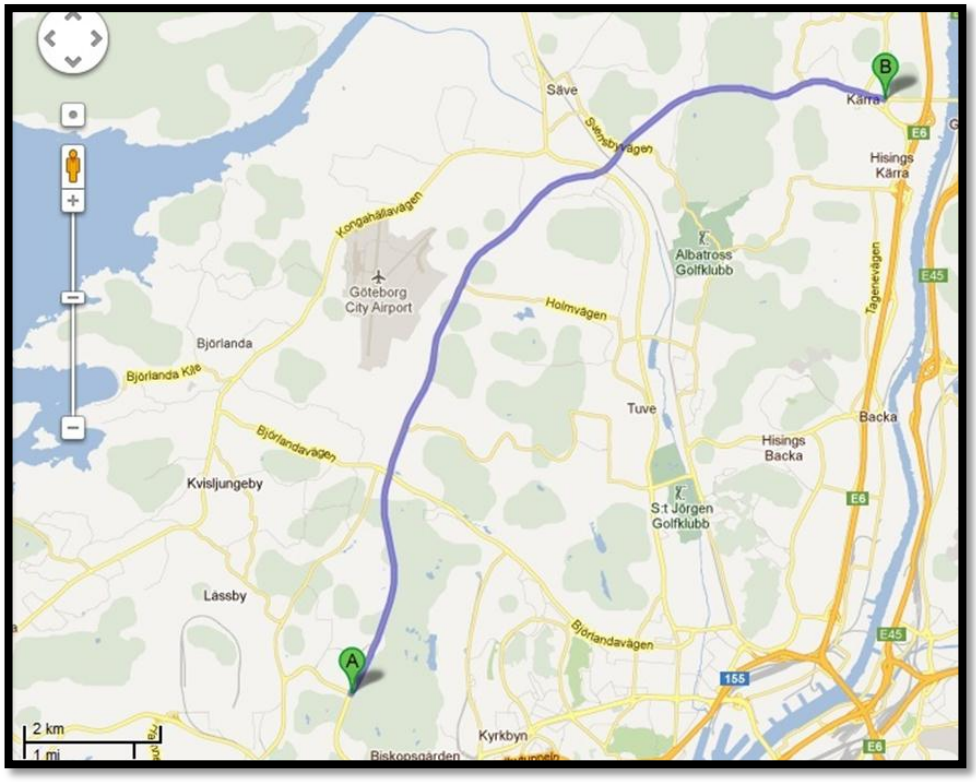


Figure 3, Validation stretch Norrleden, used in an early stage of the project.

The three remaining stretches were selected due to their variation in quality and size. Each stretch was measured three times in each direction. If the stretch has more than two lanes, only the right lane was measured. In total 1800 km of algorithms validation measurements were performed. Details of these stretches are shown in Table 2 and a map showing the three stretches are seen in Figure 4.

Table 2, Algorithms validation measurements details

Stretch	Measurement date		Length	Conditions
	Swedish Transport Administration	MOBI-ROMA		
E6	2011-04-22 2011-04-23 2011-05-10 2011-05-11 2011-05-17	2012-06-18	3x282 km	Dry
V41	2011-05-14 2011-05-16 2011-09-27	2012-06-19	3x178 km	Dry
V190	2011-05-26 2011-05-28	2012-06-20	3x140 km	Dry

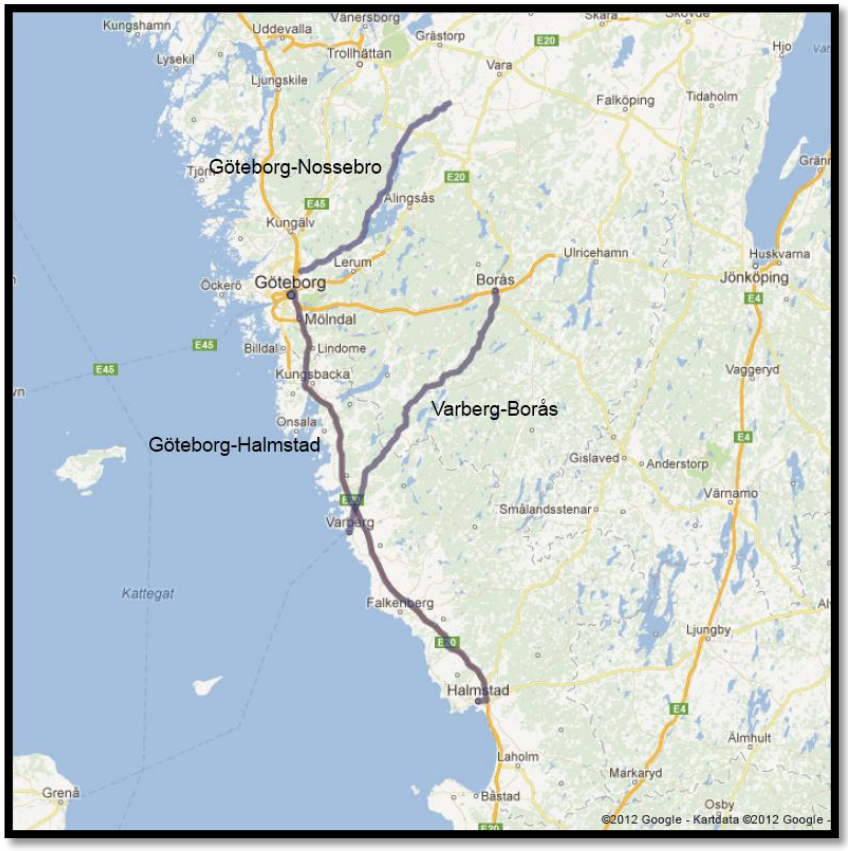


Figure 4, Three main validation stretches.

2.2.2 Maintenance Tool Validation Measurements

In addition to the measurements performed to evaluate the pavement algorithms a lot of data were collected to evaluate the performance of the maintenance tool. These measurements were done within all four seasons, on various pavement qualities, in different weather conditions and in several countries. The aim of these measurements was not to improve or validate the algorithms, but to illustrate the usability and test the performance of the web based maintenance tool.

These measurements were done sporadically during the project and the measured distance is well over 7000 km. Measurement details are shown in Table 3. Since the stretches cover multiple road numbers and names only the starting city and destination city will be stated.

Table 3, Web based maintenance tool validation measurements details

Start	Destination	Country	Back and Forth	Length	Measurement date	Conditions
Gothenburg	Kramfors	Sweden	Yes	~1708 km	2011-12-13	Dry, Wet, Snow
Gothenburg	Eskilstuna	Sweden	Yes	~742 km	2011-11-23	Dry, Snow
Gothenburg	Eksjö	Sweden	Yes	~414 km	2011-10-07	Dry, Wet
Gothenburg	Brno	Sweden, Denmark, Germany, Czech Republic	Yes	~2590 km	2012-01-14	Dry, Wet
Gothenburg	Hamburg	Sweden, Denmark, Germany	Yes	~1801 km	2012-01-23	Dry, Wet
Gothenburg	Idre	Sweden, Norway	Yes	~1435 km	2012-01-30	Dry, Snow

2.2.3 Additional measurements

In addition to the two previous measurement categories several other measurements were performed. These shorter measurements aimed to increase the accuracy of the pavement algorithms by testing them on odd road surfaces, such as cobble stone, concrete and deep snow.

Table 4, Other algorithm validation measurements details

Road Type	Country	Purpose	Measurement date	Condition
Normal road	Sweden	Analyze algorithms performance in various velocities	2011-09-14	Dry
Highway	Germany	Analyze algorithms performance on concrete paved roads	2012-01-23	Dry
City road	Germany	Analyze the algorithms performance on cobble stone paved roads	2012-01-21	Wet
Large parking	Norway	Analyze the algorithms performance in deep snow	2012-01-29	Snow

All pavement measurements were done using a Volvo V70. The vehicle was equipped with necessary hardware[4] to record all relevant data available on the CAN-bus. An external GPS[5] that provides CAN-signals is added to the setup, which allows accurate geographical positioning. Constantly using the same measurement vehicle eases evaluation of algorithms; this is because the measuring setup is kept close to constant.

Performance testing the web based measurement tool requires larger quantities of data, therefore a purpose-built hardware, developed in the BiFi (II) project was used during the project. The external hardware unit is equipped with sensors necessary to analyze surface characteristics. This allows for other vehicles than the previously used Volvo V70 to perform measurements. The downside is that no raw data is stored or uploaded to any database, only the geographical position, timestamp and the system output is stored. This removes the possibility to perform any in-depth analysis on the collected data sets.

Since the measurements are performed in normal traffic speeds the system cover large areas, about 600-900 km per vehicle and day.

Figure 5 shows an example view taken from the maintenance tool, presenting both CAN based data and data measured with the external hardware unit collected during two days. Figure 6 shows the geographical distribution of all collected data presented in chapter 2.2.

[4] The hardware used is a CANcaseXL developed by Vector.
[5] CAETEC QIC GPS MOUSE developed by CAESAR Datensysteme

Figure 5, Measurement distribution for a two days collection period (taken from the measurement tool)

Figure 6, Measurement distribution cover several countries (taken from the maintenance tool)

2.3 Spring thaw measurements from BiFi

In BiFi (II) – Bearing information through vehicle intelligence - information about the load bearing capacity of gravel roads is collected using a fleet of vehicles carrying purpose-built sensors. The system aims to detect bearing capacity reduction associated with the spring thaw process.

In colder climates the roads freeze during the winter months when temperatures plummet below freezing for extended periods of time. As spring approaches the temperatures rise and the spring thaw sets in. The spring thaw process is initiated when air temperatures reach over 0°C and melting of the road surface begins. An excess of water trapped by the frozen road beneath the thawed surface causes the load bearing capacity to decrease and can lead to collapse of the road when under stress. There is often a period when the daytime temperatures are well above 0°C, but fall below 0°C during the night time, causing a freeze-thaw process. This makes the road surface hard during the night into the early morning and soft as the temperature rises and the road surface thaws out.

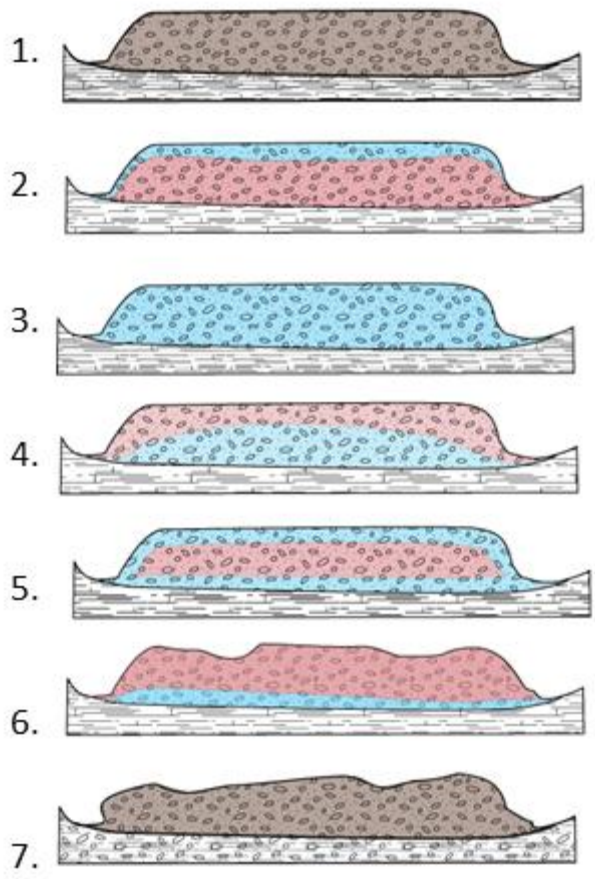


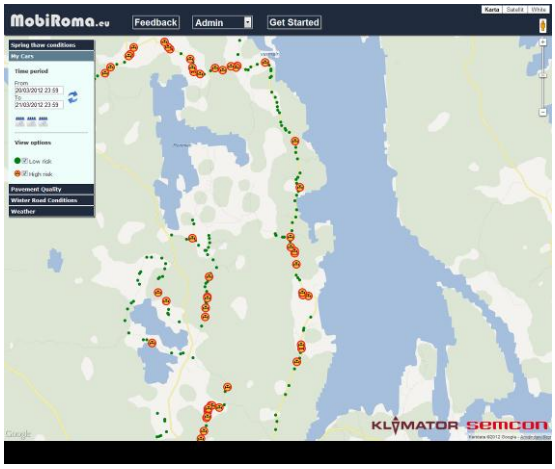
Figure 7 A schematic description of the different stages of the spring thaw process.
1. Unaffected dry/wet road.
2. Surface temperature sinks below freezing. The initial stages of the ground frost period.
3. The road is frozen solid below the depth of the road structure.
4. Initial surface melting and surface softness. The road still has a high bearing capacity thanks to the frozen subsurface.
5. Refreezing during cold nights lead to refrozen surface. Risk of collapse since the surface seems stable.
6. Heavy thawing, surface saturated with melt water. The frozen subsurface acts like a barrier, preventing drainage of excess water. Low bearing capacity, with heavy rutting.
7. Dry road bank with remnant rutting and pot-holes.

In the BiFi (II) project a total of 13 sensors were mounted in postal delivery vans in two separate areas: 5 sensors in Kramfors municipality in Västernorrland, and 8 in the municipalities of Arvika and Sunne in Värmland, Sweden. The routes chosen were picked to get the maximum coverage of dirt roads possible.

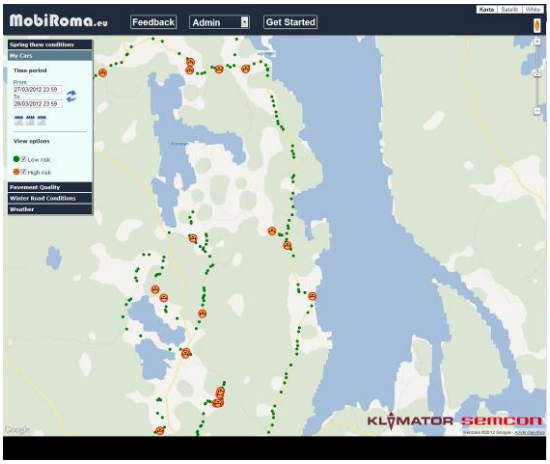
In total the eight vehicles in Värmland have delivered just above 57000 measurements during a two-month period which breaks down to about 1000 signals per day. The five vehicles in Kramfors uploaded around 25000 indications during the same period. The amount of dirt road covered varies from day to day depending on the post office driving schedule, but on average a normal route is around 100km. In total the eight vehicles manage to cover about one third of the total area of Värmland. In both Värmland and Kramfors the vehicles are out and delivering mail between 08:00 and 16:00 on weekdays. In addition to this, several postal vehicles are used to deliver the morning newspapers. This is done around 05:00 on weekdays.

Error! Reference source not found. shows the indications of spring thaw and its development between a period between the 21st of March 2012 and the 4th of May the same year, as detected by the vehicle fleet in Värmland, and as seen in the MOBI-ROMA web base maintenance tool.

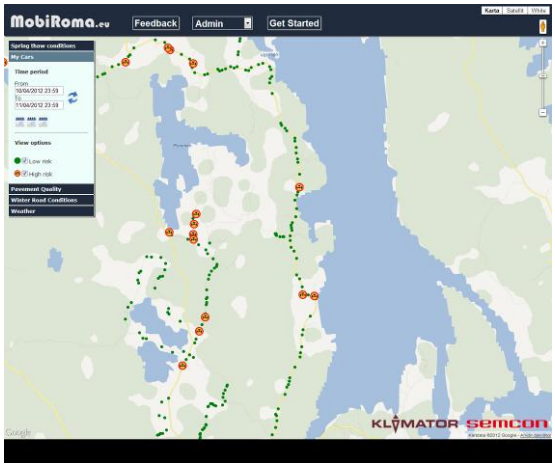
Figure 9 shows a typical spring thaw affected gravel road in the same area.



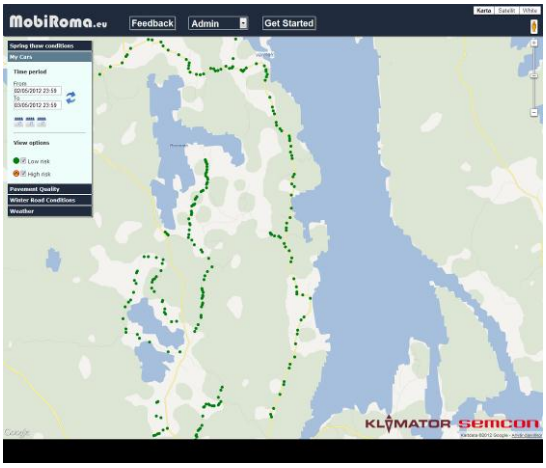
21 March, South West of Arvika, Ratio of soft signals 37%



4 April, South West of Arvika, Ratio of soft signals 13%



11 April: South West of Arvika, Ratio of soft signals 10%



4 May, South West of Arvika, Ratio of soft signals 0%

Figure 8 Reported incoming signals from an area South West of Arvika in Värmland, Sweden. Green dots indicate a hard road surface and Red/orange dots indicate soft road surface. As is seen in the progression from the 21 of March to the 4th of May, the roads start out with an even spread of soft indications. As the roads dry the soft signals become fewer and fewer until those finally go away.

Figure 9, Road in Sweden that is affected by spring thaw, severely limiting the load bearing capacity of the road

2.4 Slipperiness measurements from SRIS

Slippery situations are one of the most important factors associated with road deaths and injuries. Those are also notoriously hard to predict. To date many countries plagued by weather which causes slippery road conditions have invested in some kind of road weather information system (RWIS) that comprises of a network of weather stations placed throughout the road network. These systems warn when atmospheric conditions are likely to yield slippery conditions, such as snowfall or rain on cold road surface. However these systems are limited by the information the weather stations deliver, and that data may not always reflect the road surface conditions accurately. [8] There is therefore a need for something to fill the gaps between the weather stations and to measure parameters that correlate to road friction and slipperiness in some way. From this need the idea of SRIS or Slippery Road Information System was conceived.

SRIS uses the onboard system in a fleet of vehicles to pinpoint slippery situations in real time. The system listens for activation of the vehicles ABS and EPS systems and, when triggered, sends a positioned action via the vehicles onboard communication system to a database. As the vehicle moves along the road it also sends out a signal telling the system where it is every 30 seconds, giving the system information about how many vehicles are active and where they are at any given time. This is seen as background information where no indications of slipperiness have been reported.

Slippery situations are associated with several different weather phenomena such as frost, black ice and snowfall. These phenomena are often local in nature and can appear quickly which makes it difficult to predict them. Therefore, the vehicle fleet must be large enough to enable a significant portion of the road network to be covered at any given time. It is also important that this coverage has a high enough temporal resolution (vehicles/kilometer road/hour) to be able to capture slippery situations as they form and are remediated. The size of the vehicle fleet is directly connected to the size of the road network and the diversity of roads within the same network.

SRIS has run operationally for two seasons in 2007 and 2008. During the winter of 2007 there were 60 cars active in and around the Gothenburg area. In 2008 SRIS was extended to 100 cars (60 Volvos and 40 Saabs) in the same area. [8]

The SRIS project managed convincingly to show how vehicle data could be used to pinpoint when and where slippery situations occur. However a GUI for the system was not developed. Graphical illustrations could be generated by MATLAB[6], as seen in Figure 10.

[6] MATLAB is a programming environment for algorithm development, data analysis, visualization and numerical computation, developed by MathWorks

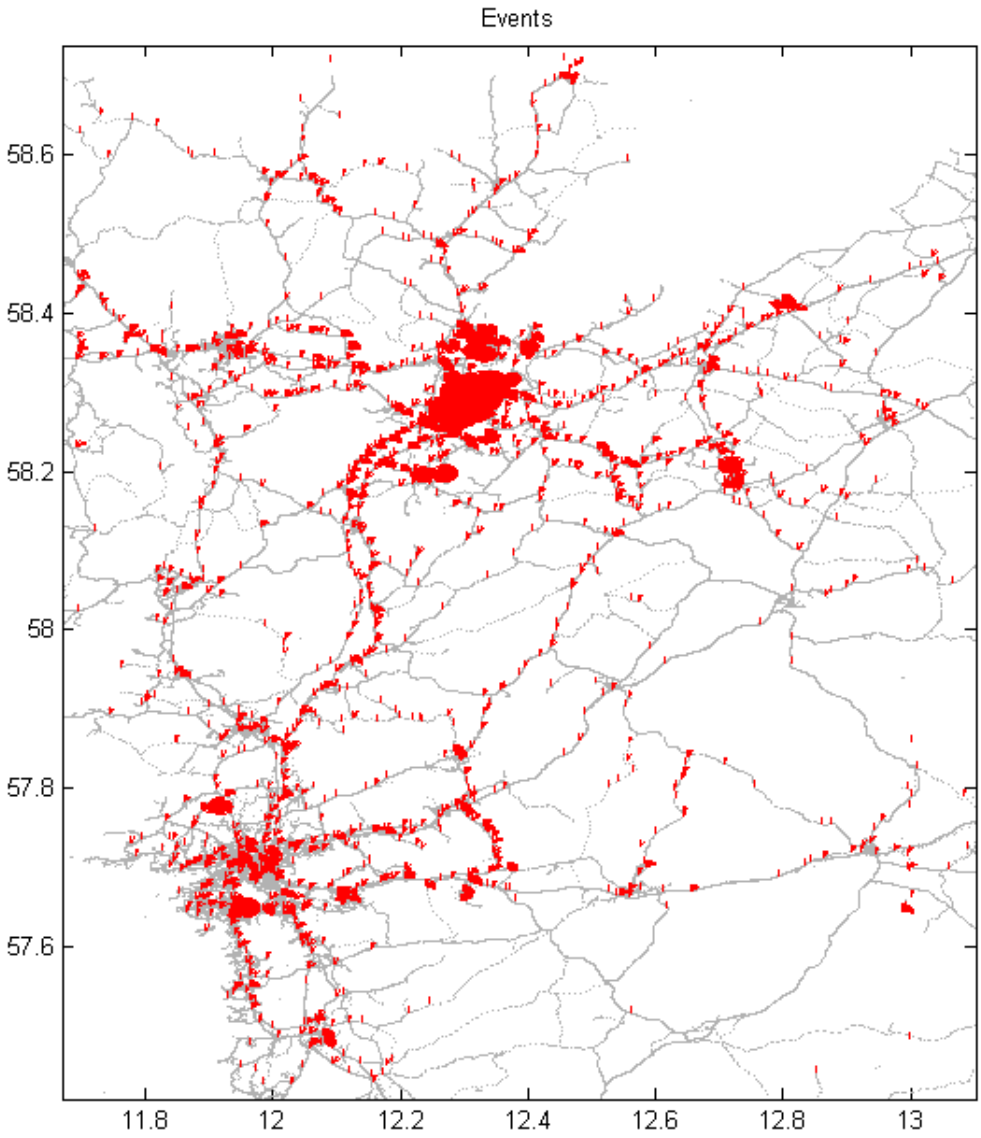


Figure 10, Slippery situations recorded during one season, in western Sweden. Each red dot represents an ABS or traction control system event.

3 Data fusion and analysis

3.1 Method for pavement analysis

The pavement quality is detected using the vehicles own vibrations. The vibrations can be retrieved in two ways, either by using the vehicles internal accelerometer or by adding an external sensor. If the internal accelerometer is used, the data is available on the CAN-bus and is retrieved through the OBD2-outlet[7]. The fetched data is converted to a known format using CANalyzer[8] and exported to MATLAB where it is analyzed.

The second method is based on a purpose-built hardware, developed in the parallel project BiFi (II), which houses several sensors, communication and storage facilities. The processing is done in the hardware's embedded processor and the data is transferred by 3G/GPRS to a central database. Both methods use an external GPS to detect the geographical position.

In an early stage the output was compared to general road roughness. It was clear that a higher Pavement Quality grade represented a poor road surface, as seen in Figure 11 and Figure 12.

Figure 11, Detected as high quality pavement

Figure 12, Detected as very low quality pavement

The final output, generated by the algorithms, is a grade from zero to ten, ten being good quality. The grade is computed by letting the vibration signal pass through several filters and algorithms developed in the parallel projects SRIS and BiFi (II). The grade, geographical coordinate and timestamp are sent to a central database. This is done automatically when the vehicles ignition is turned off. Details of the final scale are presented in Chapter 3.1.1.

If the data is fetched from the CAN-bus using the OBD2-outlet all information has to be transferred manually from the vehicle and uploaded to the database using a personal computer.

[7] OBD2 is a vehicle diagnostics standard, where CAN is one of five protocols used.
[8] CANalyzer is a universal software analysis tool for ECU networks and distributed software, developed by Vector.

3.1.1 Validation

Validation of the pavement quality algorithms was performed on three algorithm validation stretches, stated in Table 3. All three stretches were measured by MOBI-ROMA in June of 2012 using a Volvo V70 equipped with hardware necessary for logging CAN-bus data. Table 5 below states the validation parameters.

Table 5, Available validation parameters provided by the Swedish Transport Administration

International Roughness Index, IRI
Rutting depth
Macro texture, MPD, Right
Macro texture, MPD, Center
Macro texture, MPD, Left

All validation operations were performed using MATLAB and a significant similarity could only be found between the MOBI-ROMA Pavement Quality and IRI. In the evaluation, if there was a correlation between the MOBI-ROMA grade and IRI the signals were plotted against each other. To ease validation all signals were filtered over 100, 400 and 1000 meter. In the following Figures 12-19 only signals filtered over 1000 meters are shown. Appendix A – Pavement quality validation contains results filtered with a higher resolution, 100, 400 and 1000 m.

Two stretches are selected and validation for one direction is presented in this document. The outputs from the algorithms are a mean value of the three measurements performed on each stretch. In all plots the grade computed by the pavement quality algorithms are represented by a blue line and IRI measured by the Swedish Road Administration are represented by a red line. Dotted lines represent requirements of IRI between 50-120 km/h set by the Swedish Transport Administration (see referenced maintenance report [6] for further details). In this case all IRI requirements are based on a traffic flow over 2000 vehicles per day.

During evaluation there were no signs of correlation between other parameters than IRI. Due to this focus was set to only analyze correlation with IRI.

Stretch v.190 – Gothenburg-Nossebro

The gap in the red line is there due to lack of IRI. The signals follow each other well and small differences in amplitude are seen in correlation to peaks with high IRI values.

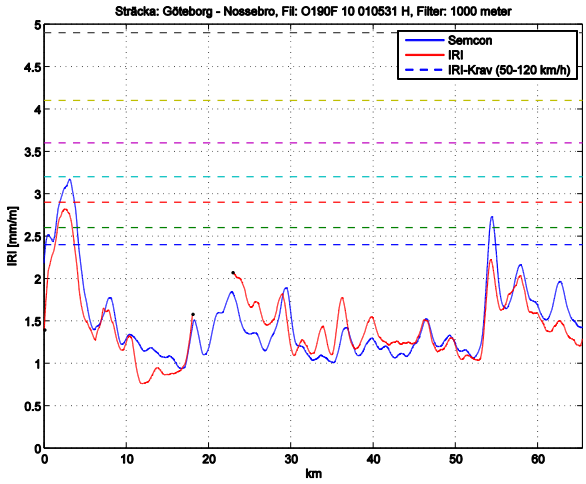


Figure 13, Gothenburg-Nossebro

To get a better understanding of how well the signals match a section has been selected and magnified.

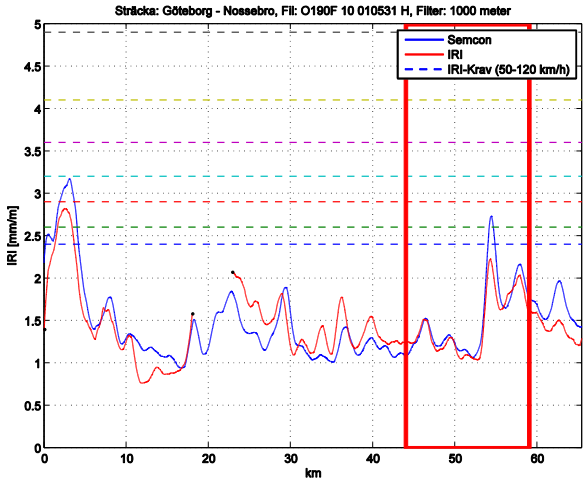


Figure 14, Gothenburg-Nossebro with selection

The enlarged section shown in Figure 15 shows a good match between the two curves. A clear sign of this is that all peaks match. A difference in amplitude can be detected in several sections.

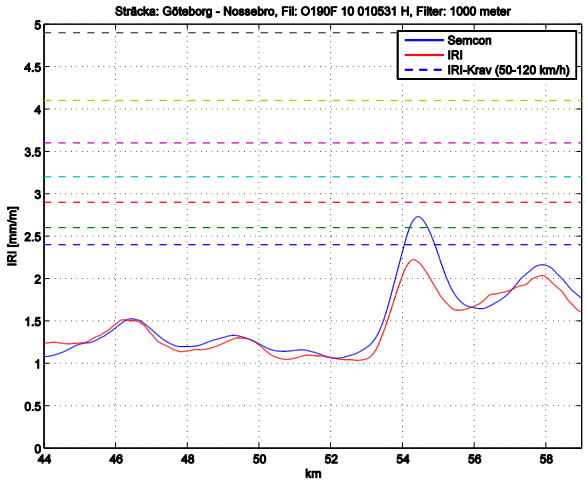


Figure 15, Gothenburg-Nossebro with magnified section

Stretch E6 – Halmstad-Gothenburg

The gap in the red line is there due to lack of IRI data during that section. This stretch has a relatively low IRI values, therefore the relative difference in amplitude is more noticeable than for stretches with higher IRI values.

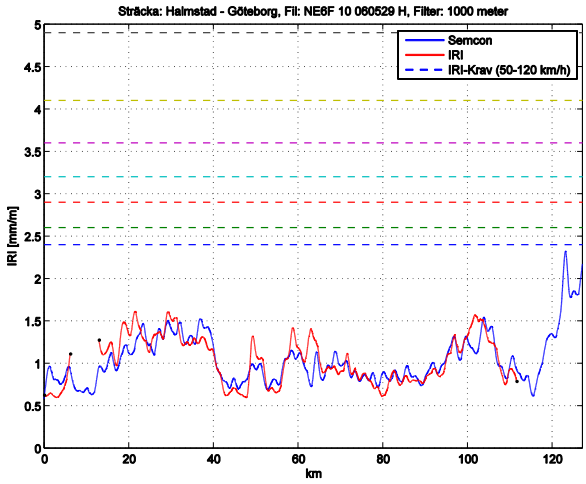


Figure 16, Halmstad-Gothenburg

A section of the stretch has been picked out for a more in detail validation.

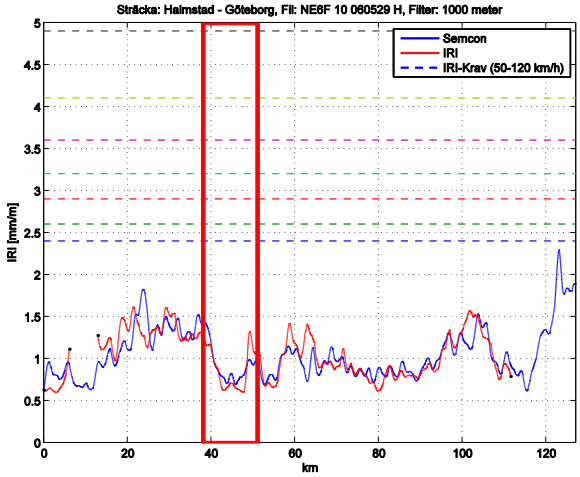


Figure 17, Halmstad-Gothenburg with selection

The magnified section shows a good match between the two curves. Amplitude difference is noticeable in the final part of the measuring stretch.

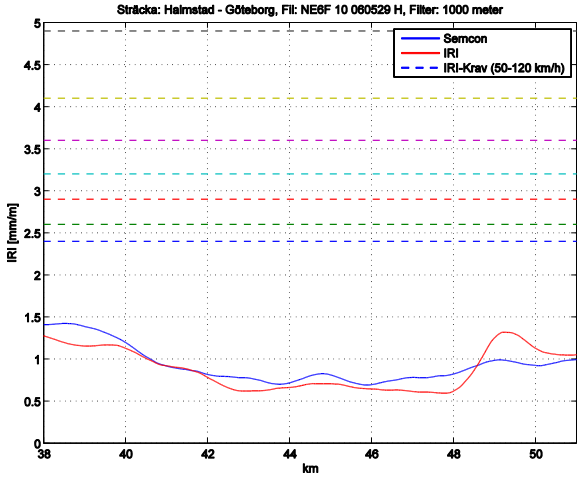


Figure 18, Halmstad-Gothenburg with magnified section

Repeatability

Each stretch was measured three times, in order to evaluate the repeatability of measurements performed by a vehicle driven by untrained personnel.

Stretch V190 – Gothenburg-Nossebro, Figure 19, shows a small difference between the three individual measurements. Parameters such as velocity, position on the road, etc. could contribute to the small differences.

Figure 20 shows the stretch E6 – Halmstad-Gothenburg. The graph show more differences between each measurement, especially ~23 km into the measurement. The peak in the green line is due to heavy traffic caused by a traffic incident. The velocity is too low for the algorithms to perform a reliable result and is normally discarded. In this case the result is kept to ease filtering. Also this measurement is affected by overtaking, position on the road, etc.

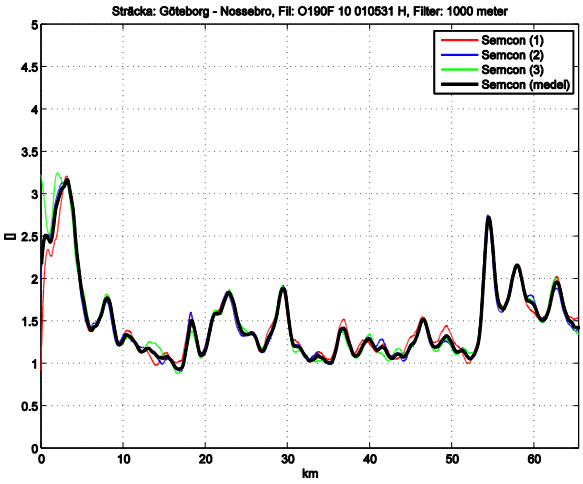


Figure 19, Gothenburg-Nossebro. Repeatability

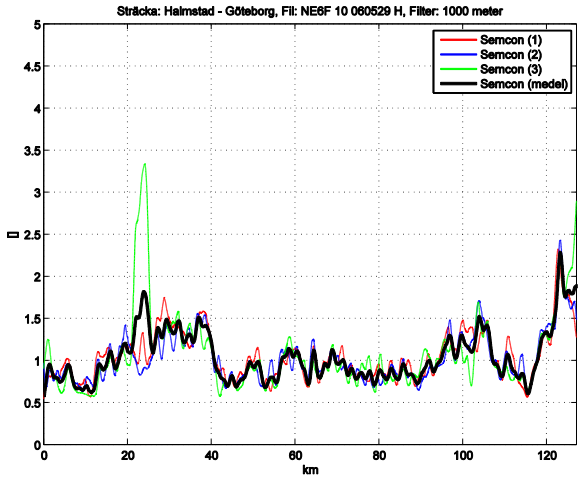


Figure 20, Halmstad-Gothenburg. Repeatability

In a FCD measuring system such as MOBI-ROMA pilot demonstration, the repeatability and mean correlation to laser measurements can be assessed with confidence only after extensive measuring samples from large car fleets. MOBI-ROMA has not yet large enough data sets to derive the mean values with confidence. Figure 19 and Figure 20 above show that there is large variation from case to case due to external factors. However, the key objective of MOBI-ROMA is to provide complementary measurements with high spatial and temporal resolution, though with less accuracy compared to present laser measurement methods. We assume that larger car fleet providing FCD will increase the amount of measurements in any given point along the road, thus increasing the correlation with IRI.

Correlation

The correlation between the pavement quality grade and national IRI requirements depends on several pre-set road variables. Connecting specific measurements with the set of road variables is the key in providing a reliable scale of results which are shown as a set of colors on the web based maintenance tool.

In the following example, the validation stretch *Gothenburg-Nossebro* has been chosen. The stretch has an average speed limit of 70 km/h with an average traffic flow of over 2000 vehicles/day. The IRI requirement of this road category, set by the Swedish Transport Administration, is: < 4.1 mm/m. The outputted color scale would then correlate all pavement quality grades over 4.1 as bad pavement (purple). Values that span 20% below the requirement are seen as moderate quality (light purple to yellow), which in this case correlate to pavement quality values between 3.28 and 4.1. Values below 3.28 will be seen as good quality (green) as shown in Figure 21. No pavement quality above 3.5 has been detected and therefore cannot be graded accurately.

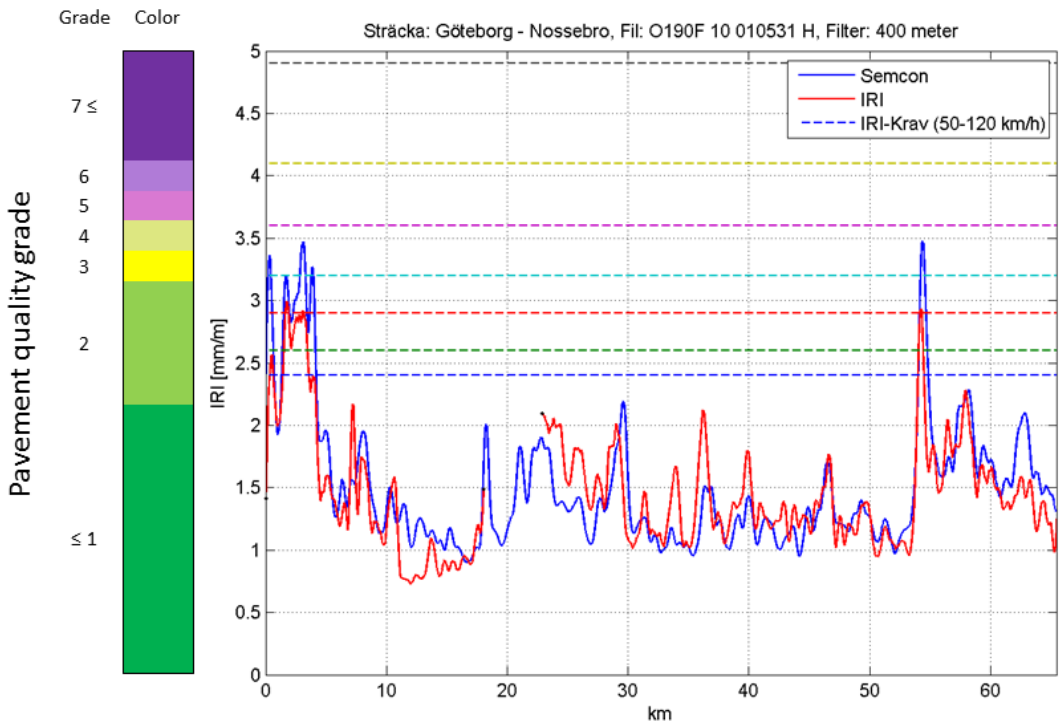


Figure 21, Correlation between Grade, IRI and Color scale

The above example is only valid for this specific stretch in Sweden, which has an average speed limit of 70 km/h. Since measurements are made on all possible road types, in various speeds and in several countries the limits has to be dynamic. A proper scale for all these cases hasn't been developed, mainly because there were no easy way to access road specific data when only knowing the latitude and longitude of the measurement. In Sweden the National Road Database (NVDB) could be used to attach MOBI-ROMA measurements to specific road data segments, however this is not an easy task. The next generation of pavement management system, PMSv3,

is more detailed and therefore also more suited for measurements based on geographical coordinates. But there will still be a harsh implementation task to perform for several countries.

Another approach is to set up grade tables for each country based on annual average daily traffic (AADT) and the actual vehicle speed. In Table 6 thresholds defined by the Swedish Transport Administration are shown. [6]

Table 6, IRI Thresholds defined by the Swedish Transport Administration.

	Vehicle speed							
AADT	120	110	100	90	80	70	60	50
0-250		≤ 4.3	≤ 4.7	≤ 5.2	≤ 5.9	≤ 6.7	≤ 6.7	≤ 6.7
250-500		≤ 4.0	≤ 4.4	≤ 4.9	≤ 5.5	≤ 6.3	≤ 6.3	≤ 6.3
500-1000		≤ 3.7	≤ 4.1	≤ 4.5	≤ 5.1	≤ 5.8	≤ 5.8	≤ 5.8
1000-2000		≤ 3.0	≤ 3.3	≤ 3.7	≤ 4.2	≤ 4.8	≤ 5.2	≤ 5.2
2000-4000	≤ 2.4	≤ 2.6	≤ 2.9	≤ 3.2	≤ 3.6	≤ 4.1	≤ 4.9	≤ 4.9
4000-8000	≤ 2.4	≤ 2.6	≤ 2.9	≤ 3.2	≤ 3.6	≤ 4.1	≤ 4.9	≤ 4.9
>8000	≤ 2.4	≤ 2.6	≤ 2.9	≤ 3.2	≤ 3.6	≤ 4.1	≤ 4.9	≤ 4.9

The above table has to be divided into sub-tables, where each sub-table represents a specific AADT/Vehicle speed entry.

Table 7, Example of a sub-table that aims to define the correlation between the MOBI-ROMA pavement quality grade and IRI.

70 / 2000-4000 (km/h / vehicles/day)		
MOBI-ROMA color	MOBI-ROMA grade	IRI (mm/m)
	≤ 1	≤ 2.2
	2	≤ 3.3
	3	≤ 3.4
	4	≤ 3.6
	5	≤ 3.9
	6	≤ 4.1
	≥ 7	> 4.1

The tables above are examples that use IRI thresholds defined by the Swedish Transport Administration. The only correlation between the MOBI-ROMA grade and the IRI is where the MOBI-ROMA grade is set to higher than 7, which correlates to the IRI threshold. By assigning MOBI-ROMA grade 3-6 linearly over the 20% below the IRI threshold a warning level is defined. Values below the 20% are assigned MOBI-ROMA grade ≤ 2.

Each MOBI-ROMA grade is attached to a color representation that aims to illustrate the need of maintenance.

Interesting pre-set road variables useful for correlating a specific pavement quality or IRI with the maintenance tool color grade are:

- Road type (Highway, Normal road, City road)
- Road category (The importance of the road regarding delivery of goods)
- Speed limit
- Traffic flow (Vehicles per day)
- Country standard (Each country has different pavement quality standards)

To attach specific measurements with the above stated road variables demand close collaboration with the involved countries' road administrations. Because the pre-set road variables differ between countries, national road databases have to be integrated with the web based maintenance tool. National road databases currently contain most of the above stated variables, but lack in segment resolution, which makes it hard to connect geographical positioned measurements with segments. To accurately connect pavement quality measurements with segments a resolution of under ~150 meter is necessary.

In the current system set up the MOBI-ROMA quality grade is defined according to a non-linear representation of worst pavement quality found in the Gothenburg area and a newly paved highway in the same area, measured using data from the CAN-bus from a Volvo V70.

The outcome of the validation of the pavement quality algorithms show that the pavement quality grade is closely related to IRI. Since the main input parameter to the pavement algorithms is lateral vibrations, deep rutting might affect the pavement quality grade to some extent, but no further investigations regarding this could be performed due to hardware restrictions. This is due to restriction in the CAN-bus signal list, as of now no vertical acceleration signals are available for retrieval through the OBD2 outlet.

Signal comparison is affected negatively by a significant difference in time between measurements provided by the Swedish Transport Administration and measurements performed within the MOBI-ROMA project. This means that maintenance work could have been performed during the one year time difference. Another source that affects the results negatively is the coordinate matching. All MOBI-ROMA measurements are attached to a geographical coordinate and the validation set provided by the Swedish Transport Administration is attached to a distance (meter) from start variable. Converting the GPS positions into distance was done using the Haversine formula between each coordinate, using a start and end coordinate. [9] [10]

The MOBI-ROMA measurements have a resolution of one value per second, due to hardware limitations. Measurements provided by the Swedish Transport Administration have a resolution of one value per 20 meters. In clear terms this means that results generated by the algorithms have a lower resolution in velocities over 72 km/h. [9] [10]

Each stretch was measured in the right drive lane and in the stated speed limit of the specific road stretch.

The correlation between the MOBI-ROMA quality grade together with its color representations and IRI is not trivial. Several parameters influence on how the exact values should be mapped together. The mapping mainly depends on country specific IRI-thresholds, vehicle velocity and AADT. Other factors also affect the correlation, such as repeatability, road type, road category and filtering affects. An approach where all MOBI-ROMA values that lie above the IRI-threshold are seen as of poor quality and are represented by a MOBI-ROMA quality grade over 7. The values that are within 20% under the IRI-threshold are seen as average quality, a MOBI-ROMA quality grade of 3-6. All values below 20% are seen as good quality (green).

It is clear that presently used alternative methods provide more exact results. However, the strength of the MOBI-ROMA method is that it is very cheap, does not need a specialized measurement truck and cover large geographical areas. At the same time it is shown that in-vehicle sensors are able to deliver results comparable with IRI data measured with laser equipped measurement vehicles.

3.2 Method for spring thaw analysis

Road weather information together with indications from an advanced, purpose-built hardware are collected and stored in a central database. By using meteorological information the road weather model classifies the risk of spring thaw within an area of 20x20 km. The risk is divided into three classes: low, medium and high risk of decreased load bearing capacity. An overview of the system is shown in Figure 22.

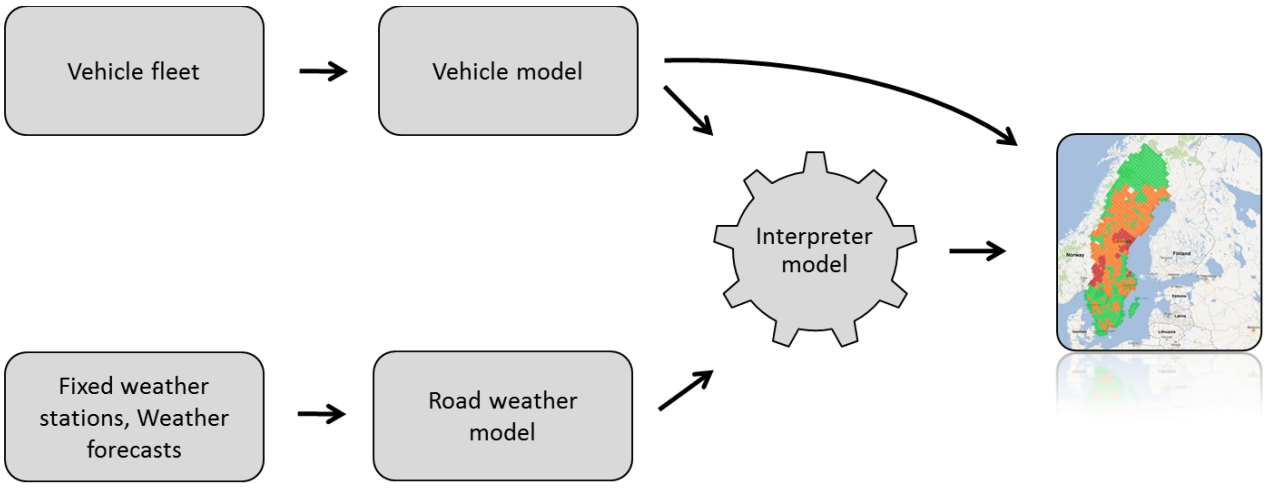


Figure 22, BiFi system overview

The hardware unit, placed in the vehicle feet, is equipped with a powerful processor, accelerometer, gyro, modem, GPS, battery and SD-card. The main sensor is the accelerometer, which is used to detect lateral vibrations. The vibrations are then run through several filters and algorithms, developed in BiFi (II), before a result is put out. The result consists of a classification grade, coordinates and a timestamp. When the vehicle is turned off the battery takes over and the data is transferred, using 3G/GPRS, to a central database.

Figure 23, Purpose built hardware with front connections visible

Figure 24, Purpose built hardware with back connections visible

As the vehicle drives through corners on a dirt road the hardware unit records the data coming from the accelerometers. This data is then processed and a judgment is made to whether the road is hard or soft. The result, together with a timestamp and GPS coordinates, is stored on the SD card until it can be transmitted. Due to lack of 3G/GPRS coverage in rural and forest regions and interference from other systems active in the vehicle the data is stored until the vehicle has come to a rest and the ignition is turned off. The hardware's internal battery supplies power as the data is uploaded to a central database from where it is accessed and analyzed.

The vehicle algorithm uses the vehicle's vibrations to detect whether the road surface is soft or not. For example, lateral acceleration occurs when the vehicle drives through a corner and the centrifugal force applies a lateral force on the vehicle, pushing it outwards. The roughness or softness of the road then affects the vibrations of the vehicle.

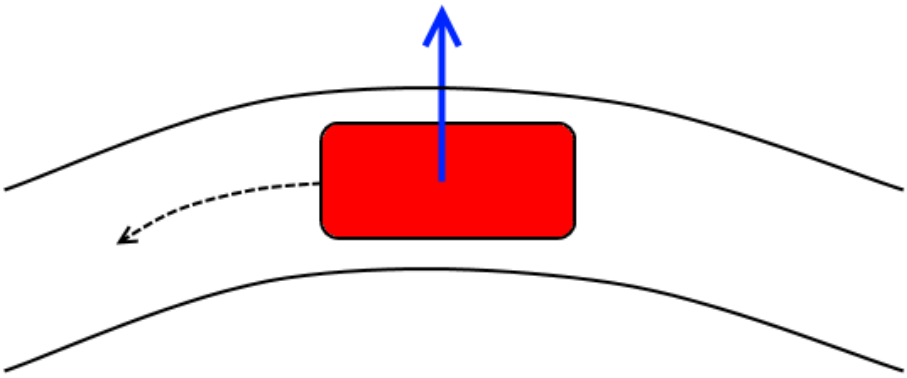


Figure 25, Centrifugal force generating lateral acceleration that creates vibrations in the vehicle

The vibrations are analyzed and different road surface characteristics can be found. Tests in BiFi have shown that relatively small vibrations are enough to generate a good result.

The algorithm contains four main parts that all have veto when a spring thaw indication is generated. The four parts use different parts of the vibration signal together with the vehicles velocity.

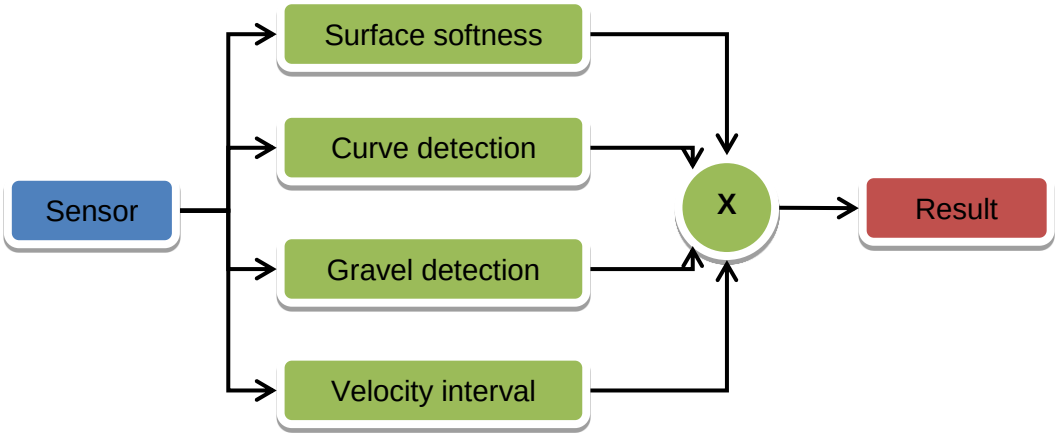


Figure 26, Hardware unit model overview

Part one analyzes how much energy the vibration signal contains after passing through a number of filters. The second part is activated when the vehicles lateral force is large enough and part three decides whether the vehicle is located on a gravel road. The last part decides whether the vehicle is within a reasonable velocity interval. For a more in detail description of the hardware unit model see referenced BiFi report [7].

The output from the hardware units are available in the MOBI-ROMA web based maintenance tool as color coded indication attached to the geographical position where the measurement took place. An example of the output is shown in Figure 27, where the orange/red markers indicate that there is high risk of decreased load bearing capacity and the green markers represent low risk of the decreased capacity.

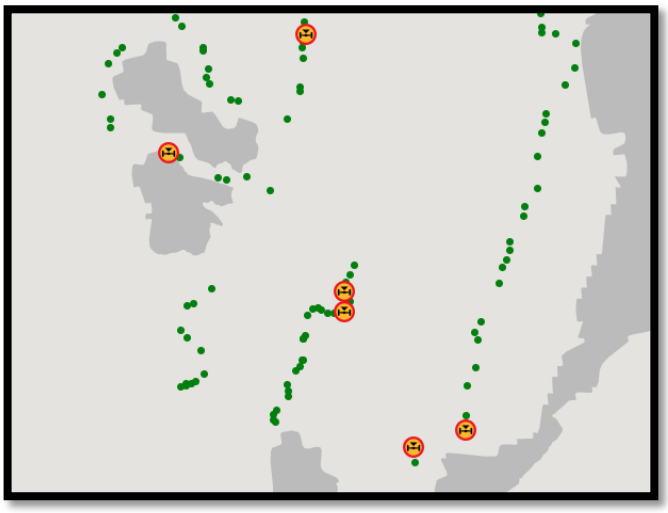


Figure 27, Surface softness result generated and uploaded by the hardware unit

The next major step in the BiFi system is to compare data generated by the hardware units with data from fixed weather stations and weather forecasts. In Sweden, this is done in a road weather model which is based on a modified energy balance model. The road weather model collects data from fixed weather stations and weather forecast data from national weather providers to compute a road weather forecast. The output is given as around 30 000 squares (4x4 km), seen in Figure 28, where each square contains a computed risk of surface softness within the square.

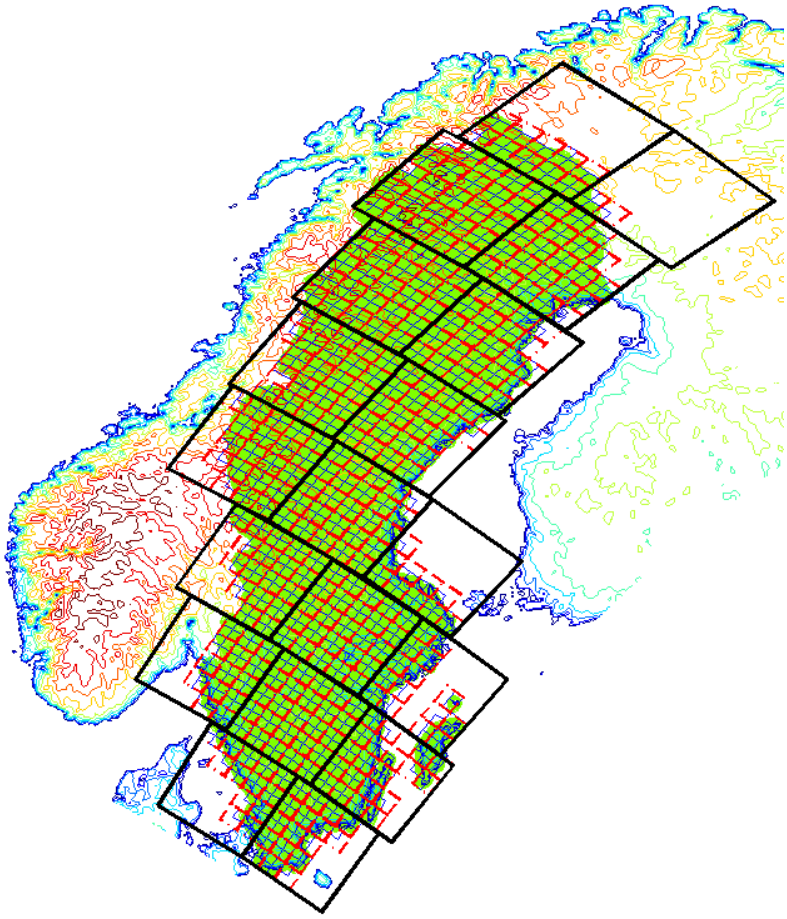


Figure 28, Road weather forecast squares covering Sweden

Data from the hardware units are then attached to the 4x4 km squares and an interpreter model generates more accurate results. The interpreter takes into account data from the vehicle fleet and merges it with the road weather forecasts.

To increase reliability and ease work load on the web based maintenance tool all squares are merged into 20x20, 40x40 and 200x200 km squares. Each square is assigned a color; green, orange or red. Where red squares indicate high risk of surface softness within the area, orange medium risk and green low risk. An example taken from the web based maintenance tool is shown in Figure 29.

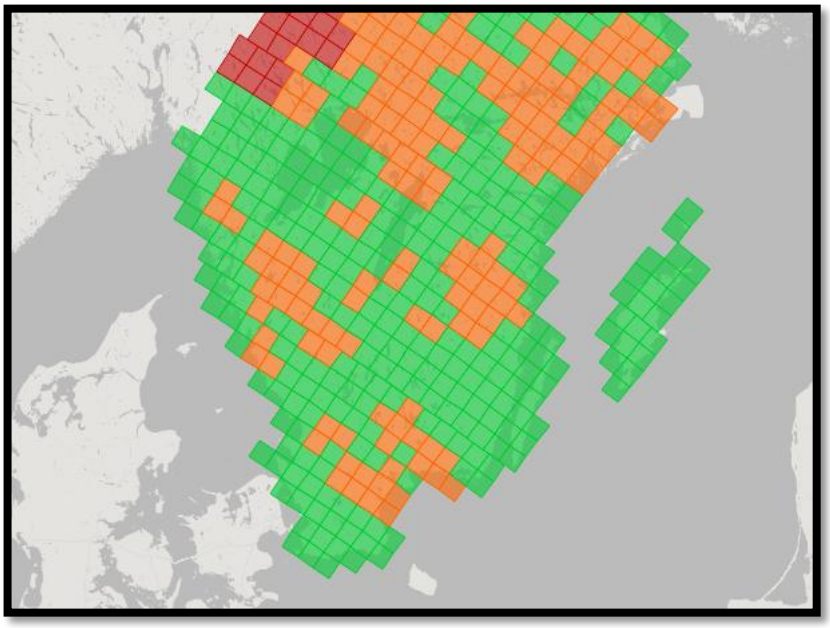


Figure 29, Final result generated by the interpreter model

3.2.1 Validation

The vehicle signals have been tested against a dynamic cone penetrator, DCP. Which is a hand held device that consists of a rod on which a cone is repeatedly forced into the road material by the action of a hammer weight being dropped from a constant height. The results can then be computed into a load bearing value; California Bearing Ratio (CBR) and compared with the system output generated by the interpreter model. DCP has been recommended as a functional and effective method for measuring bearing capacity in unbound materials [11]. During the first BiFi project tests were also performed using fall weight deflectometer (FWD) as an alternative method, it was however not found to be suited to measurements in saturated gravel.

CBR values are proportional to the shear strength of the material, a property which is controlled by several factors: grain size, grain shape and water content. In the context of ground frost, the water content plays a very important role in reducing the shear strength of the material. As the amount of pore water increases so does pore pressure and the water effectively forces the particles apart, thus reducing contact between grains and therefore the shear strength of the material. As the ground begins to thaw from the surface and down, water is trapped in the surface layer by the frozen material below. The effect of this is that the surface layer is saturated with water, decreasing the shear strength and the bearing capacity of this layer.

Table 8 CBR% values for a range of materials. There is an overlap between materials and conditions of same materials. A saturated gravel road can be as soft as clay. Values where obtained during BiFi (I), and more information can be found in BiFi Project report appendix. [7]

Material type	CBR %
Clay	0-10%
Sand	10-20%
Saturated gravel road	10-40%
Unpacked gravel road	20-50%
Wet packed gravel road (Wheel tracks)	50-100%
Dry packed gravel road (Wheel tracks)	80-170%
Frozen gravel road	140-600%

When considering a network of gravel road there is a large variability within the road network as to the timing and severity of the spring thaw. This means that any method of determining the severity of the spring thaw that uses point measurements is limited to the amount of measurement points. For the purpose of BiFi we used the average CBR value from a set number of points as reference value. The outcome was also compared with historical weather information. And the results show that when we have an increase in the ratio of soft/hard indications from the vehicles there was a corresponding decrease in CBR values, see Figure 30. At the point when the ratio of vehicle signals reached 40% the CBR values for the same area had dropped below 30%.

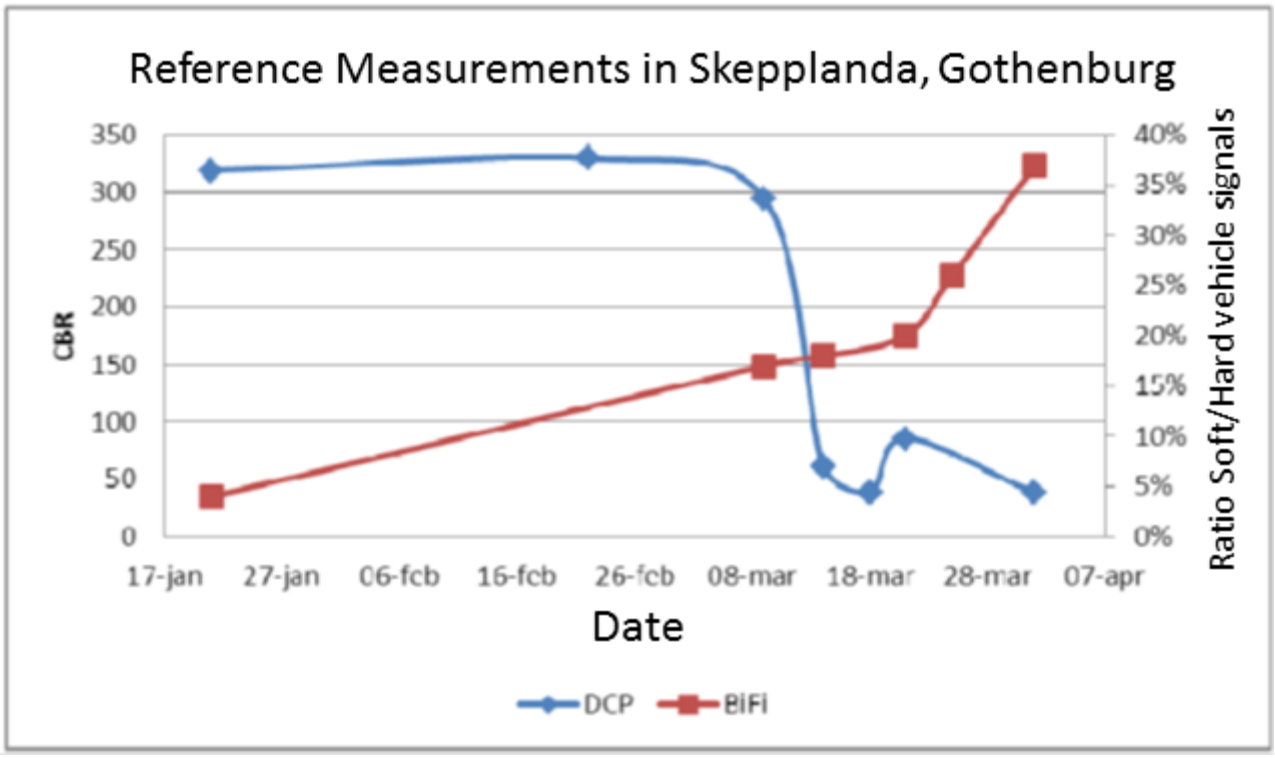


Figure 30 shows average surface CBR values on left axis and percentage of signals that indicated soft surface. The CBR values are calculated as the average of 7 measurement points along the 5km long test road.

Determining the limits for red, yellow and green to be used in a situation as is shown in the schematic in Figure 31, was done by comparing CBR values with vehicle signal ratios. When the ratio is more than 22% the system classes the area as red on the map, warning for the risk of low bearing capacity. There is a baseline ratio between soft and hard signals of ca. 5-8%, meaning that the vehicles as they were equipped during the last trials give false positive indications for surface softness. See Appendix A.3 for more details regarding reference measurements.

At this point in the development of the system the limits are set low intentionally to ensure that the system should be within the margins of error.

During the winter season (2012-2013) a demonstration project funded by the Swedish Transport Administration will seek to test the system in an operational environment and to better establish the connection between the BiFi warning categories and the bearing capacity of the gravel roads.

Table 9 Definitions of the BiFi warning categories. Currently the limits are defined as the ratio between soft/hard vehicle signals: green<12%, Yellow between 12-22% and Red >22%.

	Surface softening in large parts of the area. Heavy vehicles are advised not to operate in the area.
	Surface softening in parts of the area, alternatively no information. Heavy vehicles should use caution when operating in the area.
	Surface softening not indicated in area. Heavy vehicles can operate in area.

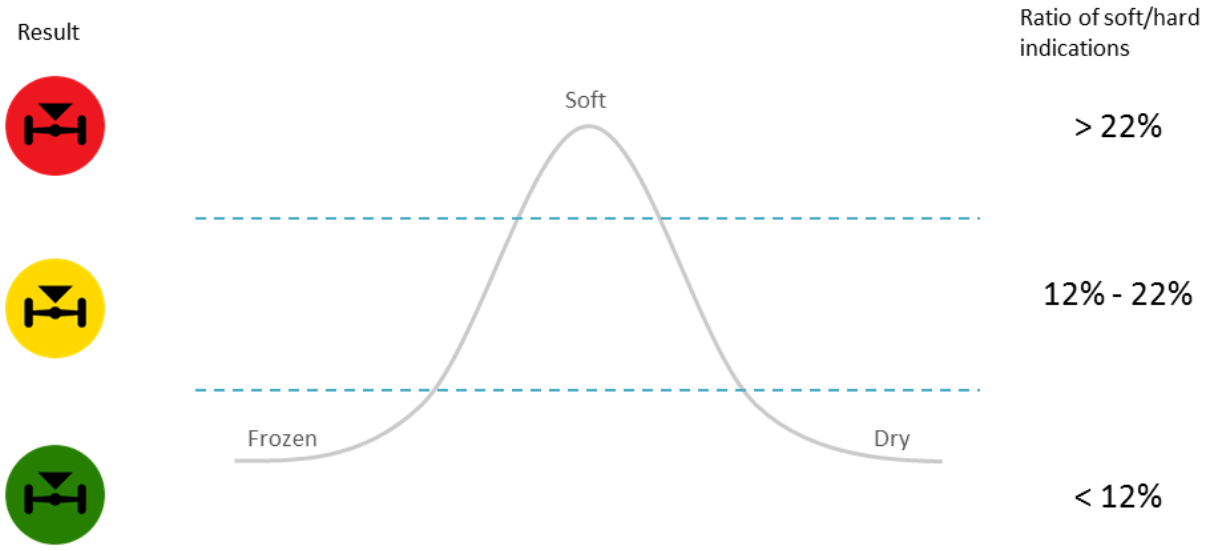


Figure 31, Schematic of distribution of high risk signals over a season and risk categories As the risk categories are defined in the current version of BiFi, green<12%, Yellow between 12-22% and Red >22%.

3.3 Method for slipperiness analysis

A SRIS system model is used to process weather and vehicle information to produce useful output information. Road weather information together with indications from vehicles standard safety systems are registered and stored in a central database. The vehicle data is fetched from the CAN-bus network through the OBD2-outlet. By combining these two data types reliable information about winter road conditions are collected.

The SRIS system model is built up by three main parts:

- Vehicle model
- Road weather model
- Interpreter model

For the SRIS system model to work the road network has to be divided into smaller segments that are connected to nearby road weather stations. By using meteorological information the road weather model classifies the slipperiness of each segment. The classification is divided into three risk categories: not slippery, slippery and very slippery. The output from the road weather model is then compared with the output of the vehicle model. The number of vehicle indications per segment then decides whether to discard or strengthen the road weather models classification.

The final result is presented by the interpreter model. The interpreter model also allows several parameter adjustments.

Figure 32 shows a schematic view of the SRIS system model. Data used as input by the model comes from two main sources, floating car data and weather related data:

1. Floating car data is delivered in real-time from the vehicles into the interpreter model; data includes air temperature, event data and spatial data. The data is weighed against the RWIS system.
2. The road weather model collects external RWIS data and weather forecasts. It also uses floating car data that has been processed by the interpreter. The road weather model produces a forecast which is sent back to the interpreter. Air temperature data from vehicles is used to iteratively adjust the road weather model as new data is delivered. Furthermore event data is used to amend the road status, producing a more accurate forecast.

An overview of the SRIS system is shown in Figure 32.

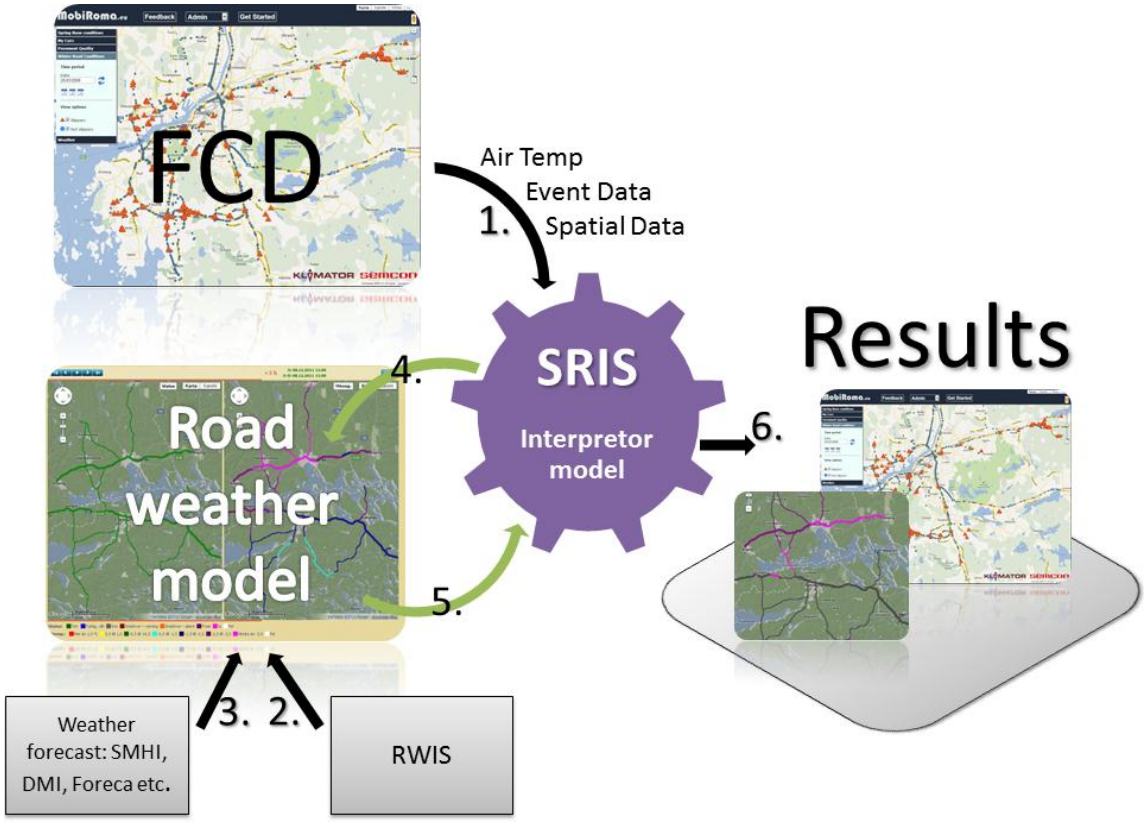


Figure 32, SRIS model overview

3.3.1 Validation

Relation between signals from the vehicle fleet and actual road conditions

The data collected from the vehicles are classified as “event data”, and are parameters that directly or indirectly are connected to road friction; the anti-lock brake system and the traction control system. When either of these is activated a signal is sent with the action and position. These systems can be provoked by aggressive driving when the road is dry and not slippery. However these false positive signals are few in number and add up to 0.84% of signals in dry non-slippery conditions.

In summary, the active systems in the car that helps the driver can be triggered in two ways:

- Through aggressive driving, i.e. driving too fast.
- Through reduced friction between the car and pavement.

In the early stages of SRIS there where several small scale tests, to test the hypothesis that vehicle data could give information concerning road weather status. A Volvo V70 was equipped with a CAN-Bus logger and the signal pattern was compared during different weather conditions. As seen in Figure 33 the amount of “event signals” correspond closely to the road conditions. This is also mirrored by the statistics from the season of 2007–2008 seen in Table 10.

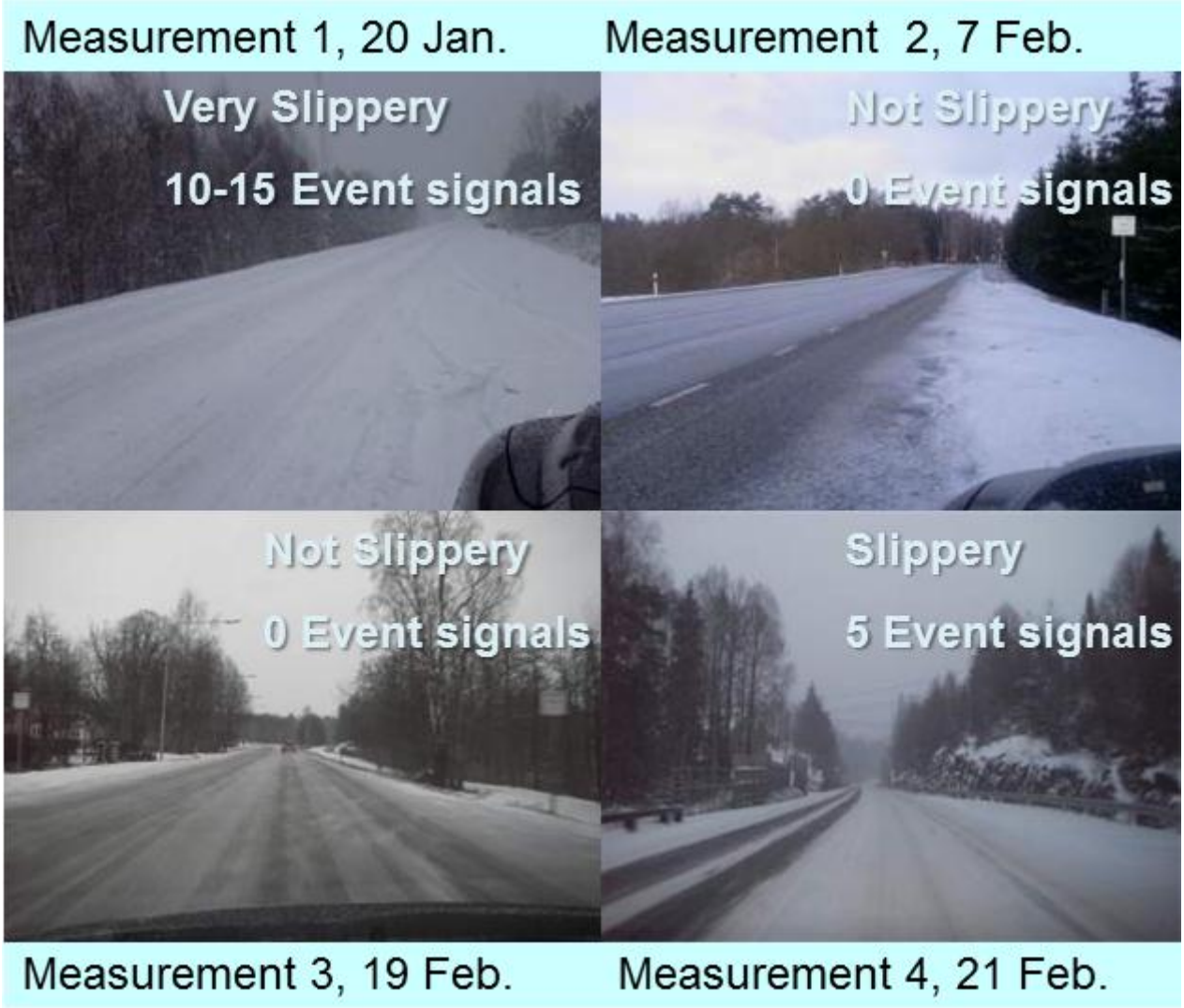


Figure 33 Validation measurements. Amount of event indications registered during different weather conditions.

For the statistical analysis, road weather data was collected from road weather stations during the seasons of 2007-2008 and was then sorted using an expert system[9] to classify the different types of slipperiness. The signals from the vehicles were sorted with regard to the type of slipperiness that was registered at the closest road weather station.

Table 10 shows the allocation of event data and background data, based on type of slipperiness. As Background data is sampled every 30 seconds, the variable Events per hour can be calculated. It is noticeable that the difference between the event rate during slippery situations and non-slippery situations is large. To test if the difference (i.e difference between dry conditions and the other weather conditions) is significant, a two-proportion z-test was conducted. If the z-value is larger than 2.6, the difference is significant on the 99%-level. The z-test shows that there is no significant different difference between the event frequency during dry and rainy conditions, which indicates that the roads were not slippery. For the weather types that suggest that the roads were slippery (Rain on cold road, Snow and Frost), the difference of event frequency compared to the dry conditions was significant.

[9] Norrman, J., Eriksson, M., and Lindqvist, S. (2000). Relationships between road slipperiness, traffic, accident risk and winter road maintenance activity. Climate research, 15:185-193.

Table 10, Distribution of event and background data in relation to weather conditions. A z-value calculated by a two-proportion z-test greater than 2.6 shows that the difference is significant on the 99%-level.

	DRY / NON-SLIPPERY	**RAIN**	**RAIN ON COLD ROAD**	**SNOW-SLIPPERY**	**FROST SLIPPERY**
Events	10861	1512	1126	3256	789
Background	1291426	174314	13459	27764	30659
Events per hour	1,0	1,0	10,1	14,4	3,1
z-value	**0,0**	**0,2**	**11,8**	**23,2**	**4,2**

Not only was the vehicle data good at mirroring the prevailing road conditions but the data also showed that the vehicles could detect situations that the RWIS system failed to predict. The following illustrations, seen in Figure 34, show a sequence of information from road weather stations (blue) and reported events from vehicles regarding slipperiness (red).

The first figure shows the RWIS stations warning for slippery conditions. At this time there are only sporadic vehicle indications.

As the day moves on it takes an hour until vehicle signals mirror what the RWIS show. This continues until the afternoon and early evening when the warning from the RWIS network decrease. However instead of decreasing in conjunction with the RWIS, the signals from the vehicles keep coming in.

Between 17.00-18.00 there are almost no warnings from the RWIS left, and still indications of slippery conditions from the vehicles in the area. This indicates that the vehicles have the ability to detect slippery conditions that the classic RWIS network misses.

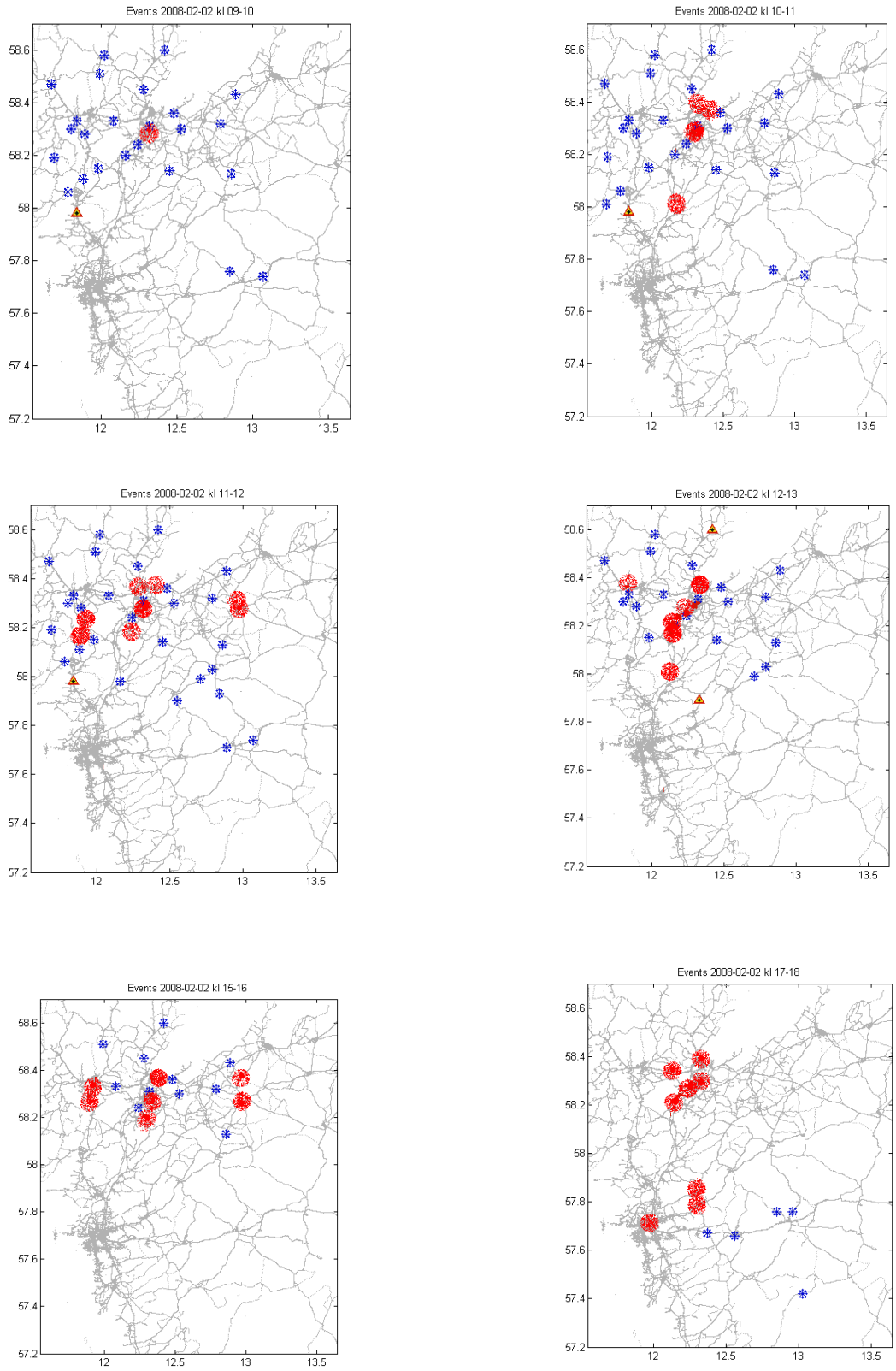


Figure 34, Collection of figures that show the indications from the vehicle fleet versus fixed weather stations. Blue snowflake: RWIS station indicating slippery conditions, Red snowflake: Vehicles indicate slippery conditions.

This same pattern is visible when comparing with Figure 35 which shows precipitation and road condition as well as the amount of event detections from the vehicles for the same time period as Figure 34.

On the morning of February 2nd, there is a snowfall that lasts until midday. As snow starts to fall, there is an increase in events from the car fleet. However as the snowfall stops in mid-afternoon there is still a large amount of event data reported from the vehicles. In contrast to the snowfall on the evening of January 31st that although it is comparable in magnitude does not produce the same amount of events.

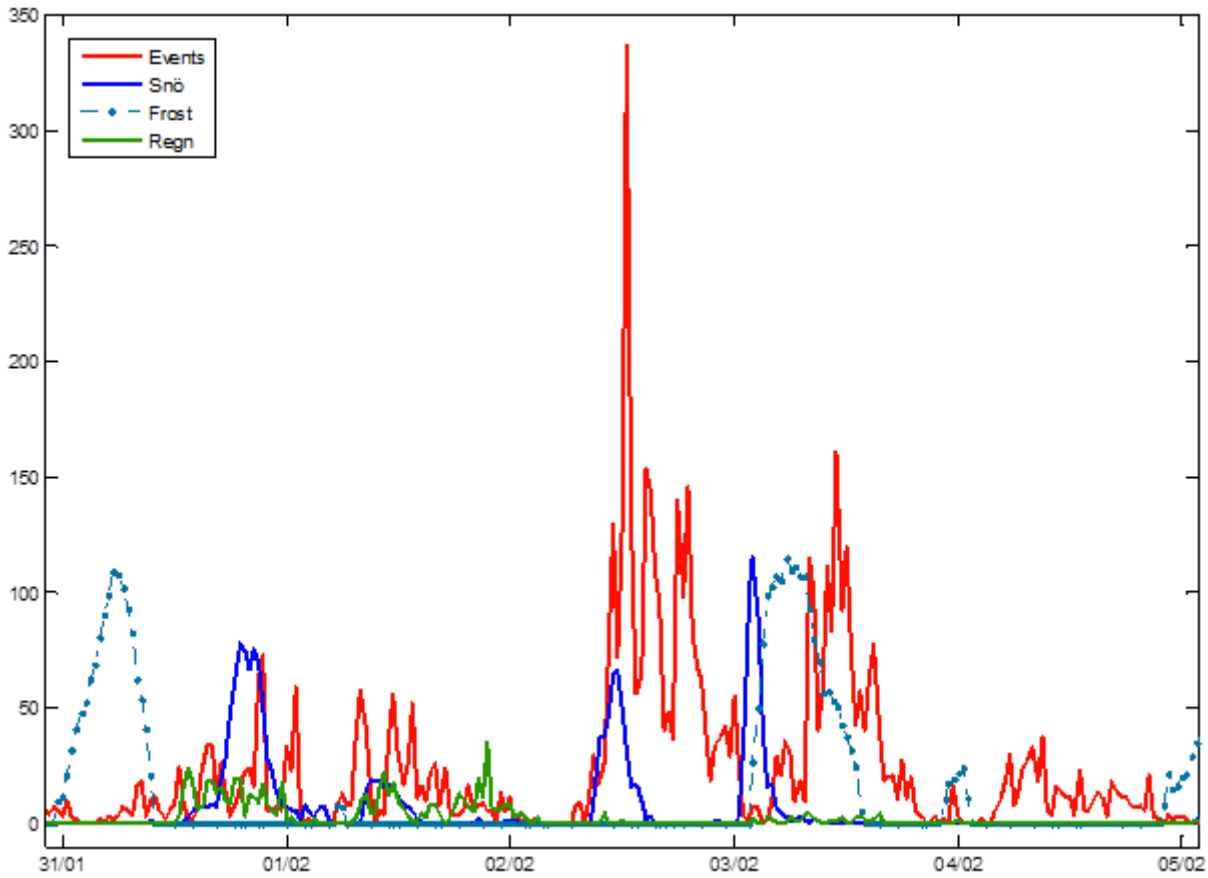


Figure 35 2008: 31st of January to the 5th of February. Red: Events, Blue: Snow, Dotted: Frost, Green: Rain.

These figures show that with road weather stations as the only data source it is difficult to predict what the conditions on the roads actually are. They also show that the SRIS floating car data can detect slippery conditions when the road weather stations do not catch the slipperiness. However there are limitations to the SRIS approach, and the main limitation is framed by the amount of vehicles that are connected in a given area at a given time, this means that the fleet that is supplying data must be sufficiently large so that it covers the area of interest.

SRIS data ingested into the maintenance tool

The ingestion in the MOBI-ROMA GUI gives the user the ability to access the data in a way that the original SRIS project never enabled. The background data was collected from vehicles at regular intervals, delivering the location and air temperature. In the GUI the temperature as well as the position is displayed enabling the user to get an overview of the amount of events as well as the temperature interval that the fleet is experiencing. The Google Maps environment also enables detailed zooming, letting the user to accurately see where the event data is coming from. As with the GUI for the pavement quality there is the possibility of adding more detail, as well as producing averages and statistics for stretches of roads and areas, features that are valuable for the end user wishing to optimize their winter maintenance operation or the local road authority given the task of oversight.

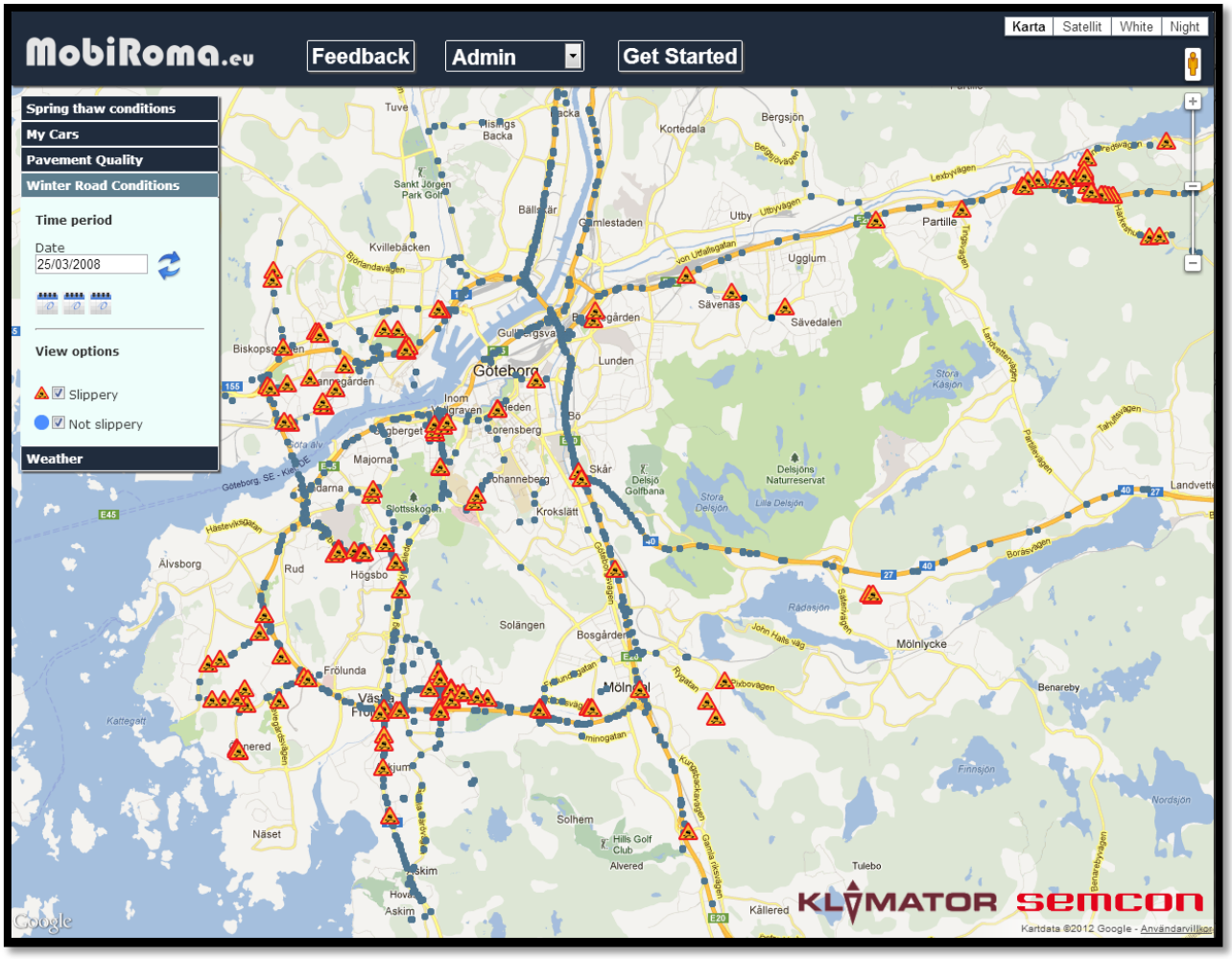


Figure 36, The 25th of March 2008, Snowfall in Gothenburg causes slippery conditions.

4 Assessing needs of maintenance with MOBI-ROMA

The European road administrations can use FCD as a novel source to provide information on the road network to allow and to increase the amount of data on which assessment of maintenance needs are based. Methods applied today focus on accuracy, which for practical and economic reasons decrease the total amount of roads that are measured. MOBI-ROMA provides a complimentary source of information to help the decision making in various specific road maintenance needs.

4.1 Pavement quality maintenance

Presently pavement quality is measured with laser equipped measuring vehicles, which is very exact but an expensive method. In Sweden the aim is to measure all roads with road number < 100, including the European road network, once every year. Roads with AADT > 4000 are also measured every year. This is in most of the cases done in the right lane in one direction. The average sized roads are measured every fourth year, in one lane and direction.

It is clear that the present method provides a limited information base on which maintenance decisions are based. To cover the majority of the road network, measurements in all lanes, and in both directions have to be done using vehicles that are already there driving for other purposes; e.g. while going to work, to the gym, to the holiday cabin, etc. This is where the strength of MOBI-ROMA and its use of FCD come into play, proving the road administrations with data for the complete road network with reasonable extra costs. MOBI-ROMA would in this case provide post-season information, which makes it possible to find degradation of specific roads that differ from the pre-set maintenance plans. [6]

Road managers are also able to adjust the tool to their own specific needs and quality thresholds according to national maintenance practices. In Chapter 3.1.1. the threshold table adjusted to the operational use for the Swedish Transport Administration is shown, but other countries and Road Administrations could tailor the scale and limits to better fit to their local practices.

4.2 Dynamic regulations of load restrictions

Information related to spring thaw can be divided into real-time and post-season. The real-time information allows for an objective and dynamic regulation of gravel roads to decide which of those should have a downgraded load bearing capacity. In a fully operational version of MOBI-ROMA system, the situation could be analysed on a daily basis at local level, covering the gravel road network extensively. As with the previous pavement quality application, the load bearing capacity thresholds can be adjusted according to local regulations and practices.

The decision making is today done based on measurements by road maintenance personnel using experience and visual inspection as methods for determining weight restrictions. However, as experience varies from person to person and visual inspection is notoriously difficult, this method can be very subjective and ambiguous. In present economic situation the old method is also too inefficient. This leaves gravel roads closed for too long periods and as a consequence the lumber industry is cut off from their products, causing delays and economic losses. With MOBI-ROMA however, the decision making can be improved both in temporal and spatial scale, minimizing the negative effects of spring thaw.

The post-season spring thaw information could be used to find problem areas, which then could be addressed before the road degrades to a limit where it has to be closed.

4.3 Winter maintenance needs

Slipperiness is difficult to forecast if only based on weather information from fixed station network and thus the use of FCD information is of high importance. By combining the two sources of information a much more accurate picture can be found, allowing traffic to travel more safely on the road network. It also provides the road administrations with an information base upon which decision regarding timely winter maintenance measures can be set and planned. However, the quality of mobile information depends on the size of the vehicle fleets.

In operational road weather forecasting, early warnings of slipperiness are the most valuable ones. Winter maintenance actions should be pre-emptive rather than reactive. Thus MOBI-ROMA system having very high spatial and temporal resolution on the road network provides a new beneficial source of slipperiness warning information that is readily exploitable in daily road weather services.

In addition, slipperiness data gathered from FCD system can be used in historical analysis evaluating the actions of maintenance contractors and how they have fulfilled the respective quality levels in winter road maintenance.

Archived data can also be used to analyse and find the problem spots on the road network, those that freeze more often and earlier than the average. These can then be treated proactively using the appropriate winter road maintenance measures.

4.4 Other MOBI-ROMA benefits

As stated above there are mainly two types of data; real time and season based. The real time information supports road administrations and their subcontractors in the daily maintenance work, indicating possible problems before there are real noticeable flaws on either dirt or paved roads.

The season based information can be used in long term maintenance planning, where MOBI-ROMA information provides information that could cover a country's complete road

network. The road administrations can then do season-by-season or month-by-month comparisons and see if the degradation follows the pre-set maintenance plan.

Comparing MOBI-ROMA with existing methods is not straightforward, mainly since the alternative methods differ to such extent that it is hard to find methods of how to compare the different data types.

Pavement quality however has alternative measurement methods in form of laser equipped measurement vehicles. In today's MOBI-ROMA system the laser measurements win in almost all categories; resolution, accuracy, number of parameters, etc. But the fact that FCD uses existing vehicles that already fill the complete road network allows for a complete coverage, which is something that laser equipped vehicles won't achieve.
This allows for less accurate measurements focused on the road network with average/low sized roads or roads with low AADT.

MOBI-ROMA both complements existing information gathering techniques and provides novel techniques in new areas. It is also possible to ingest other measurements in addition to the three applications described earlier. As an example, collection of air quality data has been tested in small scale, one case shown in Figure 37. Once applied to a larger vehicle fleet, this would result in a fourth data type that could easily be inserted in a MOBI-ROMA service application. And it would be relatively easy to add any new FCD parameters to the system, once they become part of the operational measuring routine.

In summary, MOBI-ROMA provides both real-time and season-based information upon which road administrations can take decisions about maintenance needs both during and after the current season. The information is combined and presented without any manual work; therefore all gathered information can be seen as objective. In the next phase of MOBI-ROMA, a graphical user interface is developed for effective use of the system.

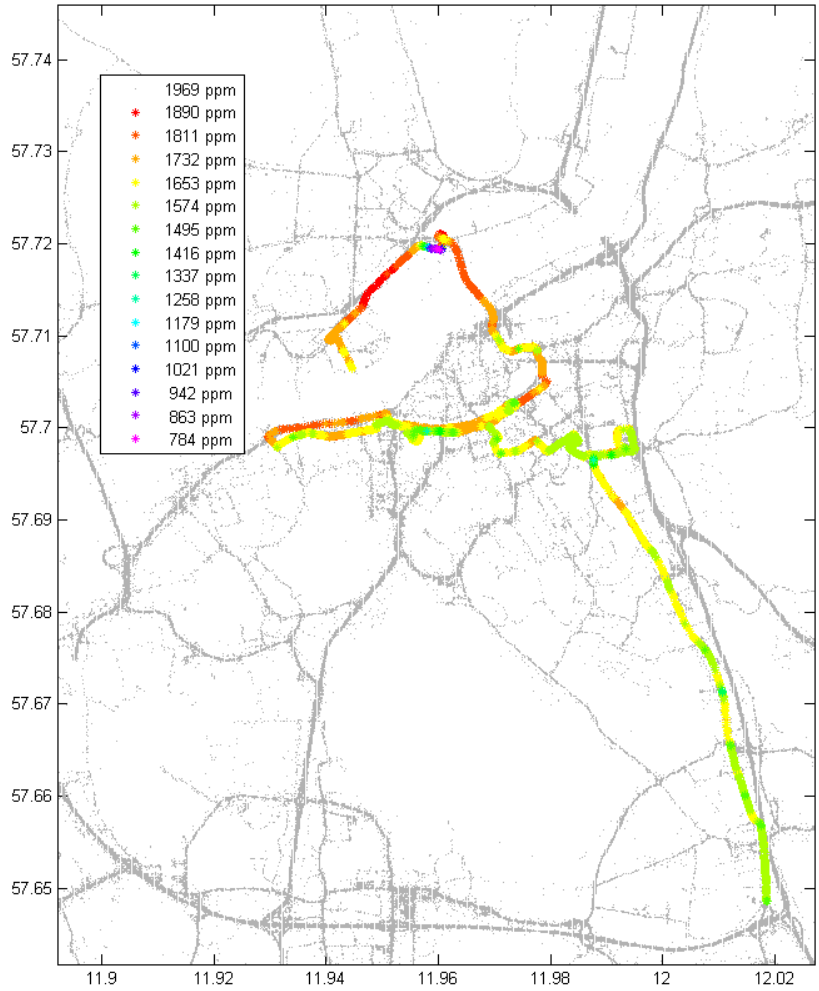


Figure 37 An example of mobile measurements of NO_2 in Gothenburg, Sweden.

5 Summary of results

This report has described the data collection and analysis phase of MOBI-ROMA. The three main data types utilized are spring thaw detection, winter road conditions and pavement quality estimation. All three types have been collected using the floating car data methodology. Spring thaw data has been generated in the on-going project BiFi (II) and data regarding winter road conditions are collected from SRIS.

It is possible to feed manually all of the above mention data types into the MOBI-ROMA system. Real-time spring thaw detection and pavement quality estimation data is ingested continuously as new data is available. Proper information channels that allow data to flow from vehicle to the database has been set up and maintained during the MOBI-ROMA project. This means that no manual transferring of data has to be performed between the sensor-equipped vehicles and the central database.

During the project time span, no car fleet was used to detect winter road conditions (slipperiness) and thus no real-time data was available for the MOBI-ROMA maintenance tool. Instead, SRIS measurements performed in 2007/2008 were inserted in the database manually.

The aim to collect and utilize data from surrounding projects has been achieved. Data from three external frameworks has been fed into the maintenance tool. This eases development of the graphical user interface and at the same time provides a base for evaluation and validation.

The majority of data collected during the project are spring thaw and pavement quality data. The real-time spring thaw information collected by postal vans has been utilized during the complete project runtime. Minor issues regarding data transfer have been detected and found to derive directly from poor cell phone reception in remote locations. The data not transferred due to this error could however be uploaded manually into the database. All pavement quality measurements have been done using the internal sensors in a Volvo V70, utilizing the CAN-bus to collect data. This data was manually added to the central database and made available in the maintenance tool. To perform algorithms validation, data were collected and compared with data from laser equipped vehicles provided by the Swedish Transport Administration.

Software related difficulties have been found during the data analysis process. The reason to this is that software has been modified to run in a web based environment. The outcome of this is that floating car data merged with road weather information has not been fully evaluated which might have slight effects on the MOBI-ROMA evaluation and validation process. Proper evaluation of data generated by the vehicle fleet has however been performed. This evaluation shows that detecting spring thaw phenomena on gravel roads can be done with good accuracy, as described in chapter 3.2.1.

In-depth evaluations of the pavement quality estimations have been performed during the summer of 2012. The evaluation shows that it is possible to detect poor pavement quality. The validations of the pavement quality algorithms, described in chapter 3.1.1, also show that there is a high correlation between the pavement quality grade and IRI.

The data collected within this project is relevant and accurate enough for the tests to be seen as fulfilling the preset objectives. The amount of data is large enough to test the performance of the maintenance tool. Having a large data set available in the maintenance tool also eases further validation of the MOBI-ROMA maintenance tool regarding usability and usefulness.

The MOBI-ROMA maintenance tool would have many specific uses to assess maintenance needs depending on the type of data ingested to the system. The tool can be used both in long term and short term assessments as described in Chapter 4. Validations show that the quality of data even at this early stage is sufficient for operational use, but quality would increase considerably once FCD fleets would be larger and data collection done comprehensively on a routine basis. Thus it is assumed that MOBI-ROMA system can be developed into a fully operational and useful new tool for road maintenance assessments.

6 Next steps

In order to demonstrate the applicability of systems that combine and process available data from fixed measuring field stations with floating car data a graphical user interface (GUI) is being developed. The advantages of combining data from several systems into one coherent maintenance tool will be demonstrated. Collected data will sparsely cover the northern and middle parts of Europe (Sweden, Norway, Denmark, Germany and Czech Republic). The GUI should be versatile enough to handle real-time floating car data and at the same time be able to present forecasts generated by combining data from fixed measuring field stations with existing weather forecasts. The data collection pilot performed in the on-going project BiFi (II) will continuously feed data into the MOBI-ROMA maintenance tool GUI. Data from pavement quality measurements and slipperiness detection will also be utilized when available.

Cost effective and proper road maintenance is very important and needs continuous access to reliable information. The project with its graphical user interface will demonstrate that information about road conditions and corresponding maintenance needs can be obtained in an on-line based web-application and applied for various decision-making needs that concern management of road surface conditions, winter road conditions or spring thaw.

Self-evaluation of the maintenance tool's graphical user interface will be performed. This will be supplemented by organizing user evaluations with stakeholders, first and foremost in the form of interviews with representatives of the national road administrations. Analysis on the benefits of the use of floating car data in road maintenance and traffic management related to national and trans-national applications will be performed.

7 References

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Appendix A – Pavement quality validation

All red colored lines in the following Chapters A.1 and A.2 represent the pavement quality grade, while the blue lines represent IRI measured by the Swedish Transport Administration. If there is a gap in the line, no data was available for the specific segment.

A.1 Stretch v.190 - Gothenburg-Nossebro

Stretch between Gothenburg and Nossebro, Sweden was validated. The stretch contains speed limits between 50 – 90 km/h. The stretch passes through minor cities were the measurements are uncertain due low velocities, i.e. at stop signs etc.

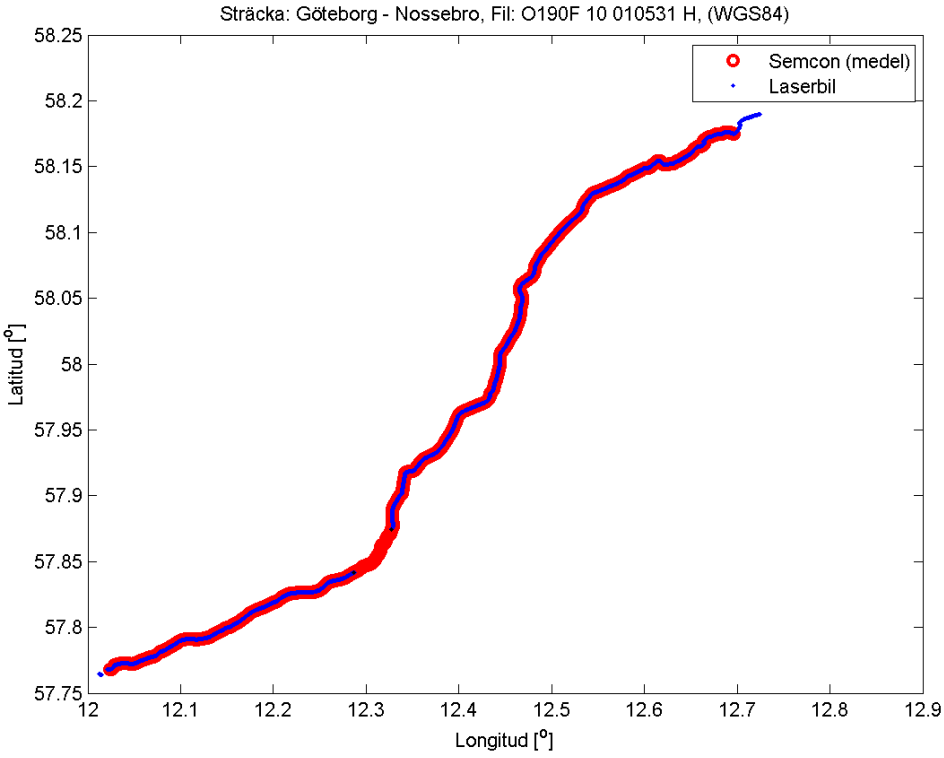


Figure A1, Stretch Gothenburg-Nossebro, Overview

Correlation, filtered over 100 meter

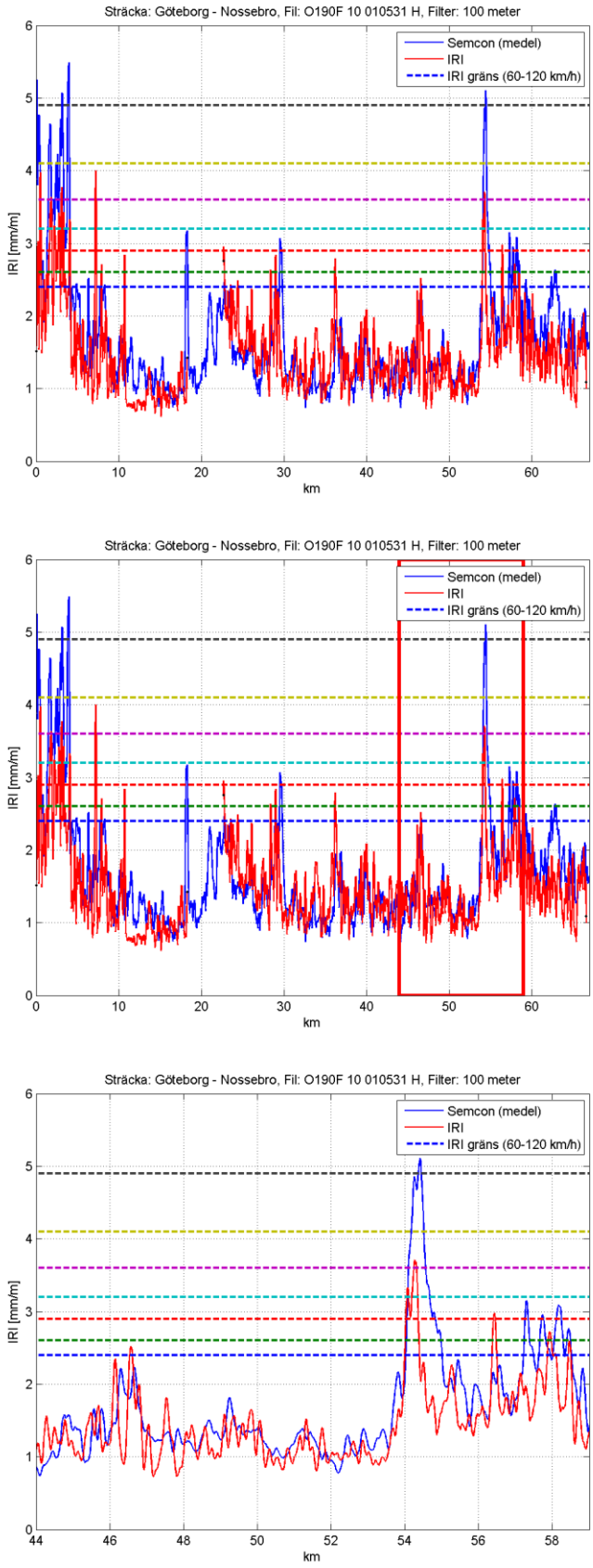
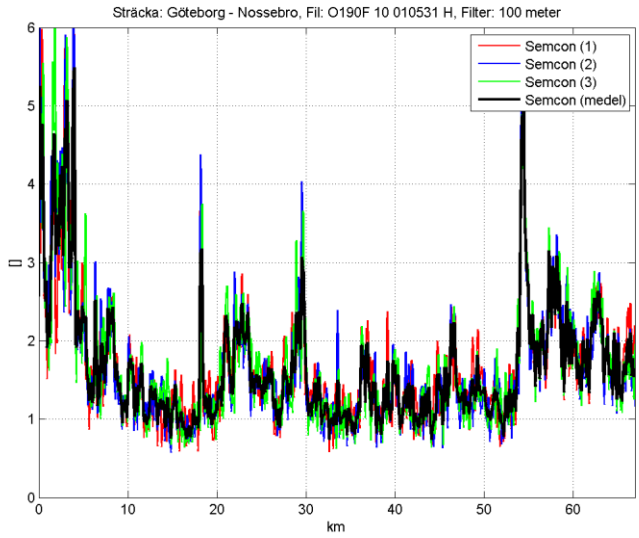
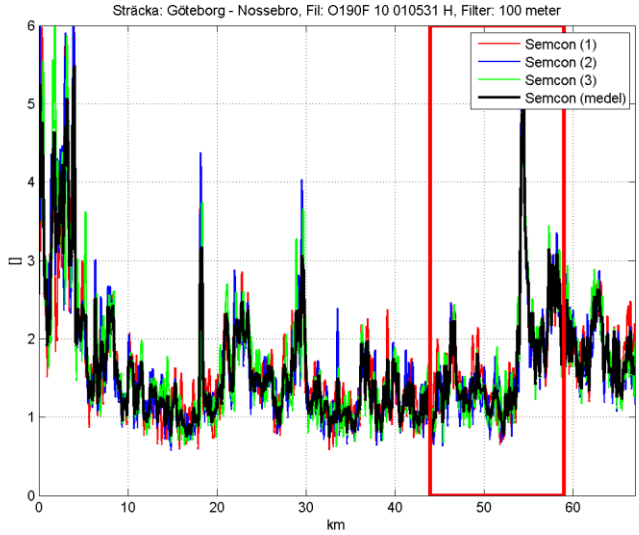
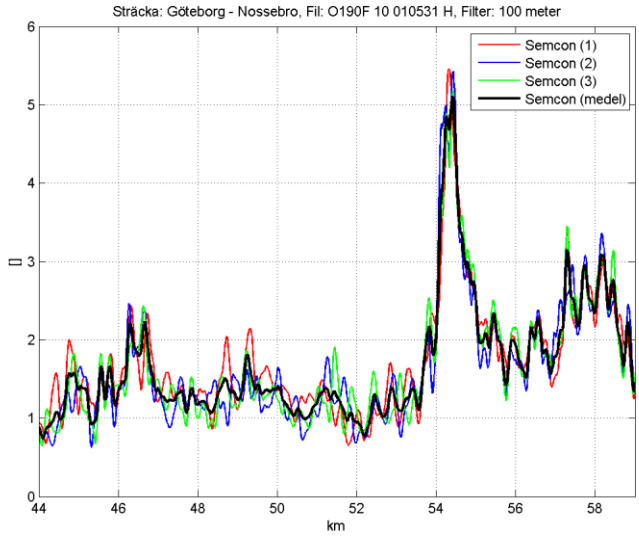


Figure A2, Gothenburg-Nossebro, Correlation, 100 m

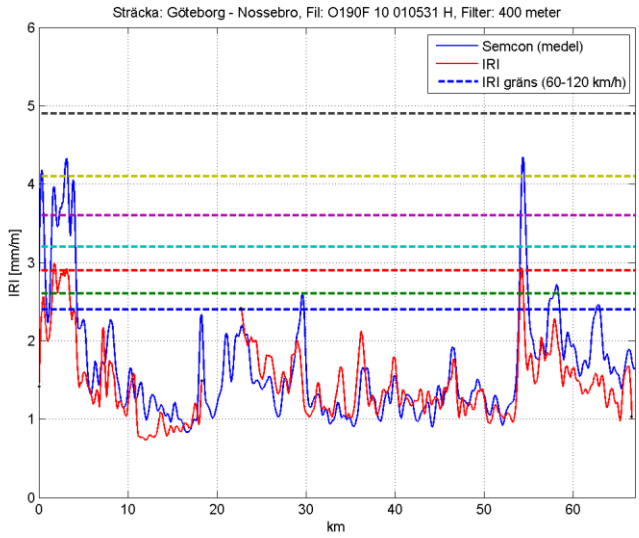


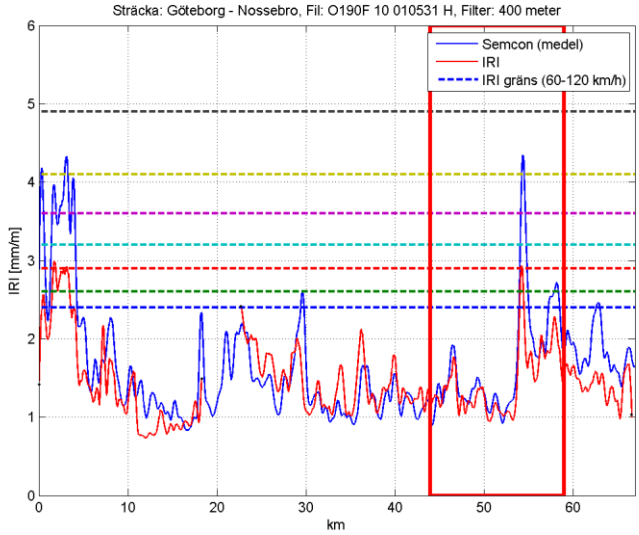


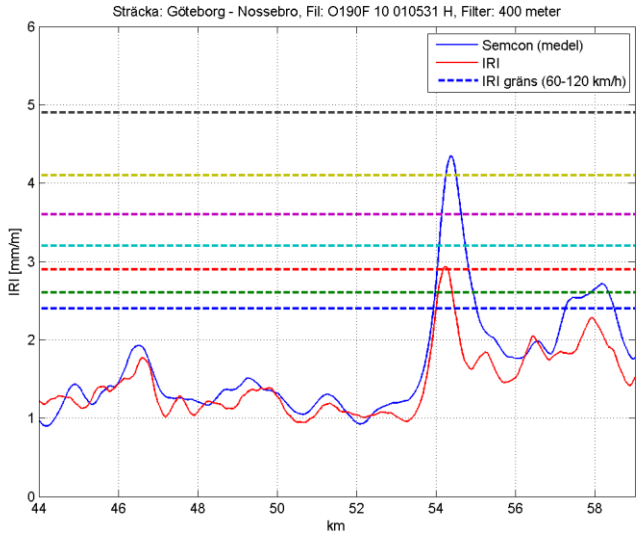


Repeatability, filtered over 100 meter

Figure A3, Gothenburg-Nossebro, Repeatability, 100 m

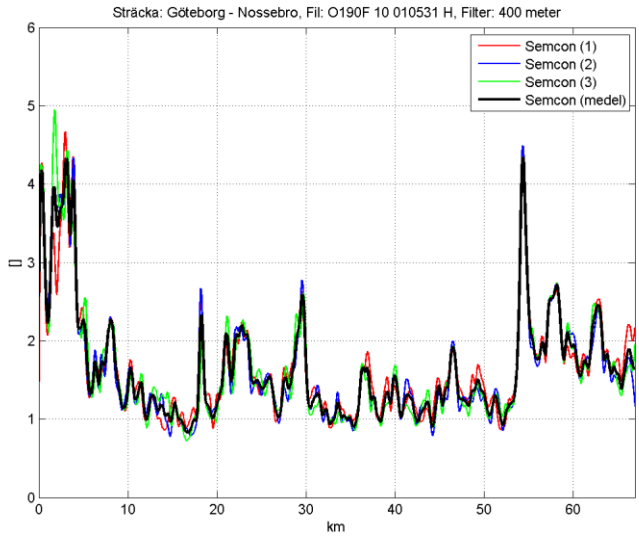


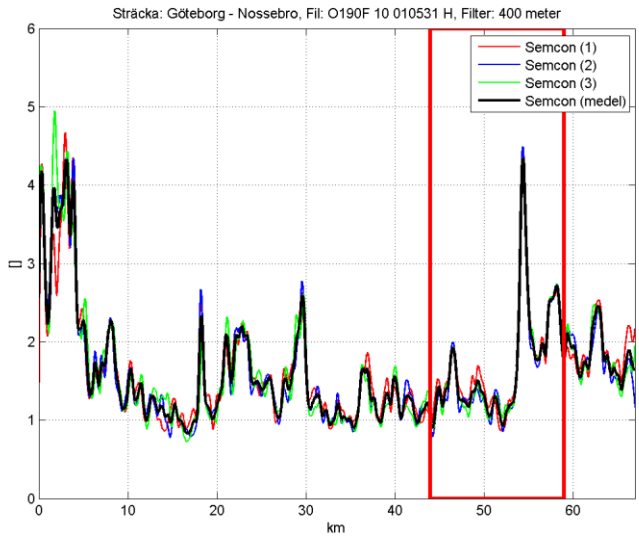


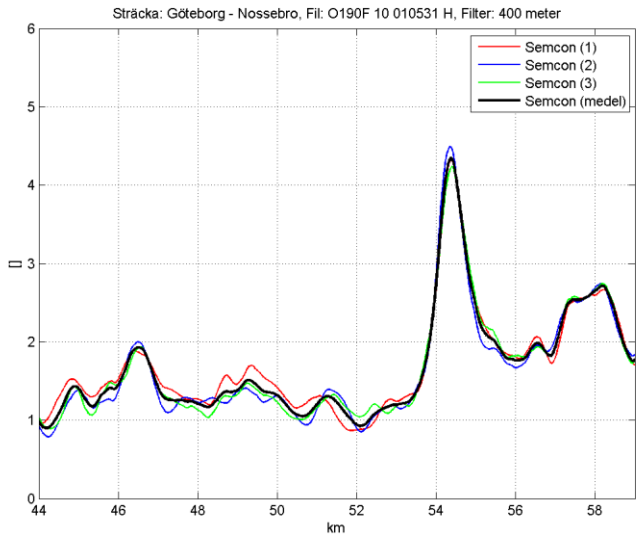


Correlation, filtered over 400 meter

Figure A4, Gothenburg-Nossebro, Correlation, 400 m

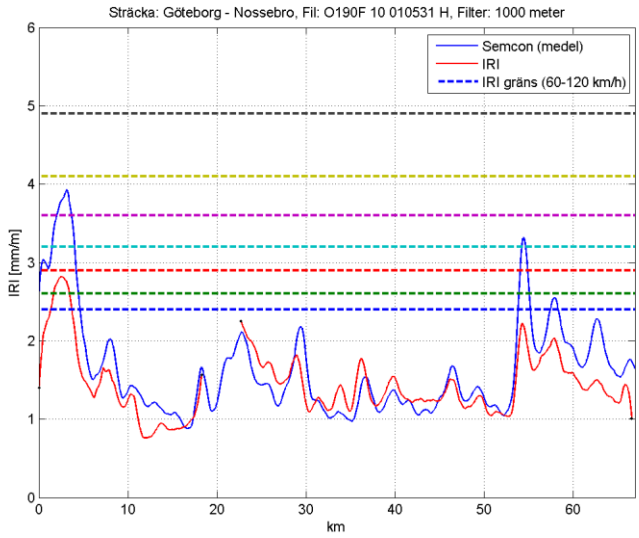


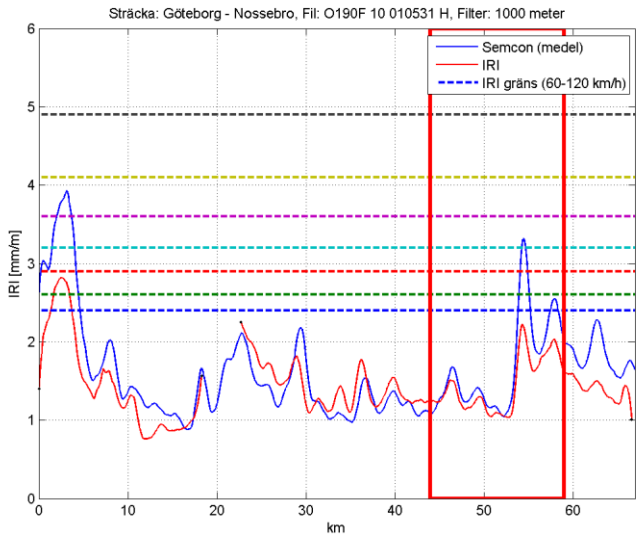


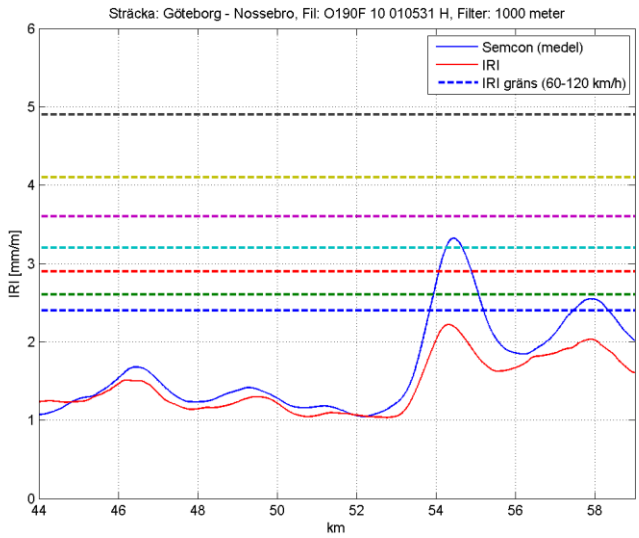


Repeatability, filtered over 400 meter

Figure A5, Gothenburg-Nossebro, Repeatability, 400 m

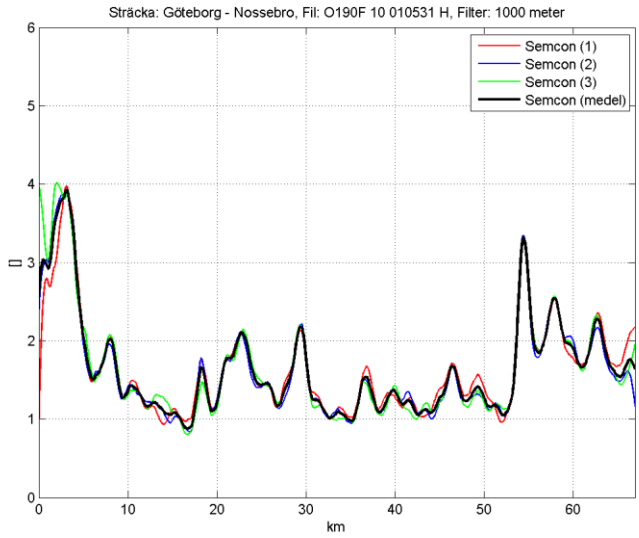


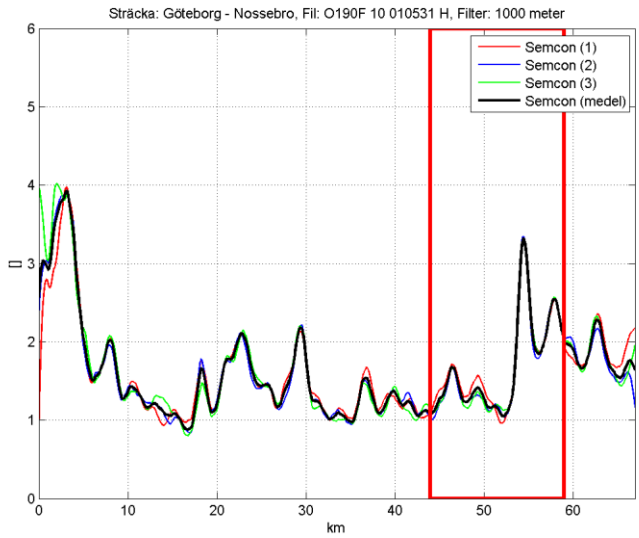


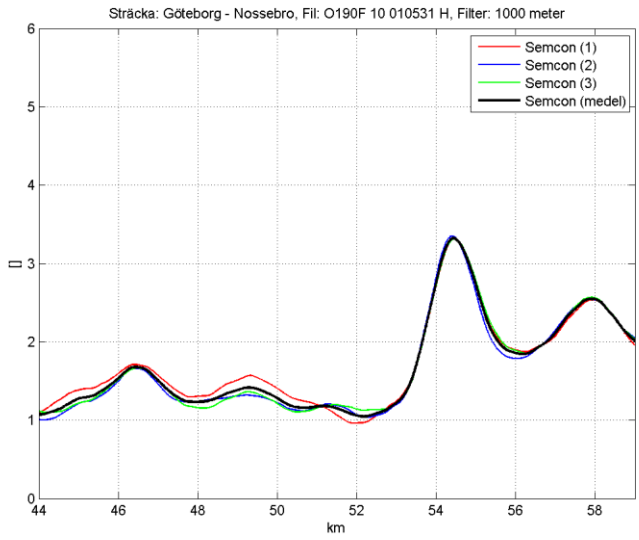


Correlation, filtered over 1000 meter

Figure A6, Gothenburg-Nossebro, Correlation, 1000 m







Repeatability, filtered over 1000 meter

Figure A7, Gothenburg-Nossebro, Repeatability, 1000 m

A.2 Stretch E6 - Halmstad – Gothenburg

The stretch between Halmstad and Gothenburg, Sweden, was validated. The stretch contains speed limits between 70 – 120 km/h. The stretch passes through several construction sites were the measurements are uncertain due low velocities and unpredictable differences with the IRI. Traffic jams that decreased the velocity under 30 km/h also affect the grade result.

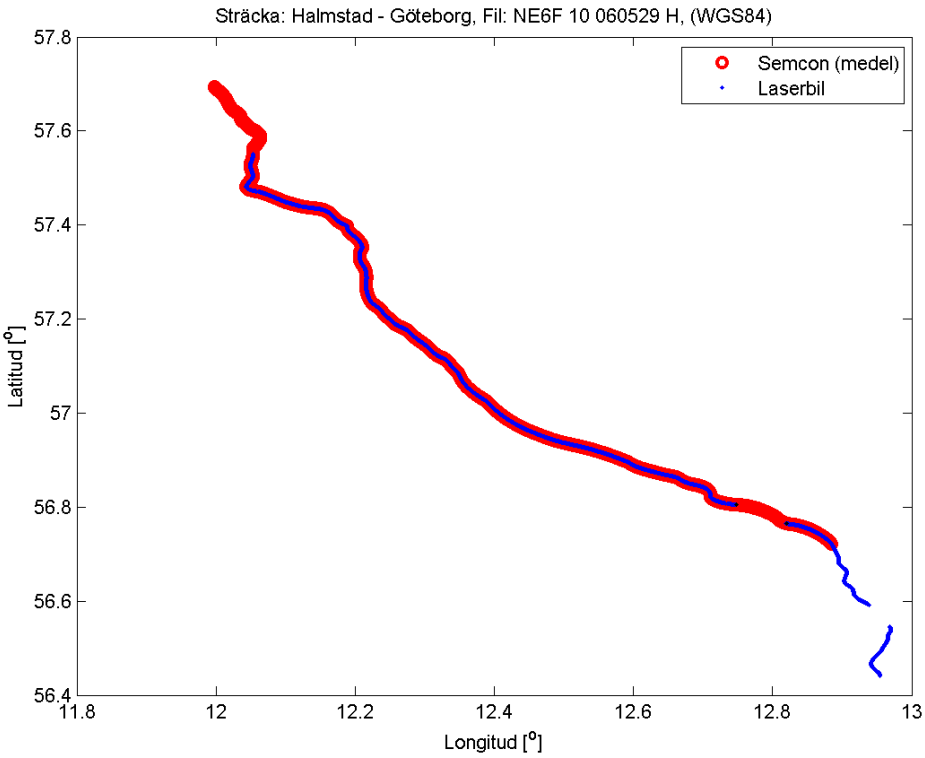


Figure A8, Stretch Halmstad-Gothenburg, Overview

Correlation, filtered over 100 meter

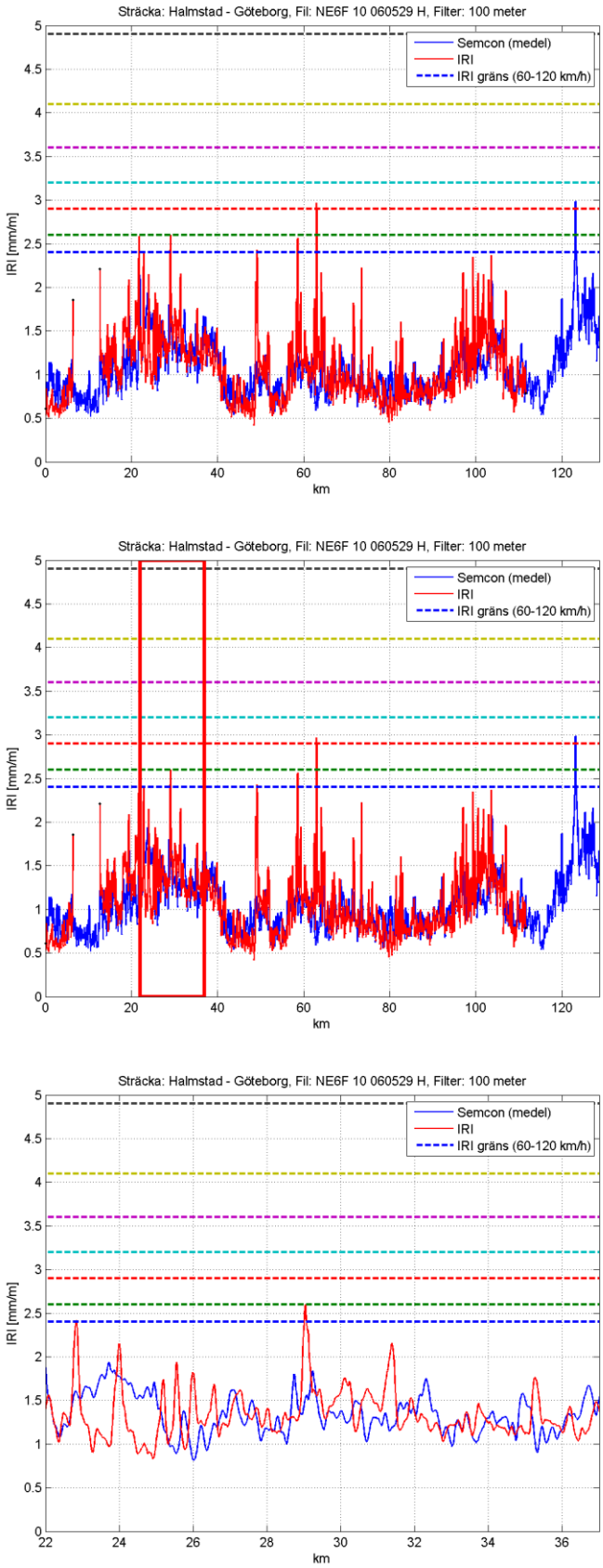
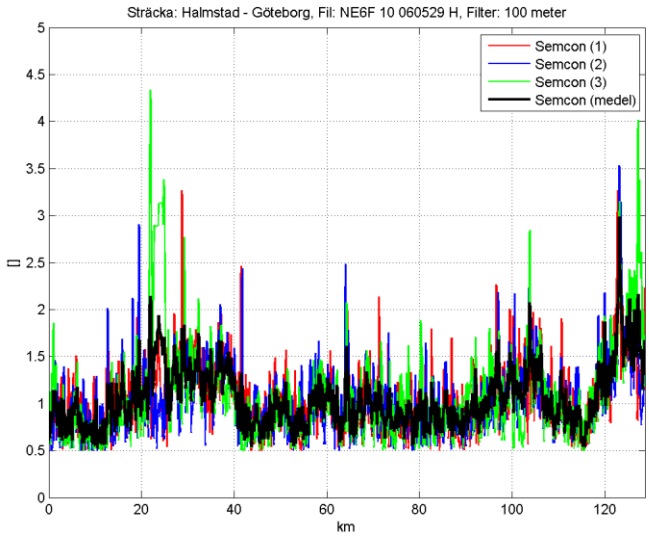
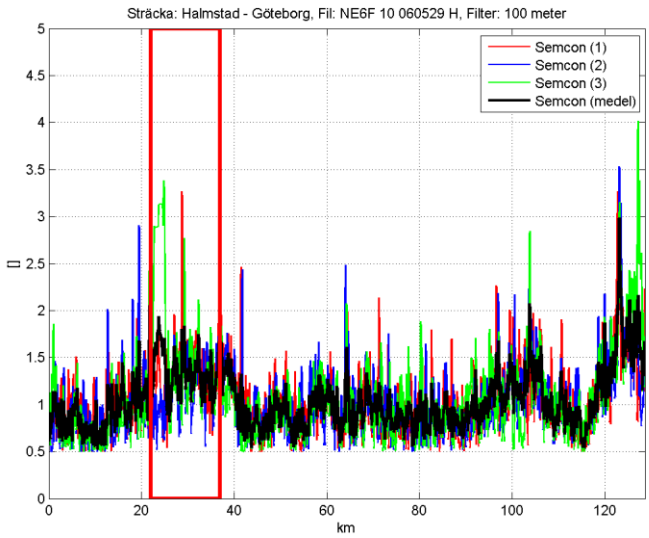
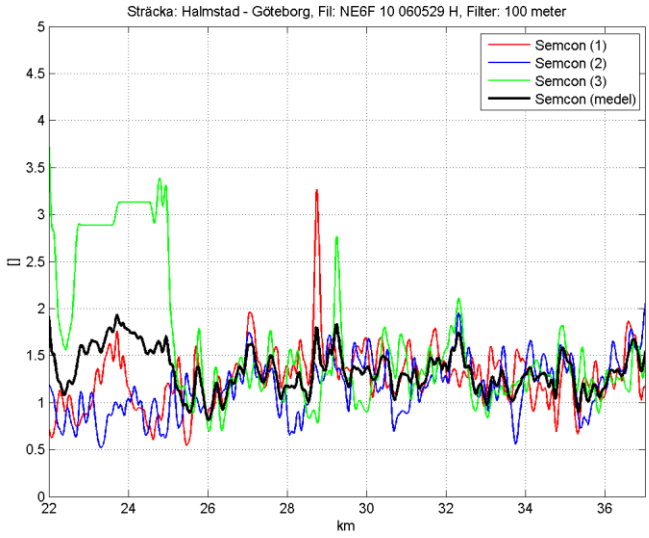


Figure A9, Halmstad-Gothenburg, Correlation, 100 m

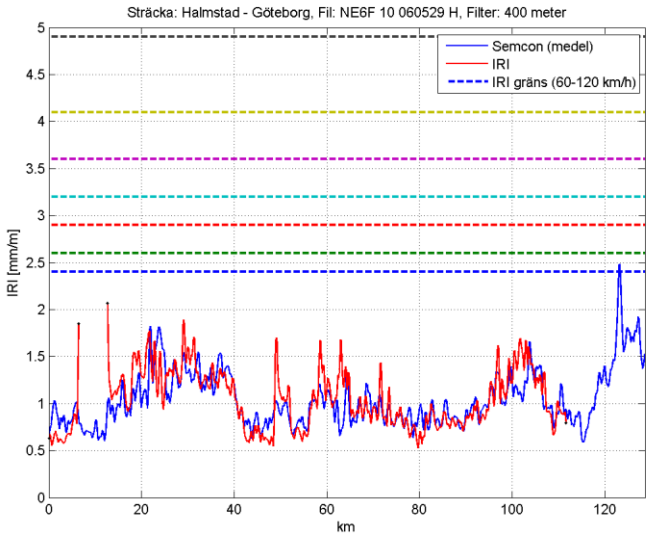


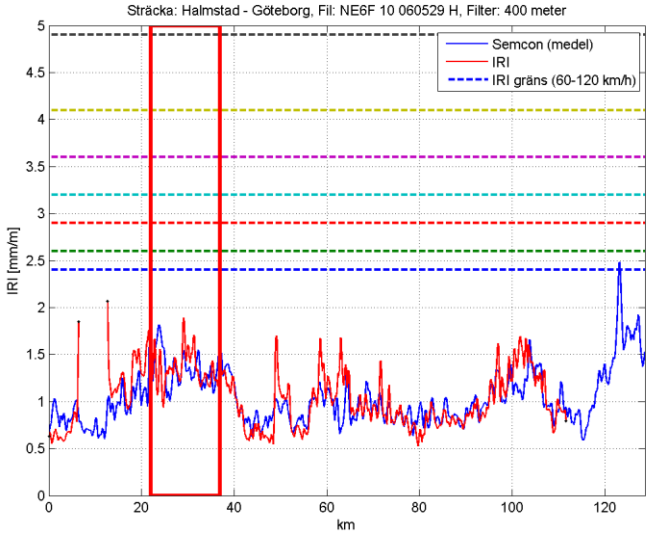


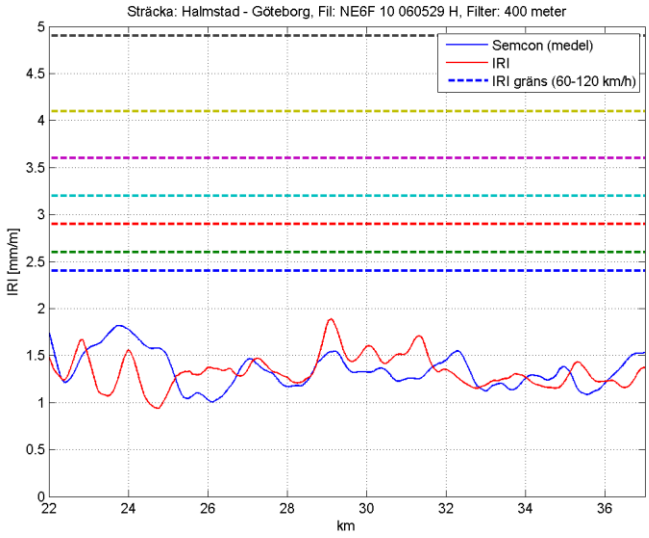


Repeatability, filtered over 100 meter

Figure A10, Halmstad-Gothenburg, Repeatability, 100 m

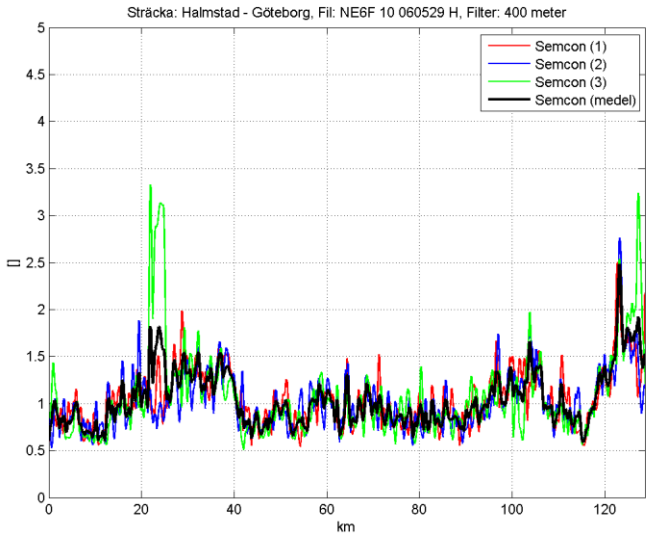


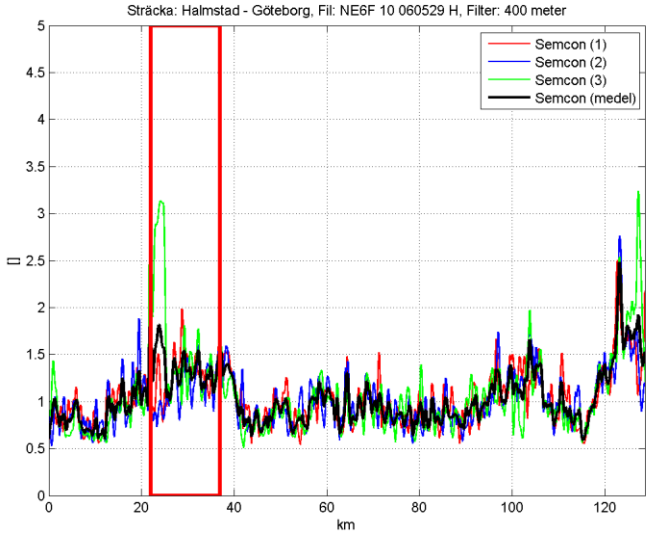


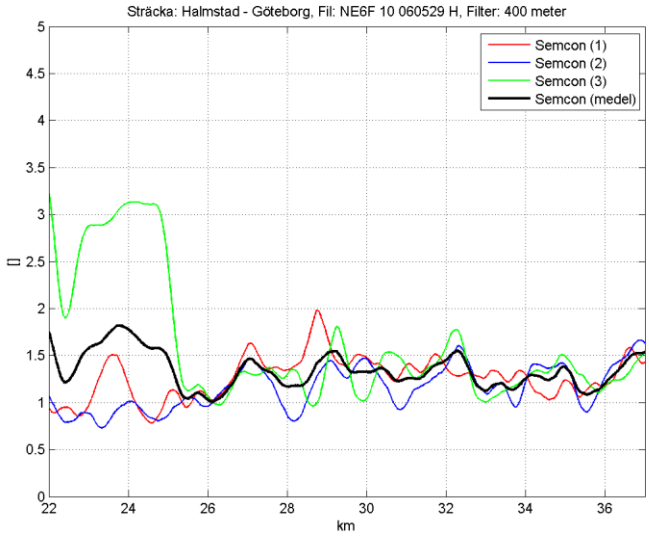


Correlation, filtered over 400 meter

Figure A11, Halmstad-Gothenburg, Correlation, 400 m



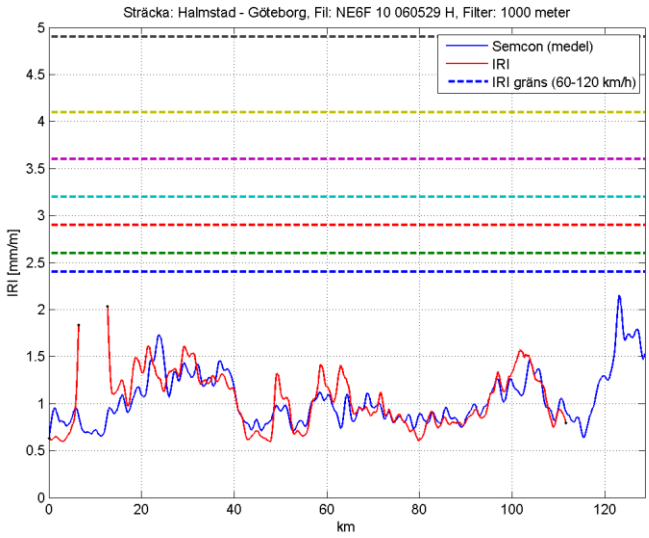


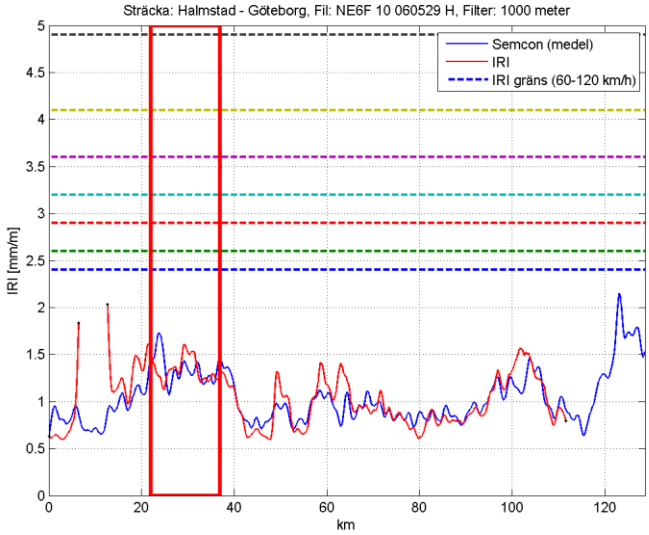


Repeatability, filtered over 400 meter

Figure A12, Halmstad-Gothenburg, Repeatability, 400 m

Correlation, filtered over 1000 meter





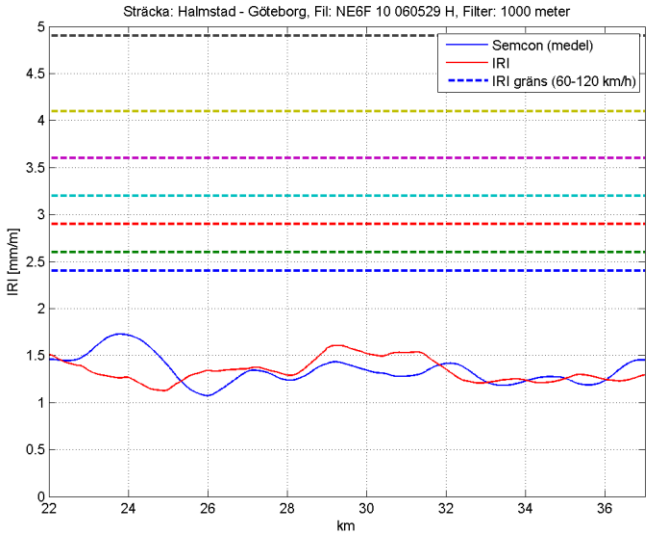
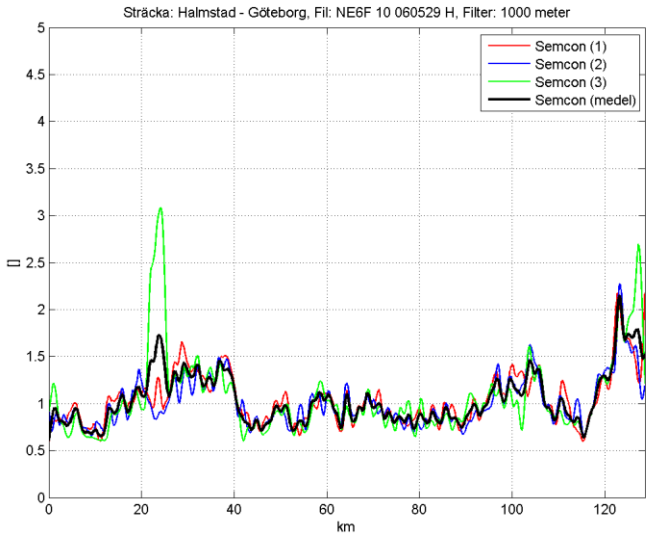
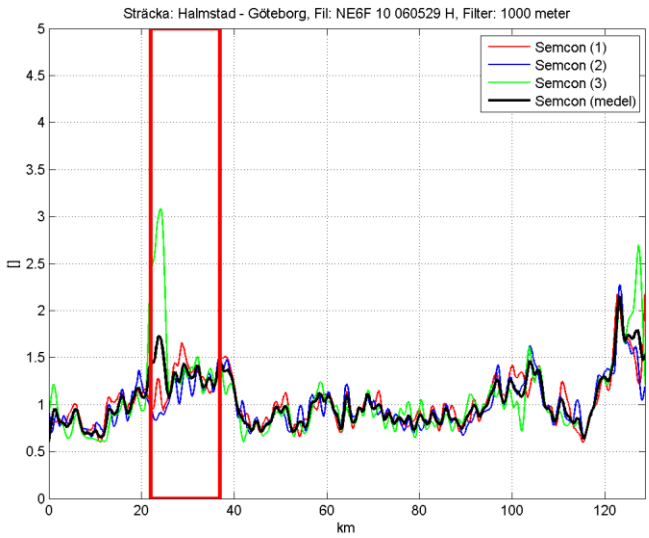
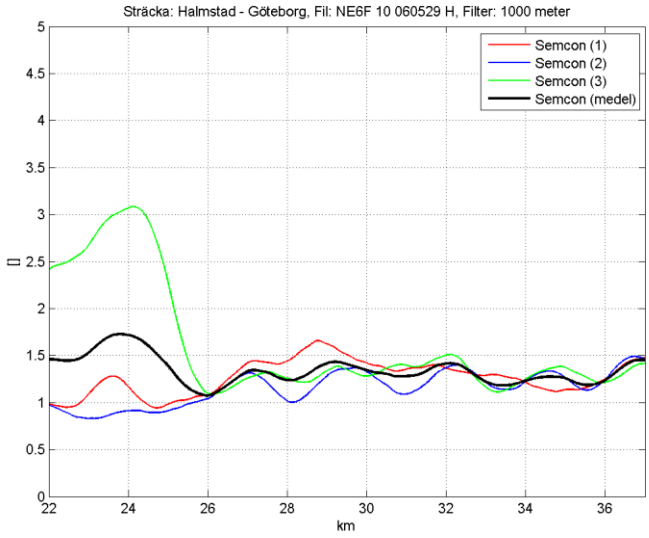


Figure A13, Halmstad-Gothenburg, Correlation, 1000 m







Repeatability, filtered over 1000 meter

Figure A14, Halmstad-Gothenburg, Repeatability, 1000 m

A.3 BiFi (I) Reference Measurements: Skepplanda

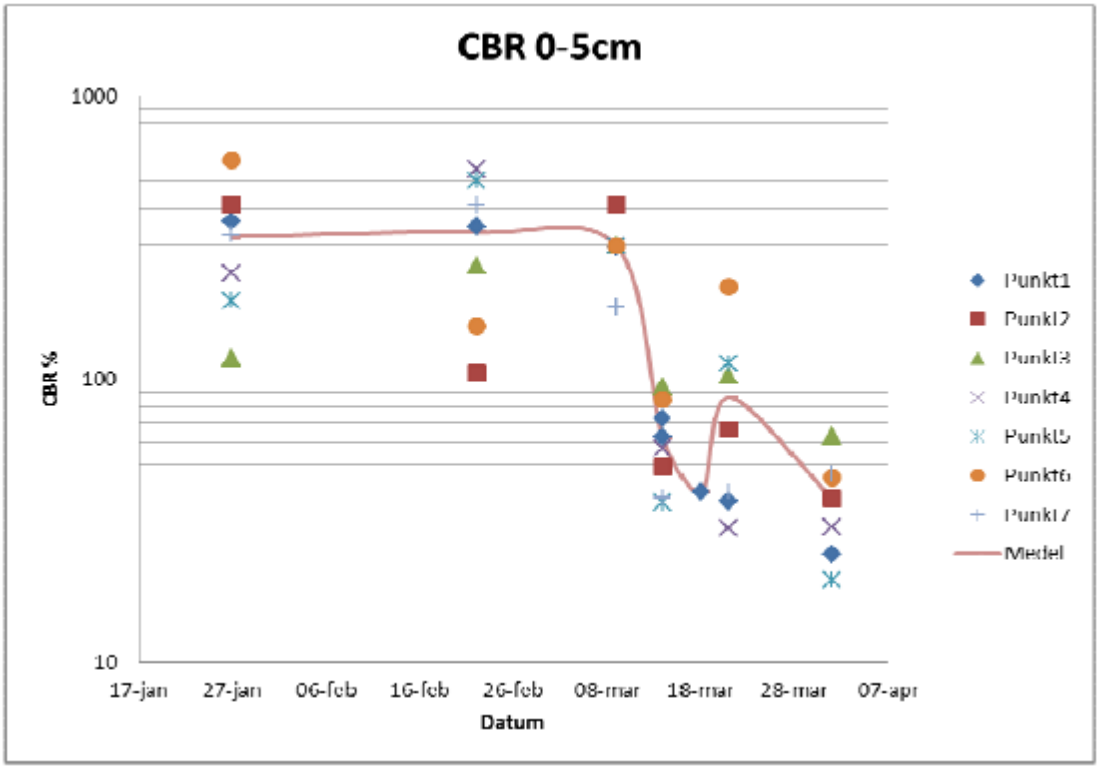


Figure A15 CBR values 0-5 cm from surface. Skepplanda

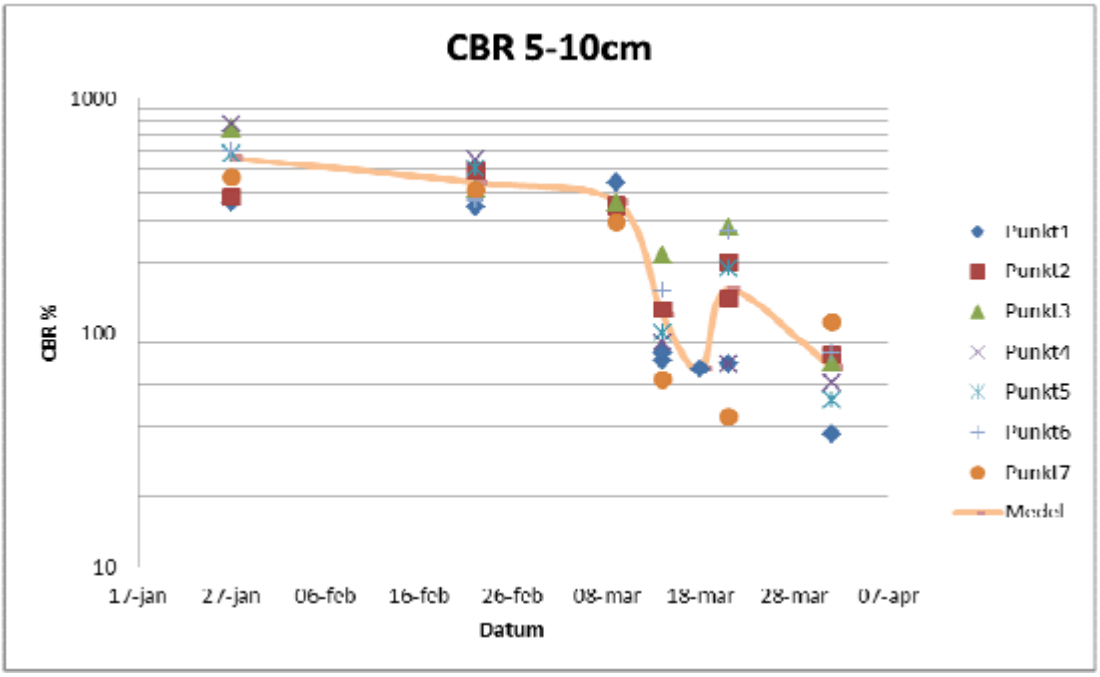


Figure A16 CBR values 5-10 cm from surface.

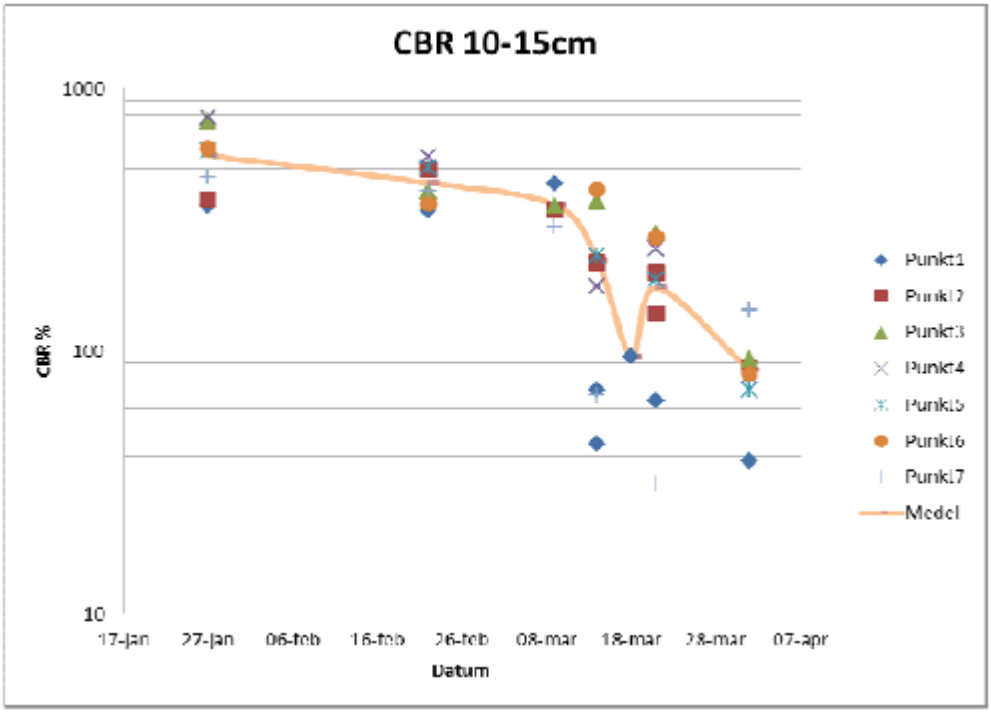


Figure A17 CBR values 10-15 cm from surface.

A.4 SRIS Reference Measurements

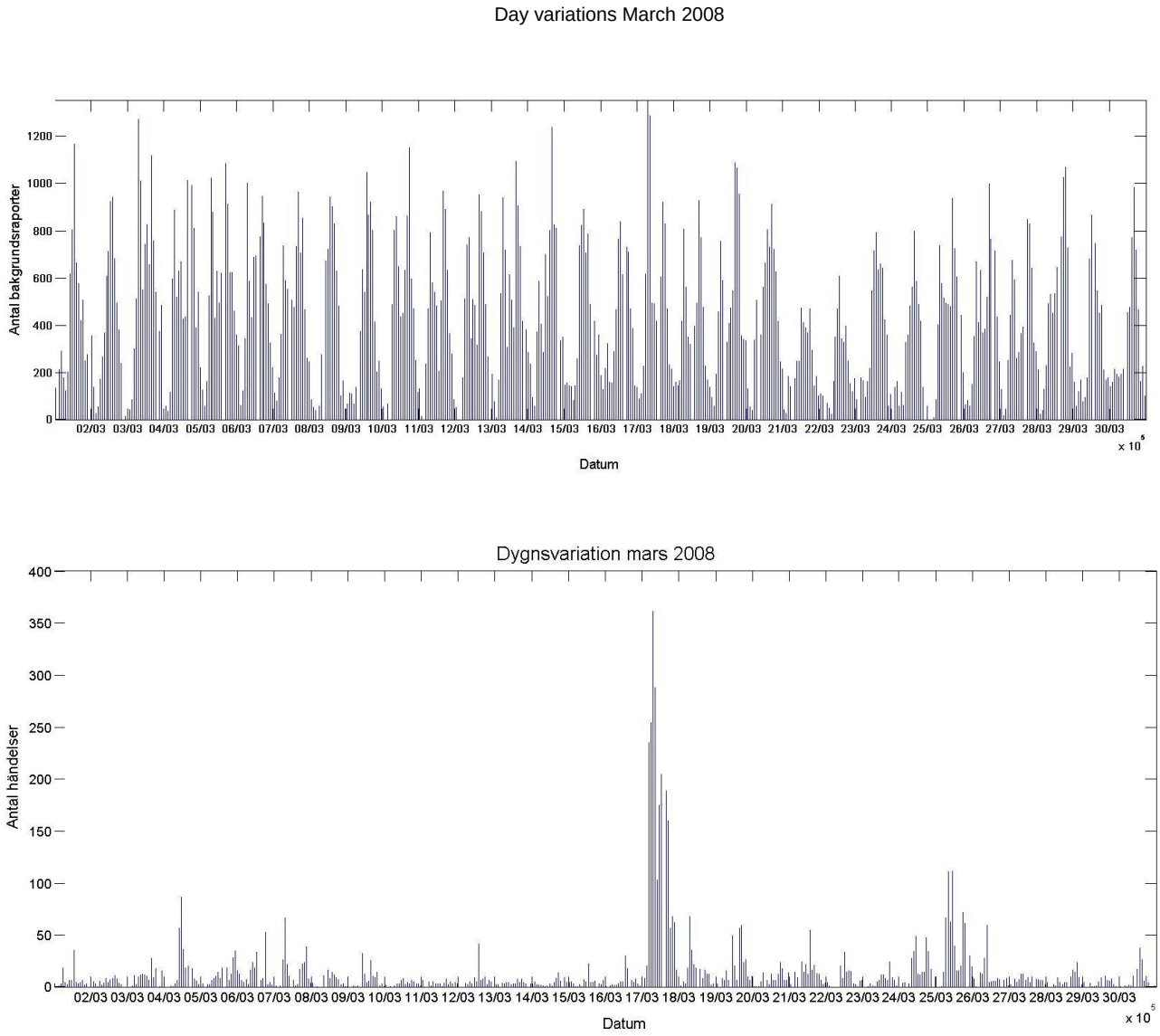


Figure A18 In the top diagram it is possible to see background data (all collected signals from cars) from March 2008. In the diagram below event data is shown for the same period. Note the increase in events during the 17th and 18th of March, associated with bad weather.